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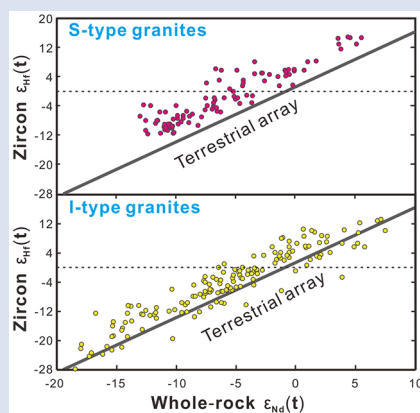
Hafnium isotopic disequilibrium during sediment melting and assimilation

C. Zhang^{1,2}, D. Liu^{1,3*}, X. Zhang⁴, C. Spencer^{5,6},
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Abstract



Identification of juvenile and mature crustal sources in granite formation relies on radiogenic isotopic systems such as Sm-Nd and Lu-Hf and assumes isotope systems reach equilibrium between the melt and residual phases prior to melt extraction. However, we hypothesise disequilibrium melting and residual zircon result in preferential retention of ^{177}Hf in residues, generating partial melts with higher $^{176}\text{Hf}/^{177}\text{Hf}$ ratios. To test this hypothesis, we evaluate radiogenic isotopic signatures of strongly-peraluminous granites from the Chinese Altai. These granites show Nd-Hf isotopic decoupling and inherited zircons with negative $\epsilon_{\text{Hf}}(t)$ values providing evidence for incomplete Hf release. This is consistent with the significant depletions in Zr and Hf. The Chinese data compilation shows that strongly-peraluminous and calcic to calc-alkalic, magnesian metaluminous or ferroan peraluminous (often respectively referred to as S- and I-type) granites show elevated $\epsilon_{\text{Hf}}(t)$ relative to the terrestrial Hf-Nd isotopic array. Hf isotope disequilibrium marked by the preferential release of radiogenic Hf is likely ubiquitous during anatexis of zircon-rich protoliths.

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Introduction

Strongly-peraluminous granites (SPG) generally indicate that partial melting of metasedimentary crustal rocks has been occurring throughout Earth's history (Harris *et al.*, 2000; Appleby *et al.*, 2010; Bucholz and Spencer, 2019). Experimental and geodynamic modelling have been applied to understanding the chemistry and physics of partial melting processes (Sawyer *et al.*, 1991, 2011). It is assumed that crustal partial melts inherit the radiogenic isotope composition of their protoliths. Hafnium (Hf) is a geochemically important element in zircon because its isotopic composition is a sensitive tracer of crustal and mantle processes (Kemp *et al.*, 2006). Zircon retains the initial melt isotopic composition because of its low Lu/Hf ratio and refractory nature in sedimentary processes (Andersen *et al.*, 2002). However, studies of SPG have shown the Hf isotopic composition of partial melts may not match the inferred magma source (Belousova *et al.*, 2005; Villaros *et al.*, 2012; Iles *et al.*, 2019). Residual zircons,

i.e. not dissolved during partial melting, may retain a significant amount of unradiogenic Hf (*i.e.* low $^{176}\text{Hf}/^{177}\text{Hf}$) causing the derivative crustal melts to have higher $^{176}\text{Hf}/^{177}\text{Hf}$ ratios relative to the bulk source (Farina *et al.*, 2014). In such cases, source composition and melting conditions exert a first order control on Hf isotopic equilibrium during anatexis (Tang *et al.*, 2014). To test the residual zircon effect on Hf isotopes in granitic rocks, we carried out a Nd-Hf-O isotopic study of SPG in the Chinese Altai. We then evaluate the generality of residual zircon effect in granitic magmatism using a compiled Nd-Hf isotope database.

The Central Asian Orogenic Belt (CAOB) is Earth's largest Phanerozoic accretionary orogen (Kröner *et al.*, 2014). The Chinese Altai is located in the central CAOB (Fig. S-1a), with >40 % of the exposed rocks being granites (Zhang *et al.*, 2017). Previous studies dated CAOB plutons as Late Ordovician-Devonian (450 to 370 Ma) and Permian (280 to 270 Ma) and also report Nd-Hf isotopic decoupling in these granites (*e.g.*, Zhang *et al.*, 2017). This paper reports new U-Pb

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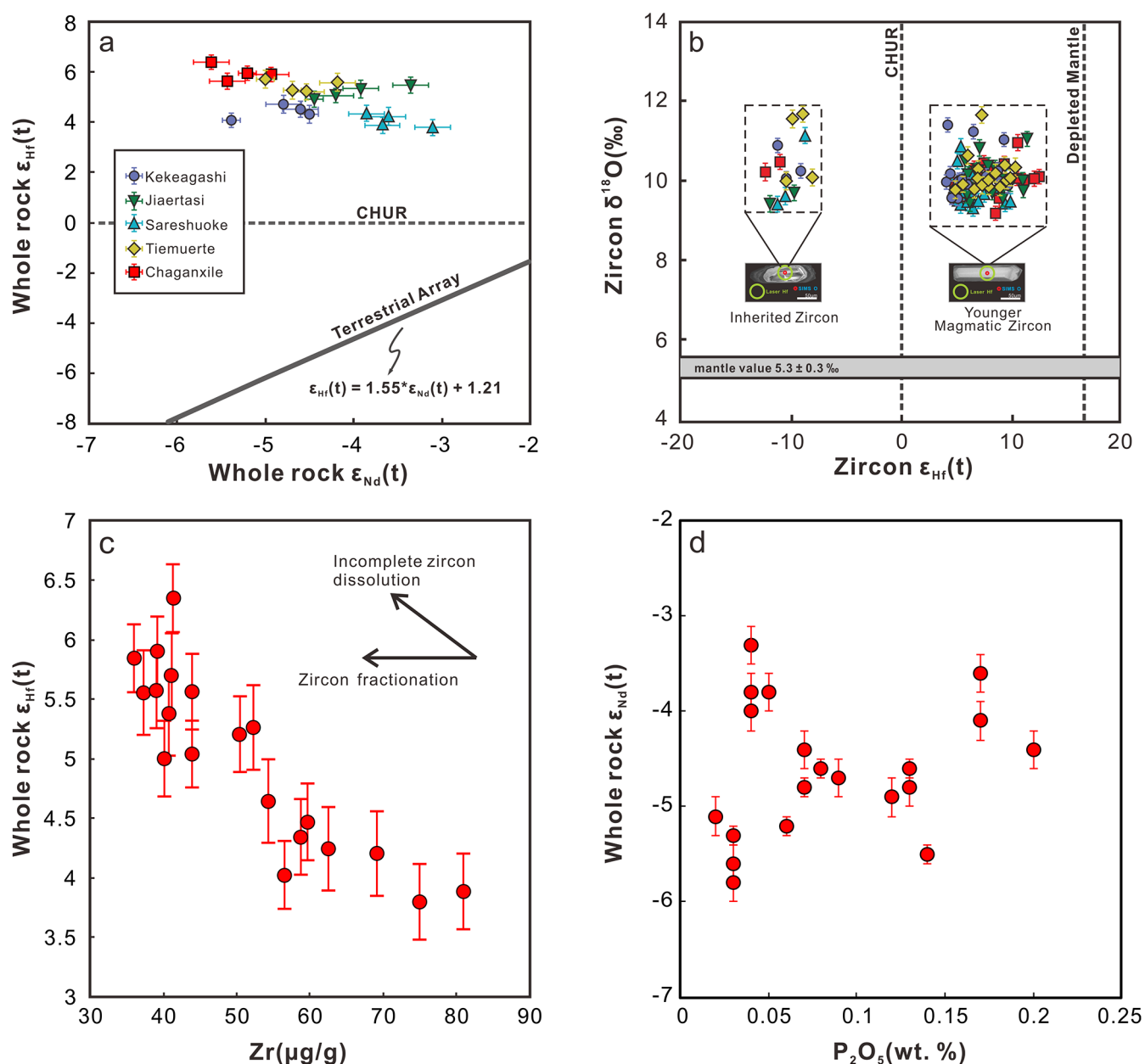


Figure 1 (a) $\epsilon_{\text{Hf}}(t)$ versus $\epsilon_{\text{Nd}}(t)$ for SPG in the Chinese Altai calculated based on U-Pb ages of the various plutons. Terrestrial array equations are from Vervoort *et al.* (2011). (b) Zircon $\epsilon_{\text{Hf}}(t)$ versus zircon $\delta^{18}\text{O}$ for SPG in the Chinese Altai. Mantle values after Valley *et al.* (1998). Inherited zircons show $\epsilon_{\text{Hf}}(t)$ and $\delta^{18}\text{O}$ values, indicating a metasedimentary source. Younger magmatic zircons show positive $\epsilon_{\text{Hf}}(t)$ values and similarly high $\delta^{18}\text{O}$ values, CHUR-chondritic uniform reservoir. (c) $\epsilon_{\text{Hf}}(t)$ versus Zr ($\mu\text{g/g}$). (d) $\epsilon_{\text{Nd}}(t)$ versus $\text{P}_2\text{O}_5(\text{wt. \%})$. Uncertainties of all isotope measurements are internal 2σ .

ages, Nd-Hf-O isotopic compositions, major and trace element geochemistry, and Hf-O isotopes of inherited zircons within SPG samples from the Chinese Altai with the aim of providing insights into SPG melting processes and isotope systematics.

Methods and Results

Granite samples from the Kekeagashi, Tiemuerte, Jiaertasi, Chaganxile, and Sareshuoke plutons in the Chinese Altai (Fig. S-1b) were analysed. *In situ* zircon U-Pb analysis was performed using laser ablation inductively coupled plasma mass spectrometry (ICP-MS). Whole rock (WR) major/trace element compositions were analysed using X-ray fluorescence spectrometry and inductively coupled plasma mass spectrometry. Nd isotope measurements were conducted using a MAT-262 thermal ionisation mass spectrometer in static mode.

Hf isotope measurements were analysed using Nu Plasma II ICP-MS. *In situ* zircon Hf isotope analyses were conducted using a Thermo Scientific Neptune ICP-MS coupled to a 193-nm laser. *In situ* zircon O isotope analyses were conducted using a Cameca IMS-1280HR secondary ion mass spectrometer. Details of analytical methods are provided in Supplementary Information.

Zircon U-Pb ages show granite crystallisation between 437 and 409 Ma (Fig. S-2). U-Pb dating of inherited zircon cores indicate that Palaeozoic zircon grains seeded on significantly older crystals, with ages ranging from 3506 to 1990 Ma (Fig. S-3). The WR $\epsilon_{\text{Nd}}(t)$ and $\epsilon_{\text{Hf}}(t)$ values range from -5.6 to -3.1 and $+3.8$ to $+6.3$, respectively. The $\delta^{18}\text{O}$ and $\epsilon_{\text{Hf}}(t)$ values of the magmatic zircon rims spanned from $+9.2$ to $+11.6$ ‰ and $+4.0$ to $+12.3$, respectively. The $\delta^{18}\text{O}$ values of zircon cores range from $+9.3$ to $+11.8$ ‰ and $\epsilon_{\text{Hf}}(t)$ values from -12.4 to -8.2 . Data are available in Tables S-1 and S-2.

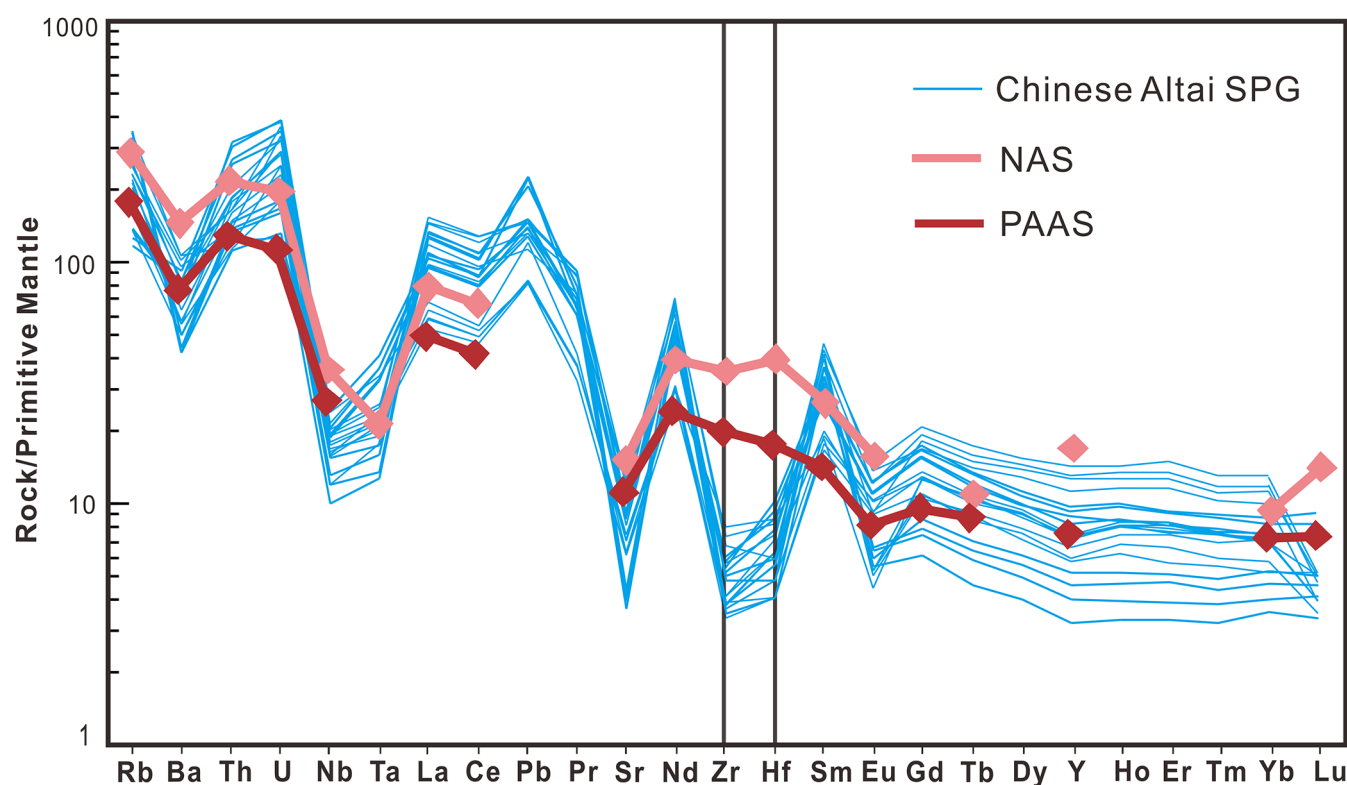


Figure 2 Primitive mantle-normalised trace element spider patterns of the studied granites, PAAS and NAS. Normalisation data from Sun and McDonough (1989). Note the Zr-Hf depletions of the SPG from this study. All the data are listed in Table S-4.

Discussion and Implications

High $\delta^{18}\text{O}$ values (+9.2 to +11.6 ‰), low $\epsilon_{\text{Nd}}(t)$ values (−5.6 to −3.1), strongly-peraluminous character ($\text{A/CNK} = 1.1\text{--}1.3$), presence of aluminous minerals (*i.e.* garnet, sillimanite, cordierite, and muscovite; Fig. S-4), and low Fe, Mg, Ca, and Na contents are consistent with derivation of melted sediment (Chappell and White, 1974).

The highly radiogenic Hf isotopes of these SPG and Nd-Hf isotopic decoupling (Fig. 1a) give contradictory implications as to the contributions of isotopically depleted and enriched materials. It is feasible that Nd-Hf isotopic decoupling is either highlighting differential source signature or caused by crustal melting processes. Mineral sorting effects during sediment transport can concentrate zircon in coarse-grained sedimentary rocks while fine-grained, clay-rich rocks are nearly devoid of zircon (Carpentier *et al.*, 2009). Consequently, zircon-depleted sediments tend towards radiogenic Hf isotope signatures, while zircon-rich sediments generally have unradiogenic Hf isotope compositions. Melting of fine-grained, zircon-poor sedimentary rocks is likely to produce magmas with radiogenic Hf isotope compositions relative to their Nd isotope composition and account for a negative correlation between magma $\epsilon_{\text{Hf}}(t)$ and Zr concentration (Fig. 1c). However, we suggest that this mechanism is unlikely to be responsible for isotopic decoupling in the investigated granites as; 1) the sedimentary rocks in the studied area are sandstones and mudstones that are enriched in zircon and have moderate to low Nd/Hf ratios (from 0.8 to 3.8, Long *et al.*, 2008); 2) fine-grained clastic sedimentary proxies (Post-Archean Australian Shales [PAAS] and North American Shales [NAS]), are not depleted in Zr and Hf while SPG of the Chinese Altai are depleted in Zr and Hf (Fig. 2); 3) inherited zircon cores are abundant in SPG, suggesting the source is not zircon-depleted. Thereby, we therefore conclude that radiogenic Hf isotopes are not source signatures nor is Nd-Hf isotopic decoupling due to melting of zircon-poor fine-grained sediments.

Nd-Hf isotopic decoupling may also be generated by disequilibrium melting with incomplete zircon dissolution (Fig. S-5; Zeng *et al.*, 2005; Farina *et al.*, 2014; Tang *et al.*, 2014; Iles *et al.*, 2018). Because Hf diffusion in zircon is slow under crustal melting conditions (Watson and Harrison, 1983), Hf isotope equilibrium during crustal anatexis is largely controlled by zircon dissolution. Inherited zircons in our samples are evidence of incomplete zircon dissolution during anatexis. Residual zircon in magma sources can retain unradiogenic Hf (*i.e.* low $^{176}\text{Hf}/^{177}\text{Hf}$) and may produce partial melts with elevated $\epsilon_{\text{Hf}}(t)$ relative to the source. This model explains Hf isotope variability recorded by zircon crystallising during partial melting and inherited zircon dissolution. This may generate melt batches with variable Hf isotope compositions, even if melts come from a single source (Tang *et al.*, 2014). This single source melting scenario is supported by the zircon O isotopic compositions for the Chinese Altai granites. If the variation in zircon Hf isotopic composition is due to mixing between mantle-derived magmas and metasedimentary materials, negative correlations between zircon $\epsilon_{\text{Hf}}(t)$ and zircon $\delta^{18}\text{O}$ (Kemp *et al.*, 2007) are expected. However, Chinese Altai granites show similar $\delta^{18}\text{O}$ (cores: +9.3 to +11.8 ‰; rims: +9.2 to +11.6 ‰) despite the large Hf isotopic variation (>20 epsilon units; Fig. 1b).

Disequilibrium melting with residual zircon can explain strong Zr and Hf depletions in the Chinese Altai granites (Fig. 2) as zircon hosts most Zr and Hf. More importantly, the WR and zircon $\epsilon_{\text{Hf}}(t)$ values of SPG correlate negatively with Zr concentrations (Fig. 1c), which is expected if residual zircon controls Hf isotopes and Zr and Hf concentrations in partial melts. Zircon fractionation during magma differentiation may also cause Zr and Hf depletions, but would not produce negative correlations between Hf isotopic composition and Zr concentration.

Nd concentrations in the melt and residue are dominantly controlled by apatite and monazite (Zeng *et al.*, 2005). Nd isotopes may be affected by disequilibrium melting with

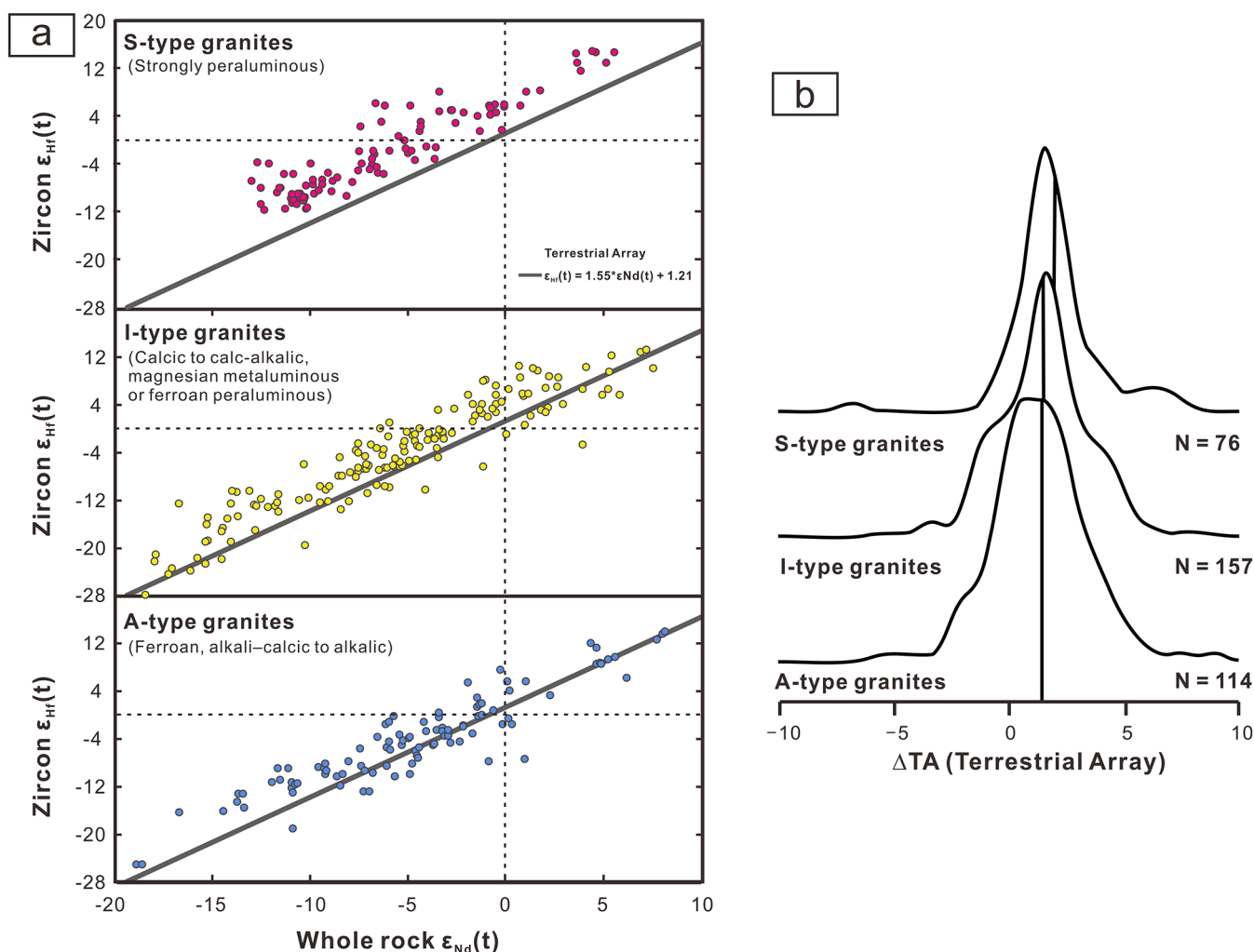


Figure 3 (a) Compilation of published neodymium and hafnium isotopic compositions of I-type, A-type, and S-type granites (as defined in the figure). Points represent average zircon values from single plutons. References listed in Table S-3. (b) Distance from the terrestrial array (TA) expressed as ΔTA calculated for the three granite groups. Vertical line represents the median of all of the samples and demonstrate an increasing shift towards greater Hf disequilibrium (above the TA) with increasing aluminosity.

residual apatite and monazite. However, zircon has extremely low Lu/Hf and thus strongly fractionates Hf from Lu while apatite and monazite only moderately fractionate Nd and Sm. Therefore, Hf isotopes are more sensitive to disequilibrium melting than Nd isotopes even if both zircon and P-bearing accessory minerals are present in the residues. This is supported by the observation that $\epsilon_{\text{Hf}}(t)$ strongly correlates with Zr concentration while $\epsilon_{\text{Nd}}(t)$ varies independently from P_2O_5 in our samples (Fig. 1d). We suggest that Nd-Hf decoupling of Altai SPG is caused by the Hf isotopic disequilibrium and incomplete zircon dissolution during sediment melting. Mineral sorting might have a minor contribution to isotopic decoupling in zircon-rich sources.

To evaluate the generality of residual zircon effects in granitic magmatism, we compiled a database of Chinese granite Nd-Hf isotope compositions. Nd-Hf isotopic decoupling is present in SPG with systematically elevated $\epsilon_{\text{Hf}}(t)$ relative to the terrestrial Nd-Hf isotope array (TA) and is also present to a lesser degree in I-type (calcic to calc-alkalic, magnesian metaluminous or ferroan peraluminous) granites (Fig. 3). This is in contrast to A-type (ferroan, alkali-calcic to alkalic) granites that overlap with the TA. We calculated minimum temperatures required to dissolve zircon completely in the source rocks (Fig. 4). We assume the melting degree to be ~30 % (Petford *et al.*, 2000). Our calculation shows that,

for peraluminous melts ($M > 1.1$), complete zircon dissolution would require $>950^\circ\text{C}$ if the source contains $>200\text{ }\mu\text{g/g}$ Zr, which appears to be too high for most SPG systems. Considering that the average PAAS and NAS contains 210 and $200\text{ }\mu\text{g/g}$ Zr, respectively (Gromet *et al.*, 1984; Taylor and McLennan, 1985), residual zircon seems to be inevitable if the source rocks are detritus-rich sedimentary rocks. I-type granites also deviate from the TA to a lesser degree than SPG but greater than A-type granite implying sediment assimilation in typical arc settings (Fig. 3). We suggest that may also be explained by a residual zircon effect if zircon is present in the sources of I-type granites.

These findings raise questions to the utility of Hf isotopes in quantifying crustal recycling as disequilibrium melting and residual zircon may lead to radiogenic Hf isotopes in the partial melts that falsely indicate juvenile sources. Therefore, Hf isotopes of SPG and I-type granites may not faithfully reflect the protoliths. Hf isotopes biased by residual zircon may lead to erroneous conclusions in detrital zircon studies as petrogenetic context is missing. Rates of crustal reworking can be significantly underestimated if only Hf isotopes are applied. Therefore, caution is needed when using detrital zircon Hf isotopes to reconstruct the net growth of the continental crust.

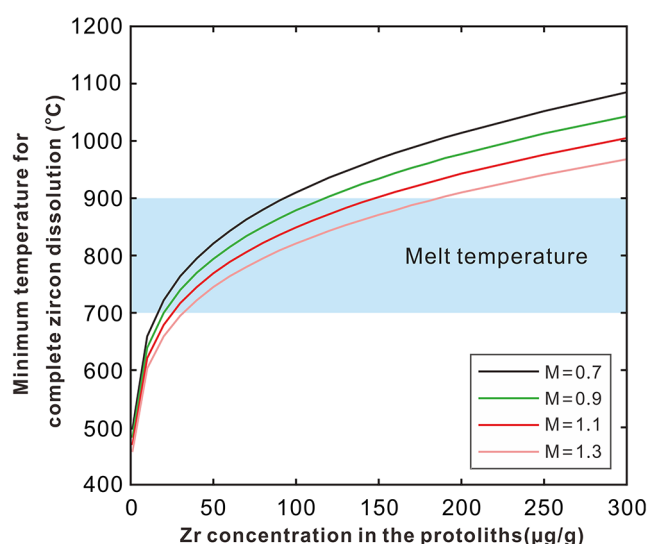


Figure 4 Calculated minimum melt temperature for zircon dissolution as a function of Zr concentration in the protoliths and M value (cation ratio). SPG have M values > 1.1 while I-type granites typically have M values < 1.0. Melt Zr concentration at zircon saturation using the zircon saturation model of Boehnke et al. (2013).

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Additional Information

Supplementary Information accompanies this letter at <http://www.geochemicalperspectivesletters.org/article2001>.



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■ Hafnium isotopic disequilibrium during sediment melting and assimilation

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■ Supplementary Information

The Supplementary Information includes:

- Analytical methods
- Tables S-1 to S-5
- Figures S-1 and S-6
- Supplementary Information References

Analytical methods

Zircon U-Pb dating

Analytical methods for determination of zircon U-Pb ages are described in Zhang *et al.* (2019). The data for reference materials are listed in Table S-5-1.

Major and trace element analysis

Analytical methods for determination of whole-rock major and trace element are reported in Zhang *et al.* (2019). The data for reference materials are listed in Table S-5-2.

Whole rock Nd isotopic analysis

Four samples were collected for each pluton, and they were ground into powders, followed by introduction of isotope tracers and dissolution by HF + HNO₃ acid in Teflon capsules. Separation of Nd was conducted on HDEHP columns where there was a 0.18 N HCl elutant. Nd isotopic analysis was accomplished at the Tianjin Institute of Geology and Mineral Resources using a thermal ionization mass spectrometry (TIMS). As identified in this research, La Jolla and BCR-1 standards were applied to control analytical quality. Detailed procedures for preparation of samples and subsequent analyses conform to those in Li *et al.* (2015). The data for reference materials are listed in Table S-5-3.

Whole rock Hf isotopic analysis

Granitic rock powders were mixed with 0.5 ml of 60 wt. % HNO₃ and 1.0 ml of 40 wt. % HF in high-pressure PTFE bombs, followed by steel-jacketing and were then placed in the oven at 195 °C for 3 days to ensure absolute digestion. Subsequently, the digestion solution was dried on an electric hot plate, and got reconstituted into 1.5 ml of 1.5 mol/L HCl. A Biorad AG50W-X8 cation exchange column was used to wash out high field strength elements using the 1.5 mol/L HCl, and these samples were then dried and re-dissolved in 3.0 mol/L HCl. The obtained solution was dropped into the LN exchange column, followed by elution of



Titanium using a 4.0 mol/L HCl + 0.5 wt. % H₂O₂ mixture. Finally, the Hf component was extracted from the column with 2.0 mol/L HF. After undergoing a slow drying process, the Hf component was re-dissolved in 1.0 ml of 2 wt. % HNO₃, which was prepared as the mother solution. 100 µl of the mother solution was then diluted to 1.0 ml of solution for precise elemental content measurement on an Agilent Technologies 7700x quadrupole ICP-MS device. Subsequently, at the State Key Laboratory of Continental Dynamics, Northwest University, Xi'an, an Aridus II desolvating nebulizer system manufactured by the Teledyne Cetac Technologies Company was used to dilute the solution (40 ppb Hf) into the Nu Instruments Nu Plasma II MC-ICP-MS. Normalisation to $^{179}\text{Hf}/^{177}\text{Hf} = 0.7325$ was implemented to internally correct the raw isotopic ratio data for mass fractionation. Periodic analysis of international isotopic standards (Alfa Hf) was carried out to take possible instrumental drift into consideration. Quality control was ensured by referring to USGS, RGM-2, AVG-2, BHVO-2, and BCR-2 materials. These isotopic results agreed with previous publications within analytical uncertainty (Weis *et al.*, 2007). The data for reference materials are listed in Table S-5-4.

***In situ* zircon Hf isotopic measurement**

We implemented *in-situ* zircon Hf isotopic analysis at the Institute of Geochemistry, Chinese Academy of Sciences (IGG-CAS) in Guangzhou, using a Neptune Plasma Multicollector-ICP-MS equipped with a 193 nm ArFexcimer laser ablation system. Procedures for analysis and calibration basically conformed to Wu *et al.* (2006). In order to achieve comprehensive and consistent data, we analysed Lu–Hf isotopes on identical zircon grains that had been implemented with O and U–Pb isotopic analyses, with an ablation pit radius of 60 µm, an ablation interval of 26 s for an individual measurement, and a repetition rate of 8 Hz at 10 J/cm². Normalisation to $^{179}\text{Hf}/^{177}\text{Hf} = 0.7325$ was conducted on the measured data. Zircon standard 91500 and Mud Tank were used for calibration. Analytical signals were selected and integrated offline using the ICPMSDataCal software, accompanied by mass bias calibration (Liu *et al.*, 2010). The data for reference materials are listed in Table S-5-5.

***In situ* zircon O isotopic measurement**

Prior to measurements, high-purity gold was used to coat zircons in a vacuum environment using the Cameca IMS-1280 Secondary Ion Mass Spectrometry (SIMS) at the Institute of Geochemistry, Chinese Academy of Sciences (IGG-CAS), Guangzhou. Subsequently, we adopted multi-collection mode to measure oxygen isotopes. Our analytical procedures conformed to Li *et al.* (2010) and Tang *et al.* (2015). Normalisation to the Vienna Standard Mean Ocean Water composition (VSMOW, $^{18}\text{O}/^{16}\text{O} = 0.0020052$) was implemented on measured data. Subsequently, the Penglai zircon standard ($\delta^{18}\text{O} = 5.3\text{‰}$, Li *et al.*, 2010) was used to calibrate the instrumental mass fractionation factor (IMF). Possible geometrical effects ('X-Y' effect) were avoided through mounting the standards to the close unknowns (Kita *et al.*, 2009; Tang *et al.*, 2015). The IMF veracity was validated by analysing another zircon standard (91500, mounted at the center) as an unknown, resulting in a weighted mean of $\delta^{18}\text{O} = 9.93 \pm 0.4\text{‰}$ (2SD), which shared good consistency with that by Wiedenbeck *et al.*, (2004), namely 9.9‰. The data for reference materials are listed in Table S-5-6.



Supplementary Tables

Table S-1 Whole-rock Nd and Hf isotopic compositions of the granites from Kekeagashi, Tiemuerte, Jiaertasi, Chaganxile, and Sareshuoke plutons.

Sample	Age(Ma)	$^{147}\text{Sm}/^{144}\text{Nd}^a$	$^{143}\text{Nd}/^{144}\text{Nd}(\pm 2\sigma)$	$(^{143}\text{Nd}/^{144}\text{Nd})_i$	$\epsilon_{\text{Nd}}(\text{t})^b$	2 σ	MSWD
Kekeagashi@01	409	0.1151	0.512189±6	0.512024	-4.6	0.1	14
Kekeagashi@02	409	0.1154	0.512175±8	0.512008	-4.9	0.2	
Kekeagashi@03	409	0.1156	0.512185±8	0.512018	-4.8	0.2	
Kekeagashi@04	409	0.1177	0.512151±6	0.511983	-5.5	0.1	
Tiemuerte@01	420	0.1427	0.512249±6	0.512046	-4.8	0.1	5.7
Tiemuerte@02	420	0.1318	0.512245±10	0.512053	-4.4	0.2	
Tiemuerte@03	420	0.1333	0.512231±10	0.512038	-4.7	0.2	
Tiemuerte@04	420	0.1355	0.512213±6	0.51202	-5.2	0.1	
Jiaertasi@01	425	0.1233	0.512261±10	0.512082	-3.6	0.2	7.3
Jiaertasi@02	425	0.1485	0.512276±6	0.512066	-4.6	0.1	
Jiaertasi@03	425	0.136	0.512268±8	0.512073	-4.1	0.2	
Jiaertasi@04	425	0.145	0.512278±8	0.512071	-4.4	0.2	
Chaganxile@01	430	0.1231	0.512178±8	0.512	-5.1	0.2	2.7
Chaganxile@02	430	0.1335	0.512182±10	0.511989	-5.6	0.2	
Chaganxile@03	430	0.1292	0.512161±10	0.511973	-5.8	0.2	
Chaganxile@04	430	0.1304	0.512185±6	0.512001	-5.3	0.1	
Sareshuoke@01	437	0.1281	0.512256±8	0.512072	-3.8	0.2	2.2
Sareshuoke@02	437	0.1266	0.512249±6	0.512068	-3.8	0.2	
Sareshuoke@03	437	0.1378	0.512271±6	0.512075	-4	0.2	
Sareshuoke@04	437	0.1268	0.512278±10	0.512093	-3.3	0.2	
Sample	Age(Ma)	$^{176}\text{Lu}/^{177}\text{Hf}^c$	$^{176}\text{Hf}/^{177}\text{Hf}(\pm 2\sigma)$	$(^{176}\text{Hf}/^{177}\text{Hf})_i$	$\epsilon_{\text{Hf}}(\text{t})^d$	2 σ	MSWD
Kekeagashi@01	409	0.0297	0.282865±10	0.282637	4.2	0.4	2.8
Kekeagashi@02	409	0.0324	0.282897±10	0.282649	4.6	0.4	
Kekeagashi@03	409	0.03071	0.282879±9	0.282644	4.5	0.3	
Kekeagashi@04	409	0.03106	0.282869±8	0.282631	4	0.3	
Tiemuerte@01	420	0.02935	0.282890±10	0.282659	5.3	0.4	1.8
Tiemuerte@02	420	0.02851	0.282892±10	0.282668	5.6	0.4	
Tiemuerte@03	420	0.02953	0.282890±9	0.282658	5.2	0.3	
Tiemuerte@04	420	0.02851	0.282896±10	0.282672	5.7	0.4	
Jiaertasi@01	425	0.02851	0.282892±9	0.282665	5.6	0.3	3.8
Jiaertasi@02	425	0.02772	0.282869±9	0.282649	5	0.3	
Jiaertasi@03	425	0.02614	0.282868±10	0.282659	5.4	0.4	
Jiaertasi@04	425	0.02566	0.282854±8	0.28265	5	0.3	
Chaganxile@01	430	0.03326	0.282938±8	0.282669	5.8	0.3	3.9
Chaganxile@02	430	0.02772	0.282885±9	0.282662	5.6	0.3	
Chaganxile@03	430	0.0297	0.282923±8	0.282684	6.3	0.3	
Chaganxile@04	430	0.02851	0.282901±8	0.282671	5.9	0.3	
Sareshuoke@01	437	0.03019	0.282866±10	0.282619	4.2	0.4	2.4
Sareshuoke@02	437	0.0297	0.282853±9	0.28261	3.9	0.3	
Sareshuoke@03	437	0.03326	0.282895±9	0.282622	4.3	0.3	
Sareshuoke@04	437	0.03037	0.282856±9	0.282607	3.8	0.3	



^a $^{147}\text{Sm}/^{144}\text{Nd}$ are calculated using whole-rock Sm and Nd contents in Table S-4.

^b $\epsilon_{\text{Nd}}(t) = (^{143}\text{Nd}/^{144}\text{Nd}_{\text{sample}}/^{143}\text{Nd}/^{144}\text{Nd}_{\text{CHUR}} - 1) \times 10000$, $^{143}\text{Nd}/^{144}\text{Nd}_{\text{CHUR}} = 0.512638$.

^c $^{176}\text{Lu}/^{177}\text{Hf}$ are calculated using whole-rock Lu and Hf contents in Table S-4.

^d $\epsilon_{\text{Hf}}(t) = (^{176}\text{Hf}/^{177}\text{Hf}_{\text{sample}}/^{176}\text{Hf}/^{177}\text{Hf}_{\text{CHUR}} - 1) \times 10000$, $^{176}\text{Hf}/^{177}\text{Hf}_{\text{CHUR}} = 0.282772$.

Table S-2 Zircon Hf-O data and model ages of the granites from Kekeagashi, Tiemuerte, Jiaertasi, Chaganxile, and Sareshuoke plutons.

Sample	$^{176}\text{Yb}/^{177}\text{Hf}$	2 σ	$^{176}\text{Lu}/^{177}\text{Hf}$	2 σ	$^{176}\text{Hf}/^{177}\text{Hf}$	2 σ	$\epsilon_{\text{Hf}}(t)$	f_{Lu}/Hf	$T_{\text{DM1}}(\text{Ma})$	$T_{\text{DM2}}(\text{Ma})$
Kekeagashi@01	0.073498	0.001756	0.002136	0.000435	0.282651	0.000026	4.10	-0.94	878	994
Kekeagashi@02	0.053081	0.000152	0.001331	0.000037	0.282712	0.000015	6.60	-0.96	774	874
Kekeagashi@03	0.068717	0.006191	0.002252	0.000046	0.282663	0.000026	4.43	-0.93	866	978
Kekeagashi@04	0.054894	0.000066	0.001343	0.000058	0.282208	0.000018	-11.30	-0.96	1481	2099
Kekeagashi@05	0.069904	0.006118	0.002532	0.000039	0.282688	0.000024	5.41	-0.92	829	927
Kekeagashi@06	0.051713	0.006844	0.001545	0.000032	0.282275	0.000025	-9.19	-0.95	1404	1970
Kekeagashi@07	0.068208	0.007796	0.002143	0.000046	0.282664	0.000021	4.45	-0.94	864	976
Kekeagashi@08	0.066105	0.002736	0.002241	0.000036	0.282723	0.000015	6.55	-0.94	779	980
Kekeagashi@09	0.063511	0.000037	0.002346	0.000048	0.282655	0.000014	4.04	-0.93	883	997
Kekeagashi@10	0.052296	0.003462	0.001349	0.000032	0.282237	0.000016	-10.55	-0.96	1453	2055
Kekeagashi@11	0.091889	0.004046	0.002247	0.000037	0.282818	0.000017	9.61	-0.93	647	704
Kekeagashi@12	0.065296	0.004246	0.001754	0.000047	0.282669	0.000015	4.40	-0.95	854	971
Kekeagashi@13	0.112903	0.001227	0.003641	0.000045	0.282818	0.000029	9.28	-0.89	673	724
Kekeagashi@14	0.082798	0.000045	0.002443	0.000031	0.282756	0.000026	7.65	-0.93	739	818
Kekeagashi@15	0.075901	0.002107	0.002041	0.000037	0.282689	0.000028	5.19	-0.94	832	939
Kekeagashi@16	0.057023	0.001279	0.001535	0.000033	0.282667	0.000018	4.53	-0.95	850	966
Kekeagashi@17	0.073796	0.006794	0.001849	0.000047	0.282712	0.000015	6.31	-0.95	784	996
Kekeagashi@18	0.079503	0.007701	0.002232	0.000036	0.282786	0.000015	8.79	-0.93	691	759
Kekeagashi@19	0.091911	0.001766	0.002236	0.000047	0.282785	0.000018	8.69	-0.93	691	759
Kekeagashi@20	0.065303	0.005773	0.001735	0.000036	0.282735	0.00002	5.92	-0.95	797	899
Tiemuerte@01	0.069316	0.002366	0.001954	0.000045	0.282727	0.000015	6.88	-0.94	772	968
Tiemuerte@02	0.069308	0.002829	0.002342	0.000048	0.282758	0.000019	7.84	-0.93	737	813
Tiemuerte@03	0.051815	0.003351	0.001244	0.000039	0.282229	0.000016	-10.62	-0.96	1463	2069
Tiemuerte@04	0.052109	0.005185	0.001557	0.000042	0.282295	0.000029	-8.23	-0.95	1376	1919
Tiemuerte@05	0.046913	0.005102	0.001644	0.000037	0.282664	0.000026	4.84	-0.95	852	965
Tiemuerte@06	0.052607	0.007495	0.001844	0.000038	0.282715	0.000029	6.57	-0.95	784	880
Tiemuerte@07	0.045906	0.006624	0.001647	0.00004	0.282798	0.000019	9.48	-0.95	665	729
Tiemuerte@08	0.050911	0.003208	0.001356	0.000047	0.282266	0.000019	-9.23	-0.96	1411	1982
Tiemuerte@09	0.070803	0.004283	0.002435	0.000042	0.282737	0.000122	7.24	-0.93	768	851
Tiemuerte@10	0.069314	0.004772	0.002332	0.000035	0.282758	0.000028	7.87	-0.93	737	813
Tiemuerte@11	0.066798	0.004716	0.002333	0.000044	0.282815	0.000023	9.95	-0.93	649	704
Tiemuerte@12	0.074902	0.003832	0.002539	0.000034	0.282722	0.000013	5.97	-0.92	814	904
Tiemuerte@13	0.075811	0.002693	0.002644	0.000031	0.282815	0.000021	9.84	-0.92	654	707
Tiemuerte@14	0.092123	0.005844	0.002837	0.000031	0.282697	0.000023	5.53	-0.92	836	931
Tiemuerte@15	0.062815	0.002334	0.002131	0.000039	0.282778	0.000026	8.49	-0.94	704	775
Tiemuerte@16	0.035719	0.007551	0.001531	0.000047	0.282256	0.000018	-9.64	-0.95	1432	2008
Tiemuerte@17	0.052519	0.000093	0.001949	0.000045	0.282748	0.000027	7.54	-0.94	743	824
Tiemuerte@18	0.061023	0.003296	0.002238	0.000047	0.282787	0.000023	8.89	-0.93	691	756



Tiemuerte@19	0.066812	0.001643	0.002342	0.000057	0.282825	0.000016	9.42	-0.93	664	722
Tiemuerte@20	0.074906	0.006382	0.002537	0.000043	0.282793	0.000027	9.33	-0.92	682	742
Jiaertasi@01	0.061112	0.002522	0.001933	0.000033	0.282724	0.000025	6.99	-0.94	772	860
Jiaertasi@02	0.063321	0.007818	0.002044	0.000038	0.282696	0.000022	5.90	-0.94	818	916
Jiaertasi@03	0.068414	0.002488	0.002038	0.000043	0.282756	0.000025	8.15	-0.94	731	808
Jiaertasi@04	0.075709	0.004045	0.002249	0.000035	0.282757	0.000019	7.81	-0.93	735	809
Jiaertasi@05	0.047123	0.005554	0.001444	0.000037	0.282726	0.000019	7.26	-0.96	762	854
Jiaertasi@06	0.033801	0.001231	0.001039	0.000039	0.282778	0.000013	9.12	-0.97	683	757
Jiaertasi@07	0.046903	0.005416	0.001444	0.000046	0.282699	0.000018	6.09	-0.96	805	909
Jiaertasi@08	0.047512	0.002039	0.001437	0.000034	0.282747	0.000027	7.76	-0.96	733	817
Jiaertasi@09	0.060905	0.005917	0.001839	0.000038	0.282698	0.000024	5.80	-0.95	813	915
Jiaertasi@10	0.055816	0.005691	0.001348	0.000045	0.282248	0.000021	-9.84	-0.96	1439	2023
Jiaertasi@11	0.055709	0.006317	0.001735	0.000044	0.282842	0.000023	11.33	-0.95	595	640
Jiaertasi@12	0.032218	0.005762	0.001048	0.000049	0.282838	0.000027	10.95	-0.97	598	647
Jiaertasi@13	0.044106	0.000646	0.001449	0.000042	0.282762	0.000015	8.35	-0.96	705	782
Jiaertasi@14	0.064813	0.003571	0.002132	0.000033	0.282725	0.000015	6.93	-0.94	776	863
Jiaertasi@15	0.031512	0.000514	0.000939	0.000033	0.282684	0.000023	5.67	-0.97	808	917
Jiaertasi@16	0.033209	0.005268	0.000948	0.000046	0.282777	0.000021	6.66	-0.97	780	881
Jiaertasi@17	0.041803	0.001366	0.001648	0.000049	0.282188	0.000023	-12.04	-0.95	1535	2161
Jiaertasi@18	0.062412	0.002192	0.001937	0.000045	0.282783	0.000028	9.01	-0.94	685	750
Jiaertasi@19	0.022012	0.004309	0.000731	0.000042	0.282828	0.000018	10.79	-0.98	607	661
Jiaertasi@20	0.034913	0.001599	0.001139	0.000043	0.282795	0.000039	9.80	-0.97	657	723
Chaganxile@01	0.060314	0.001485	0.002134	0.000035	0.282762	0.000022	8.45	-0.94	718	789
Chaganxile@02	0.078716	0.003205	0.002234	0.000043	0.282864	0.000019	12.07	-0.93	574	609
Chaganxile@03	0.053909	0.000797	0.001647	0.000036	0.282686	0.000029	5.61	-0.95	823	926
Chaganxile@04	0.041813	0.000772	0.001541	0.000046	0.282225	0.000129	-11.12	-0.96	1491	2107
Chaganxile@05	0.066509	0.003328	0.002036	0.000048	0.282177	0.000029	-12.41	-0.94	1566	2187
Chaganxile@06	0.121308	0.004636	0.003647	0.000046	0.282838	0.000029	10.34	-0.89	643	684
Chaganxile@07	0.147512	0.003785	0.004247	0.000035	0.282743	0.000025	6.73	-0.84	817	870
Chaganxile@08	0.062014	0.004152	0.002032	0.000032	0.282784	0.000039	9.21	-0.94	687	752
Chaganxile@09	0.147908	0.000381	0.004139	0.000039	0.282765	0.000015	8.02	-0.89	749	811
Chaganxile@10	0.053107	0.004948	0.002149	0.000035	0.282876	0.000016	12.30	-0.94	558	628
Chaganxile@11	0.057112	0.004257	0.001648	0.000033	0.282747	0.000029	7.88	-0.95	737	818
Chaganxile@12	0.201503	0.007956	0.005535	0.000033	0.282752	0.000025	7.30	-0.85	794	848
Chaganxile@13	0.162905	0.006778	0.004537	0.000043	0.282677	0.000025	4.72	-0.88	896	980
Chaganxile@14	0.061209	0.000112	0.001536	0.000053	0.282756	0.000014	8.40	-0.95	721	797
Chaganxile@15	0.162901	0.000868	0.004645	0.000045	0.282674	0.000022	4.73	-0.88	896	981
Chaganxile@16	0.087612	0.002795	0.002244	0.000041	0.282822	0.000018	10.41	-0.93	632	680
Chaganxile@17	0.106708	0.000345	0.002737	0.000037	0.282841	0.000026	10.96	-0.92	612	654
Chaganxile@18	0.057113	0.000189	0.001649	0.000036	0.282764	0.000017	8.70	-0.95	708	781
Chaganxile@19	0.059504	0.002692	0.001842	0.000038	0.282766	0.000027	6.41	-0.95	799	894
Chaganxile@20	0.201515	0.007064	0.005742	0.000059	0.282795	0.000029	8.75	-0.85	730	775
Sareshuo@01	0.041706	0.001181	0.001242	0.000049	0.282685	0.000022	5.94	-0.96	814	917
Sareshuo@02	0.043911	0.006826	0.001337	0.000046	0.282674	0.000024	5.68	-0.96	831	939
Sareshuo@03	0.057017	0.005292	0.001742	0.000048	0.282686	0.000021	6.02	-0.95	825	927



Sareshuoke@04	0.047707	0.003986	0.001538	0.000039	0.282667	0.000015	5.06	-0.95	850	958
Sareshuoke@05	0.053616	0.004768	0.001657	0.000046	0.282652	0.000019	4.66	-0.95	866	979
Sareshuoke@06	0.039908	0.006017	0.001337	0.000044	0.282715	0.000024	6.68	-0.96	788	884
Sareshuoke@07	0.047113	0.001577	0.001336	0.000038	0.282673	0.000028	5.56	-0.96	831	939
Sareshuoke@08	0.038709	0.001438	0.001241	0.000044	0.282217	0.000029	-10.59	-0.96	1477	2080
Sareshuoke@09	0.041609	0.003623	0.001233	0.000037	0.282688	0.000016	5.94	-0.96	814	917
Sareshuoke@10	0.043915	0.004752	0.001347	0.000337	0.282712	0.000016	7.06	-0.96	774	866
Sareshuoke@11	0.127808	0.002511	0.003634	0.000038	0.282683	0.000026	5.30	-0.89	870	954
Sareshuoke@12	0.057513	0.003967	0.001739	0.000045	0.282784	0.000029	9.42	-0.95	682	745
Sareshuoke@13	0.072206	0.004749	0.002038	0.000045	0.282784	0.000016	9.33	-0.94	687	750
Sareshuoke@14	0.117314	0.002354	0.003441	0.000035	0.282716	0.000023	6.26	-0.90	820	899
Sareshuoke@15	0.091031	0.001598	0.002542	0.000039	0.282664	0.000018	5.02	-0.92	873	973
Sareshuoke@16	0.048802	0.001077	0.001339	0.000046	0.282197	0.000025	-11.33	-0.96	1509	2126
Sareshuoke@17	0.101907	0.000478	0.002941	0.000043	0.282778	0.000028	8.72	-0.91	719	781
Sareshuoke@18	0.088613	0.005945	0.002449	0.000034	0.282279	0.000023	-8.81	-0.93	1439	1679
Sareshuoke@19	0.127809	0.003734	0.003632	0.000032	0.282687	0.000027	5.34	-0.89	870	954
Sareshuoke@20	0.053913	0.003474	0.001831	0.000034	0.282688	0.000017	9.74	-0.95	669	729
Sample	$^{18}\text{O}/^{16}\text{O}$	1SE(%)	$\delta^{18}\text{O}(\text{‰})$	2SE(‰)	MSWD	[U]($\mu\text{g/g}$)	[Th]($\mu\text{g/g}$)	Age(Ma)	1 σ	
Kekeagashi@01	0.002031	0.012	9.95	0.12	27	152.6	82.3	408	16	
Kekeagashi@02	0.002031	0.014	9.79	0.14		264.5	255.1	408.3	11	
Kekeagashi@03	0.002031	0.009	10.02	0.09		153.9	139.8	407.1	13	
Kekeagashi@04	0.002037	0.008	10.88	0.12		147.9	66.3	2159.6	37	
Kekeagashi@05	0.002025	0.011	9.53	0.11		250.7	82.8	408.6	15	
Kekeagashi@06	0.00203	0.013	10.23	0.12		212.6	63.5	2678.3	48	
Kekeagashi@07	0.002031	0.011	9.78	0.11		308.5	251.6	409.4	14	
Kekeagashi@08	0.002035	0.012	11.23	0.12		154	88.3	412.9	16	
Kekeagashi@09	0.002035	0.012	11.39	0.12		258.7	239.6	408.3	10	
Kekeagashi@10	0.002033	0.011	10.05	0.09		186.9	58.3	2930.7	39	
Kekeagashi@11	0.002031	0.011	9.86	0.11		157.2	94.2	410.5	12	
Kekeagashi@12	0.002031	0.012	10.16	0.12		248.5	81.8	410.1	15	
Kekeagashi@13	0.002033	0.009	11.02	0.09		121.8	78.7	408.3	11	
Kekeagashi@14	0.002031	0.02	10.1	0.2		314.4	255.2	407.7	14	
Kekeagashi@15	0.00203	0.01	9.5	0.1		152.5	75	407.3	17	
Kekeagashi@16	0.00203	0.01	9.55	0.1		178.1	94.5	409.4	12	
Kekeagashi@17	0.002032	0.011	10.02	0.12		158.3	119.8	410.6	11	
Kekeagashi@18	0.002031	0.014	9.98	0.14		161	99.3	408.4	12	
Kekeagashi@19	0.002032	0.015	10.23	0.15		251.9	81.8	408.2	15	
Kekeagashi@20	0.002031	0.008	9.88	0.08		128.5	84.6	413.8	13	
Tiemuerte@01	0.002029	0.011	11.64	0.11	17	537.2	179.5	421	14	
Tiemuerte@02	0.002031	0.011	10	0.11		421	358	424	14	
Tiemuerte@03	0.002033	0.011	9.98	0.12		225.7	86.9	3459.8	59	
Tiemuerte@04	0.002031	0.011	10.08	0.12		221.9	71.2	2930.1	48	
Tiemuerte@05	0.002032	0.013	9.75	0.13		166.7	83.8	418.5	11	
Tiemuerte@06	0.002032	0.012	9.77	0.12		477.8	427.3	421.4	17	



Tiemuerte@07	0.002032	0.012	9.99	0.12		118.5	100	421.7	14
Tiemuerte@08	0.002033	0.011	11.75	0.11		256.8	83.7	3255.7	40
Tiemuerte@09	0.002032	0.009	9.9	0.09		576.5	192.2	421.7	10
Tiemuerte@10	0.002032	0.009	9.83	0.09		428.7	377.4	417.9	12
Tiemuerte@11	0.002032	0.014	9.86	0.14		195.9	158.9	419.1	12
Tiemuerte@12	0.002034	0.013	10.62	0.13		165.8	85.1	418.2	12
Tiemuerte@13	0.002032	0.009	10.05	0.09		497.2	441.4	421.4	17
Tiemuerte@14	0.002032	0.01	9.89	0.1		119.2	97.5	422.4	17
Tiemuerte@15	0.002033	0.015	10.17	0.15		541.9	182.2	421.1	10
Tiemuerte@16	0.002031	0.015	11.62	0.16		267.3	68.1	1989.8	42
Tiemuerte@17	0.002032	0.012	9.93	0.12		203.5	168.7	424.2	12
Tiemuerte@18	0.002032	0.013	9.82	0.13		166.1	84	420	11
Tiemuerte@19	0.002033	0.016	10.19	0.16		491.5	442.4	419.5	18
Tiemuerte@20	0.002033	0.015	10.35	0.15		119.8	99.2	423.3	16
Jiaertasi@01	0.002034	0.011	10.78	0.11	14	458.2	263.7	425.6	12
Jiaertasi@02	0.002033	0.01	10.11	0.1		817	567.9	423.8	13
Jiaertasi@03	0.002032	0.007	9.65	0.07		510.5	392.6	424	11
Jiaertasi@04	0.002032	0.013	9.84	0.13		503	294.8	419.8	16
Jiaertasi@05	0.002033	0.012	10.18	0.12		603.2	502.8	426.1	14
Jiaertasi@06	0.002031	0.012	9.54	0.12		858	479.9	424.2	14
Jiaertasi@07	0.002031	0.023	9.41	0.23		466.3	266.8	425.9	14
Jiaertasi@08	0.002033	0.023	10.38	0.23		802.7	540.9	424.7	14
Jiaertasi@09	0.002031	0.013	9.6	0.13		528.1	417.4	428.5	14
Jiaertasi@10	0.002033	0.012	9.65	0.12		285.6	152.3	3103.8	41
Jiaertasi@11	0.002028	0.011	11.01	0.11		514.8	306.4	424.9	15
Jiaertasi@12	0.002032	0.016	9.72	0.16		593.3	485.1	424.5	19
Jiaertasi@13	0.002033	0.012	10.27	0.12		706.7	362.6	427.4	18
Jiaertasi@14	0.002033	0.014	10.17	0.14		453.1	261.6	427.5	13
Jiaertasi@15	0.002033	0.007	10.46	0.07		804.5	553.1	428.4	13
Jiaertasi@16	0.002032	0.017	9.8	0.17		521.5	406.7	425.2	12
Jiaertasi@17	0.00203	0.011	9.31	0.16		373.6	105.5	2306.7	31
Jiaertasi@18	0.002032	0.011	10.01	0.11		499.9	294	428.4	16
Jiaertasi@19	0.002033	0.009	10.13	0.09		603.7	503.1	426	16
Jiaertasi@20	0.002032	0.009	9.88	0.09		754.1	400.3	424.1	16
Chaganxile@01	0.002032	0.011	9.76	0.11	16	688.6	457.2	430.2	7
Chaganxile@02	0.002032	0.012	10.09	0.12		486.5	113	430.2	20
Chaganxile@03	0.002031	0.016	9.59	0.16		2331.5	885.5	430.5	6
Chaganxile@04	0.00203	0.015	10.46	0.13		984.3	331.6	2987.3	36
Chaganxile@05	0.002033	0.013	10.22	0.15		549.3	238.1	3505.7	43
Chaganxile@06	0.002032	0.012	10.04	0.12		1484.2	804.9	430.2	11
Chaganxile@07	0.002033	0.014	10.21	0.14		145.3	66.6	430.4	10
Chaganxile@08	0.002033	0.012	10.42	0.12		540	172.7	429.2	8
Chaganxile@09	0.002033	0.019	10.25	0.19		522.2	153	431	9
Chaganxile@10	0.002032	0.018	10.11	0.15		563.7	369.2	430.9	8
Chaganxile@11	0.002033	0.013	10.16	0.13		2613.3	1062.9	430.4	5



Chaganxile@12	0.002033	0.013	10.44	0.13		1538.7	842.2	430.3	18
Chaganxile@13	0.002032	0.011	9.89	0.11		167.6	86.4	430.3	10
Chaganxile@14	0.002031	0.016	9.18	0.16		496.2	152.5	430	7
Chaganxile@15	0.002025	0.012	9.57	0.12		519.6	155.6	431.4	8
Chaganxile@16	0.002028	0.009	10.96	0.09		619.1	416.4	430.4	7
Chaganxile@17	0.002032	0.012	9.99	0.12		2629.9	1054.1	430.7	4
Chaganxile@18	0.002025	0.008	9.54	0.08		1473.3	832.2	430.8	19
Chaganxile@19	0.002033	0.014	10.3	0.14		172.1	92.9	430.8	8
Chaganxile@20	0.002025	0.007	9.56	0.07		467.1	142.7	430	6
Sareshuo@01	0.002026	0.01	10.1	0.1	12	572.7	255.4	436.5	12
Sareshuo@02	0.002026	0.013	9.7	0.13		647.6	480.4	437.7	9
Sareshuo@03	0.002031	0.013	9.44	0.13		867.3	512.2	439.1	10
Sareshuo@04	0.002025	0.013	9.48	0.13		506.8	258	437.3	18
Sareshuo@05	0.002026	0.01	9.63	0.1		1378.9	1176	435.9	8
Sareshuo@06	0.002025	0.009	9.57	0.09		1029.3	637.2	436.4	13
Sareshuo@07	0.002026	0.01	10.09	0.1		567.7	256.7	437.5	15
Sareshuo@08	0.002024	0.008	9.58	0.12		651.1	204.9	2625.3	38
Sareshuo@09	0.002025	0.009	9.45	0.09		667.8	488.2	437.1	9
Sareshuo@10	0.002026	0.012	9.62	0.12		884.8	531.2	440.5	12
Sareshuo@11	0.002025	0.016	9.46	0.16		478.5	226.4	440.9	23
Sareshuo@12	0.002026	0.014	10.06	0.14		1181.1	973.8	441.4	15
Sareshuo@13	0.002025	0.01	9.42	0.1		1019.6	649.9	439	18
Sareshuo@14	0.002025	0.011	9.57	0.11		570.8	255.1	437.4	13
Sareshuo@15	0.002032	0.011	10.48	0.11		662.9	478.4	437.7	10
Sareshuo@16	0.002031	0.012	9.38	0.12		682.9	223.3	2857.9	36
Sareshuo@17	0.002026	0.016	9.8	0.16		880.3	519.2	438.2	10
Sareshuo@18	0.002035	0.013	11.12	0.13		697.2	129.7	3043.6	20
Sareshuo@19	0.002034	0.013	10.85	0.13		1217.2	1002.6	437.8	13
Sareshuo@20	0.00203	0.012	9.45	0.12		1023.6	643.5	437.3	16

Table S-3 Global compilation of published Hf and Nd isotopic compositions of A-type granites.

Reference	Sample number	Mean value of $\epsilon_{Nd}(t)$	Sample number	Mean value of $\epsilon_{Hf}(t)$
Niu <i>et al.</i> , 2011	DZZ1-DZZ6	-16.833	DZZ3	-15.102
Luo <i>et al.</i> , 2018	L63-L68	2.243	L64	4.4
	L42-L46	-1.4	L42	2.9
Yang <i>et al.</i> , 2006	JH-07-JH30	-13.85	03JH029-40	-13.344
	FW01-162-FW01-164	-13.55	FW01-162	-11.985
Zhang <i>et al.</i> , 2013	09KZ01-09KZ04	-1.467	09KZ05	0.915
	09GL01-10	-0.178	09GL07	1.431
	09HLJ V-1-9	0.1025	2010 HLJ III-V, 08KT01, HLJ026-28	0.379
Zheng <i>et al.</i> , 2017a	ZK1902-Y-8-ZK3204-Y-2	-5.514	ZK1902-Y-7 -ZK2805-Y	0.811
Yan <i>et al.</i> , 2018	15SJW-1-15SJW-5	-4.53	15SJW	0.792
Zhao <i>et al.</i> , 2015a	BSS-2-BSS-8	-3.575	BSS-4-BSS8	0.164
	12JGS-3-12JGS-5	-3.3	12JGS-5	-1.026



	12WS-1-12WS-4	-4.125	12WS-1-12WS-4	-1.473
Yang <i>et al.</i> , 2012	XL-5-XL17	-4.678823529	XL-11	-4.738
	DQW-1-DQW-3	-5.36		
Chen <i>et al.</i> , 2015b	BZS-1-BZS-6	-11.733	BZS4-BZS5	-7.661
	DMS-1	-11.2	DMS-1-DMS-19	-7.726
Cai <i>et al.</i> , 2017	X3-X7	-1.754	X3-X5	-1.923
Feng <i>et al.</i> , 2014	09HT-1-09HT-10	-9.257	HT-9a	-8.054
	09EP-1-09EP-4	-8.133	EP-4	-6.639
	09HT-9b	-7.3	HT-9b	-8.036
Zhao <i>et al.</i> , 2013	08TS-09TS	-9.667	08TS-48	-7.509
	08GX-20-08GX-25	-13.8	08GX-20-08GX-24	-11.915
Zhang <i>et al.</i> , 2014	BYH-10	4.835	BYH1	9.76
Chen <i>et al.</i> , 2015c	LLS2-LLS8	-11.65	LLS2-LLS6	-9.61
Hu <i>et al.</i> , 2017	13ZJ26-13ZJ89	-3	13ZJ28-13ZJ89	-1.353
Li <i>et al.</i> , 2018a	12WN-12-12WN-16	-1.967	12WN-12-12WN-16	6.623
Li <i>et al.</i> , 2018b	HC1-HC23	-4.86	HC4-17	-7.025
Sun <i>et al.</i> , 2017	8047-8052	-9.325	08047	-8.688
	8041-8045	-9.36	08042	-7.627
Zhao <i>et al.</i> , 2009	SC7-SC15,DF9-DF-11	-7.36	DF-43	-11.656
	SC11,DF33-DF38	-6.85	DF-38	-8.536
Zhou <i>et al.</i> , 2015a	12ZX11-12ZX17	0.265	12ZX13	-0.44
Shen <i>et al.</i> , 2011	08WLG13-08WLG17	5.65	08WLG07-08WLG16	14.027
	08QH24-08QH29	7.12	08QH25-08QG27	11.688
Zhao <i>et al.</i> , 2008	KD06-32-KD06-189	0.971	KD06-32-KD06-157	6.817
Gu <i>et al.</i> , 2017	13CZYS-02-13CZYS-10	-6.053	13CZYS02-13CZYS08	-3.293
Deng <i>et al.</i> , 2016	GJY6-GJY22	-5.713	GJY6-GJY22	-9.018
Wang <i>et al.</i> , 2013a	DYC14-DYC38	-9.316	DYC12-DYC36	-6.883
Xia <i>et al.</i> , 2012	JLH03--JLH06	-4.967	JLH03	-8.76
	JJ03-JJ07	-7.025	JJ03-JJ07	-11.645
Sun <i>et al.</i> , 2011	LS12-LS15	-13.5	LS15	-14.294
Jiang <i>et al.</i> , 2011	TS1-TS9	-3.75	TS-4	-3.9
	DMS1-DMS16	-3.206	DMS2-DMS9	-2.364
	TS-4-2	0.9	TS-4-2	-6.163
Zhou <i>et al.</i> , 2012	HG1-HG3	0.033	HG1-HG3	6.908
Zhou <i>et al.</i> , 2015b	ZK10C02-ZK14B04	-8.691	HG-3-5-20	-9.111
Wang <i>et al.</i> , 2010	LG78-LG88	4.608	17.1	12.515
Xin <i>et al.</i> , 2018	JCHGY-Y1-JCHGY-Y7	-3.456	XTB-2016-N1-XTB-2016-N2	1.510
Jiang <i>et al.</i> , 2018b	JHS01-JHS21	-6.747	JHS01-JHS21	5.571
Zhou <i>et al.</i> , 2017	12ZX03-12ZX08	-10.988	12ZX03	-17.764
Xia <i>et al.</i> , 2016	MH01-MH23	-2.86	MH01-MH23	-3.392
	SH03-SH06	-0.9	SH03	-6.491
Zhao <i>et al.</i> , 2016a	ZJJ3-ZJJ6	-7.45	ZJJ-3	-7.25
	ZJJ8-ZJJ11	-6	ZJJ-8	-4.690
	12THD-1-12THD-4	-6.15	12THD-1-12THD-4	-4.271
	XZD1-XZD10	-6.15	XZD-2	-4.305



Jiang <i>et al.</i> , 2017	HMG01-HMG08	-11	HMG06	-11.8
	TPL06-TPL09	-11.05	TPL07	-10.925
Chen <i>et al.</i> , 2016b	DL-500-DL-640	-8.548	DL-500-DL-640	-10.537
Zheng <i>et al.</i> , 2017b	XS-Y-1-XS-Y-4	-6.65	XS-Y-6	-2.528
Gürsu <i>et al.</i> , 2018	DPK17A-DPK72	-4.25	Z17A-DPK27-DPK72	-0.016
Zhou <i>et al.</i> , 2018	1-18	-6.043	1-18	-0.011
	PT03-PT04	-2.213	PT03-PT04	-0.8
Zhang <i>et al.</i> , 2018b	Taerbaha-01-Taerbaha-04	4.795	Taerbaha	9.963
	KujibeiEa-KujibeiEb	4.636	KujibeiEa-KujibeiEb	9.813
	Qibaertie-01-Qibaertie-04	5.2	Qibaertie	10.404
	WuerkashierN-01-WuerkashierN-04	7.73	WuerkashierN	13.705
	WuerkashierE-01-WuerkashierE-04	5.583	WuerkashierE	10.912
	HebukessairSW-01-HebukessairSW-04	8.033	HebukessairSW	14.755
	HebukessairN-01-HebukessairN-04	8.105	HebukessairN	15.218
Cao <i>et al.</i> , 2014	G1	-7.5	G1	-4.42
Li <i>et al.</i> , 2018a	XHL5-XHL7	-6.171	XHL5-XHL7	-7.254
Wang <i>et al.</i> , 2015a	13FRS-14-13FRS-20	-3.475	13FRS-12-13FRS-15	0.791
Li <i>et al.</i> , 2018b	Qitianling	-6.59	Qitianling	1.5
	Qianlishan	-6.7775	Qianlishan	2
	Jinjiling	-7.475	Jinjiling	2
	Tongshanling	-4.7	Tongshanling	1.5
	Baoshan	-6.3	Baoshan	1.5
	Xihuashan	-10.7925	Xihuashan	2.5
	Guposhan	-3.783333333	Guposhan	1.5
	Huashan	-3.523333333	Huashan	1
	Huangshaping	-5.233333333	Huangshaping	2
	Hehuaping	-6.52	Hehuaping	1.5
Gao <i>et al.</i> , 2016	ZK702-ZK804	-14.575	119	-14.9
Ye <i>et al.</i> , 2016	13TR02	-3.017	13TR01-12TR07	-2.114
Zhang <i>et al.</i> , 2017d	XS1507-XS1530	-4.967	XS1507-XS1530	-2.576
Wang <i>et al.</i> , 2017	1504FY3	-6.2	1403FY13-5	-0.3
	1410SMS1-1410SMS4	-2.225	07SMS	-0.61
Lan <i>et al.</i> , 2015	CY2-49-CY2-92	-4.633	CY2-92	-5.573
	CY2-43-CY2-44	-4.5	CY2-43	-4.235
Zhong <i>et al.</i> , 2017	13ts14B-13ts14I	-1.255	13ts14B-13ts14I	3.039
Ding <i>et al.</i> , 2014	BLGTC104-B1-BLGTC104-B11	-3.3	BLG-TC104-B1-BLGTC104-B9	-1.497
	XI01-X102	-5.333	XI01-X102	-3.05
Zhu <i>et al.</i> , 2016	HCQ1003-HCQ1308	-0.335	HCQ1003	8.792
	KMZ1001-KMZ1103	-5.82	KMZ1001	1.056
Li <i>et al.</i> , 2015c	11QJ5-10QJ-3D	4.3	10QJ-3D	13.143
Chen <i>et al.</i> , 2013a	KH128-KH174	-0.675	KH128-KH174	1.889
Su <i>et al.</i> , 2013	FC2	-8.4	FC2	-8.732
	HS5	-5	HS5	-2.735
Tang <i>et al.</i> , 2010	06XJ017-06XJ23-2	-1.502	06XJ17	4.105
	06XJ04-06XJ15	0.126	06XJ13	5.333



Hu <i>et al.</i> , 2016	YNG12	-2.403	YNG1201	-3.35
	QMX12	-3.713	QMX12	-3.71
	DL09	-3.01	DL09	-2.355
Liu <i>et al.</i> , 2008	JX1-JX10	-18.733	JXZ01-JXZ19	-23.732
	WL2-WL12	-19	WLZ01-WLZ17	-23.724
Guo <i>et al.</i> , 2012	XHS3-XHS35	-10.72	XHS-4	-10.218
	X09,XHS1-24	-11.02	XHS-22	-10.047
	XHS15-XHS37	-10.85	XHS15-XHS37	-10.367

Table S-3 (continued). Global compilation of published Hf and Nd isotopic compositions of I-type granites.

Reference	Sample number	Mean value of $\epsilon_{Nd}(t)$	Sample number	Mean value of $\epsilon_{Hf}(t)$
Yan <i>et al.</i> , 2017	TXH1-TXH4	-4.997	TXH-1	-4.382
Konopelko <i>et al.</i> , 2018	4-17	-4.800	04-11	-0.054
Yang <i>et al.</i> , 2017	DY001-DY006	-6.651	DY002	-8.480
	JZ001-JZ006	-5.799	JZ006	-5.433
Qiu <i>et al.</i> , 2017	HC2-HC7	-9.160	HC1	-11.272
Jiang <i>et al.</i> , 2018a	G1,ZK301.4-ZK301.9	-11.867	ZK301-4	-11.881
	G2,340.13-340.30,ZK301.1,ZK301.3	-11.714	340-13	-11.444
Yu <i>et al.</i> , 2017	KN01-KN04	-0.567	KN01-KN04	5.133
	ALT66-ALT67	0.600	ALT66-ALT67	11.500
	ALT03-ALT04	-0.250	ALT03-ALT04	5.450
	ALT15-ALT17	-1.267	ALT15-ALT17	5.067
	HM02-HM12	-2.725	HM02-HM12	4.250
	KW14-KW16	-0.567	KW14-KW16	3.733
	JDY13-JDY15	-1.133	JDY13-JDY15	9.233
Li <i>et al.</i> , 2015b	AG1-AG10,ABG1-ABG2,AGM1	7.455	ABG1-AGM1	11.183
Zhou <i>et al.</i> , 2011	XT4-XT12,LJG1-LJG9	2.540	XT3	8.115
Luo <i>et al.</i> , 2018	L49-L52	0.050	L52	7.650
	L53-L57	-3.500	L53	-0.150
	L37-L41	1.960	L38	7.850
Zhao <i>et al.</i> , 2018	RJ01-RJ09	0.863	RJ01	6.573
Zhu <i>et al.</i> , 2011	LiN2-LiN6	-6.340	LiN4	-3.356
	LuN1-LuN2	-5.250	LuN1	-2.800
	BW1-BW6	-6.067	BW1	-0.230
He <i>et al.</i> , 2018a	BMXS1-BMXS12	-6.323	BMXS1,BMXS10	-2.438
Li <i>et al.</i> , 2016a	EK4.1-EK4.2,Zh1.1	1.567	EK4.2,Zh1.1	10.810
	Zh2.10-Zh5	0.800	Zh2.1	6.853
	Ash2-Ash5	0.650	Ash-5	9.681
Deng <i>et al.</i> , 2018	SK45-SK77	3.850	SK76	7.595
Cao <i>et al.</i> , 2014	G21-G23	-13.833	G21	-9.636
Yu <i>et al.</i> , 2016	XQ10.1-XQ10.13	-9.550	XQ10.3	-8.571
	XQ10.11-XQ10.15	-8.000	XQ10.15	-6.244
Zhang <i>et al.</i> , 2017e	12JH160-12JH243	-10.637		-10.937
Cao <i>et al.</i> , 2017	10BSD9-10BSD12, BSD01*- BSD02*	5.180	BSD9,BSD13	7.575



	BS16-BS17,BSZK15-5-405	5.767	BS-16	6.767
Wang <i>et al.</i> , 2017	KFP2-KFP10	-1.233	KFP4	-5.278
Jia <i>et al.</i> , 2018	SGS01.1-SGS01.3,AM01-1	-3.293	AM01,SGS02	0.149
	WC01.1-WC01.2	-3.290	WC01	0.396
	SR04.1-SR04.3	-3.873	SR04	-0.425
Gao <i>et al.</i> , 2014b	TSM1-TSM60	-11.667	TSM20	-13.000
	TQG1-TQG6,13TQG1-13TQG6	-3.500	TQG1	4.150
Zhou <i>et al.</i> , 2017	12WW08-12WW76	2.090	12WW15,12WW52	4.456
Wu <i>et al.</i> , 2017	SCM11h-SCM16h	-4.067	SCM10	-0.839
	JDC2H-JDC3H,CJM2-CJM9	-6.950	JDC2	-1.692
	HZS1H-HZS15H	-8.000	HZS8	-8.550
Liu <i>et al.</i> , 2017	13ZJS10-13ZJS18	-5.480	13ZJS14	-5.445
	13ZJS10.1-13ZJS18.1	-5.323	13ZJS16.1	-5.128
Karsli <i>et al.</i> , 2016	CM6-CM19	-4.580	CM21	-1.800
	CS5-CS10	-3.975	CS10	0.220
He <i>et al.</i> , 2018b	ZK0810.1-ZK0814.1	-4.648	ZK0810.1,ZK0813.1	-4.254
Zhong <i>et al.</i> , 2011	ALH-0702,ALH-0401	-6.630	ALH-0401,ALH-0702	-2.218
Qin <i>et al.</i> , 2009	MG02,MG08	-6.385	MG01-MG29	0.995
	ME23,ME26	-6.500	ME03-ME19	1.102
Yuan <i>et al.</i> , 2016	EL10.9.1-EL10.9.8	4.025	EL10.9.1	11.383
	EL10.6.1-EL10.6.2	2.150	EL10.6.5	9.847
	9HS16.1-9HS16.2,9HS15.3.2,9HS15.6.1	1.100	9HS16-2,9HS15.3.2	6.890
Xia <i>et al.</i> , 2017	13NGT01.1-13NGT01.12	-12.067	13NGT12.1	-1.200
Moghadam <i>et al.</i> , 2015	K12-3,K12-23	-1.637	KR12	3.172
Yang <i>et al.</i> , 2016a	HNDSTB3-HNDSTB4,HNBYS8	-6.233	HNDSTB3,HNDSTB4	-5.558
	HZK0906B24-HZK0906B33	-7.317	HZK0906B29	-5.733
Mao <i>et al.</i> , 2017	YCLB1-YCLB32	-5.300		-1.803
Chen <i>et al.</i> , 2014	08JH256-08JH272	-1.271	MG	3.600
Wang <i>et al.</i> , 2015c	WR12.40-WR12.48	-0.580	WR12	6.728
Wang <i>et al.</i> , 2014b	XWC11.01-XWC11.33,SXWC10-04-SXWC10-45	-7.600	XWC11	-5.497
	RL12.01,RL12.08,HS12.05	-7.733	RL11,HS10	-7.070
	TCG12.05,TCG12.10	-5.450	TCG11.01	-4.654
Wang <i>et al.</i> , 2015b	WT2-WT6	-15.840	WT3	-20.657
	WT7-WT13	-13.733	WT13	-16.329
	SP4-SP9	-14.520	SP7	-15.684
	SP1-SP3	-8.633	SP2	-6.912
	WT1-WT15	-12.550	WT9	-10.865
Zhang <i>et al.</i> , 2015	BL004-BL009	2.860	BL004	5.140
	BL050-BL065	5.207	BL050.1-BL065.24	10.470
Zhou <i>et al.</i> , 2015b	TBD05-TBD10	-1.980	TBD-05	6.631
	TBD09-TBD14	-1.740	TBD-12	2.184
Li <i>et al.</i> , 2013	B80628-8.2,DDQ09824-1.1-DDQ09824-2.1	-0.733	B80628-8.2.1-15,DDQ09824-1.1.1-13-DDQ09824-2.1.1-13	4.324
Dan <i>et al.</i> , 2016	09AL147-09AL148	-8.400	09AL147	-6.817



Song <i>et al.</i> , 2018b	DST1-DST3	3.867	DST1	-1.678
Yang <i>et al.</i> , 2016b	SKS6-SKS50	-6.025	SKS31,SKS36	-8.865
Li <i>et al.</i> , 2015a	TR1.5-TR1.8	-7.733	TR1.1	-2.579
	TR2.1-TR2.3	-7.600	TR2.3	-3.123
Liu <i>et al.</i> , 2013	MC1.1,MC4	-2.800	MC1	0.275
Ma <i>et al.</i> , 2013	JJLL2-JJLL10	-19.031	JJLL1-JJLL6	-13.596
Gao <i>et al.</i> , 2017	RLB3-RLB9	-6.525	RL-B3,RL-B9	-5.973
	RLZK0002B7-RLZK0002B26	-7.200	RLZK20002B20	-5.800
Zi <i>et al.</i> , 2012	SJ110,SJ143	-7.130	SJ143	-9.856
Chen <i>et al.</i> , 2015a	YC1203-YC1211	-17.267	YC1204	-23.388
Zhang <i>et al.</i> , 2016	AHg01-AHg13	-7.050	AHG13	-5.098
Dan <i>et al.</i> , 2014	09AL10-09AL42	-11.705	09AL22,09AL27	-9.947
	09AL33-09AL38	-14.100	09AL33,09AL37	-11.523
He <i>et al.</i> , 2013	DC0901-DC0923	-7.213	DC0910,DC0922	-4.897
	XC0902-XC0905	-6.000	XC0903	2.013
Zhang <i>et al.</i> , 2008	04YC02,04YC05	-9.250	04YC02.1-04YC05.15	-9.200
	04YC11,04YC20	-8.100	04YC11	-11.107
	05XF08-05XF24	-8.475	05XF23	-12.471
Chen <i>et al.</i> , 2017b	XITG12-XITG29	-7.270	XITG23,XITG27	-3.586
Nabatiev <i>et al.</i> , 2016	GNT01-GNT081	1.704	GNT01,GNT02,GNT12	4.097
	GNT002-GNT033	1.970	GNT033	3.778
	GNT03-GNT05	0.897	GNT04	1.721
	GNT06-GNT049	1.213	GNT047	3.160
Wang <i>et al.</i> , 2015d	09GS28,10GS08-10GS93	-0.033	09GS28,10GS93	0.132
Li <i>et al.</i> , 2015d	J11-5-2,J11-5-2R	4.850	J11-5-1	6.642
Gao <i>et al.</i> , 2014c	FN46-FN161	-13.127	FN46,FN63,FN89,FN126	-9.441
Yin <i>et al.</i> , 2017	WJ1126.1-WJ1126.3,WJ1136.1-WJ1136.3	5.309	WJ1126,WJ1136	13.243
Chen <i>et al.</i> , 2016a	C14.1-C14.3,CG72-CG81,HKAM168-HKAM182	2.625	CG71,CG79	9.575
Liu <i>et al.</i> , 2012	YSH01.1-YSH01.5	-0.967	YSH01.1	3.006
Wang <i>et al.</i> , 2014a	JHH,GHH1	-12.850		-16.100
Liu <i>et al.</i> , 2009	PH5.4,PH5.7,PH4.6,PH4.7,PH3.1,PH3.7,XD1,XD6,PDX4,PDX16	-9.560	PDXZ01,XDZ01,PHZ01	-11.473
Li <i>et al.</i> , 2007	2KSC3-2KSC79,P1-P9	-9.050	2KSC3,2KSC79	
	2KF396-2KF403	-6.233	2KF405	-8.753
	MR28,MR42	-6.100	MR42	-5.513
	2KG4.1-2KG4.4	-7.575	2KG1.3	-1.405
Ma <i>et al.</i> , 2014	DX66A-DX-66F	-1.780	DX66B,DX66D	5.127
	DX57,DX59A	-1.400	DX57-DX58	4.133
Zhong <i>et al.</i> , 2013	J03161-J03162,FD05-FD09,FD11.1	-5.125	J03162	0.465
Xiao <i>et al.</i> , 2017	11LY1.1-11LY1.20	-3.455	11LY1.18	0.908
	11XY1.6-11XY1.7	-4.475	11XY1.6	0.952
	11JK1.2,11JK1.4	-3.515	11JK1.2	-3.713



	11NS1.1-11NS1.2	-5.695	11NS1.2	-3.947
Liao <i>et al.</i> , 2018	SK14.02-SK14.15	3.209	SK14.02-SK14.15	13.799
Qian <i>et al.</i> , 2017	TS-7-1	-0.600		8.150
	TS-14-1	-1.200		9.050
Dong <i>et al.</i> , 2018	SSWM5.1-SSWM5.4	-5.825	SSWM5.1	-5.175
	SSWM4.1-SSWM4.12	-4.450	SSWM4.1	-2.077
Bao <i>et al.</i> , 2018	ZS23-ZS41	-3.233	ZS21,ZS26,ZS34	-0.742
Chen <i>et al.</i> , 2013b	08JH332,08JH332,10JH184	-3.600	08JH332	-2.299
	08JH310,10JH189	-3.700	08JH308	-0.713
Cao <i>et al.</i> , 2016	ZK603.146,ZK403,360,BE2.0,ZK205.82,BHS	6.780	ZK003.233,BHS,BTC196	13.944
	ZK403.175,ZK603.116	7.100	BXS	14.239
Zhou <i>et al.</i> , 2018	13GD14.1,14GD10-14GD12	1.318	13GD14.1	11.183
Zhao <i>et al.</i> , 2012	Q93102-Q93106	-16.775	Q93105,LT28	-11.584
	Q93108.1-Q93108.6,LN05-LN18,LNS01-LNS16	-15.385	M0602,LN05	-21.696
	B0001.7,B0003.9,B2101.11,ZK001	-20.640	ZK0001	-29.311
	JD11-JD14	-15.333	JD23	-15.031
	JDC7-JDC100	-15.300	JDC34	-17.835
	sjwb1,sjwb2	-15.400	sj1	-17.959
	Q93109.1-Q93109.7,LF01-LF04	-17.950	LF04,HS10	-20.188
	HS6,HS9	-17.100	HSB1,HSB6	-22.359
	W2-W7	-12.900	WY15,W4	-11.853
	N1-N9	-16.183	NN18,N3,N6	-22.830
	MLG01,MLG06	-18.450	MLG06	-26.280
	LW01,HYY01 -HYY03	-10.300		-18.650
	LB01,LB03,LSB10-LSB92	-18.027	LSB43,LSB46,LSB47	-21.236
	LN1-LN4	-14.550	QYG16-5 19,LN3	-20.850
	YH108-YH146,43294-43297	-14.080	YH-110,07.15,07.16	-17.993
	Q9304.1-Q9304.7,HY01-HY60	-14.582	HY02,HY14,HY74,HY73,HY0701,HY0702,YCL.1	-16.194
	07DG02,07DG06	-15.300	DG2,DG5,DG0908	-13.980
	RY09.1-RY09.7,RY0907a,RY0907b	-14.263	RY0709	-14.170
	TSM1-TSM60	-12.200	TSM31,TSM20	-12.163
	LHK1307.1-LHK1307.51	-12.825	LHK 1307	-11.905
	Q9401,Q9402,FN37-FN161	-14.036	FN46,FN63,FN89,FN126	-9.402
	Mh16,Mh9,09392.1-09392.8,9396,93101	-10.167	Q93101,MHG30	-10.545
	Xigou	-10.400	XG01,GG06	-4.992
	ML17,ML21	-4.200	09CL260,ML28/1B, ML32/1B	-9.169
	Q9308.1-Q9308.9,Q9309,L01-L09	-4.725	LJSB1,LJSB8	0.074
	101-3,CG3-CG8,SG20,201-58,201-60,101-25,1301-40	-5.240	CG2	-1.136



Table S-3 (continued). Global compilation of published Hf and Nd isotopic compositions of S-type granites.

Reference	Sample number	Mean value of $\epsilon_{Nd}(t)$	Sample number	Mean value of $\epsilon_{Hf}(t)$
Zhao <i>et al.</i> , 2017a	MON-37	0.800	MON37	5.207
	MON-60	1.850	MON-60	7.564
	MON-65	-0.433	MON65	3.925
Li <i>et al.</i> , 2016b	NL1-NL13	-12.350	NL1-NL12	-12.265
Dan <i>et al.</i> , 2014	09AL225-09AL233	-0.160	09AL233	1.133
	09AL258-09AL262	-0.043	09AL258	4.871
Zhang <i>et al.</i> , 2017b	B2068-B2138	-1.250	B2127	0.824
Chen <i>et al.</i> , 2017a	L13JP-21-L13JP-29	-4.975	L13JP-20	-2.747
	L13JP-37-L13JP-46	-4.767	L13JP-40	-2.490
	L13TC-02-L13TC-05	-6.700	L13TC-1	-2.986
Feng <i>et al.</i> , 2018	Shimensi	-6.525		-6.150
	Pengshan	-5.890		-2.500
Qin <i>et al.</i> , 2014	10QL151-10QL158	-9.380	10QL151	-7.312
Wu <i>et al.</i> , 2017	AJSD-1h-AJSD-3h	1.545	AJSD-1-1-AJSD-1-12	-7.514
Zhang <i>et al.</i> , 2018a	Wukuli-1-Wukuli-4	-3.550	Wukuli-1-Wukuli-15	-1.933
	Kadelat-1-Kadelat-4	-3.575	Kadelat-1-Kadelat-15	-3.879
	Aketas-1-Aketas-6	5.233	Aketas-1-Aketas-15	12.364
Zheng <i>et al.</i> , 2018	BS-18-BS-30	-5.140	BS-18-02-BS-18-28	-0.630
	BH-16-BH-26	-5.090	BH-24-01-BH-24-32	-2.085
Peng <i>et al.</i> , 2015	11ST-60C-11ST-61C	-10.938	11ST-60F	-11.206
Wang <i>et al.</i> , 2013b	10DX-43a-10DX-45d	-6.800		-4.788
	10DX-85-10DX-90	-8.100		-9.950
	11ML-73-11ML-77	-6.800		-3.783
Hu <i>et al.</i> , 2015	GE08191-GE08195	-6.950	GE08191,GE08195	-5.642
	BS08031-BS08034,BS1001-BS1005,BS0715	-6.588	BS08031,BS08034	-5.146
Liu <i>et al.</i> , 2015	HH-43A-HH-45A,ML-34A-ML-34G	-9.875		-8.163
Wang <i>et al.</i> , 2016	14XZ2.1,14NX3	-9.950	14NX3-2,14XZ2.1-3	-4.610
Guo <i>et al.</i> , 2018	JLN-22,JLN-25	-10.200	JLN-22-3-JLN-22-27	-12.093
	DYL801-36-1-DYL801-160-1	-10.167	DYL801-36-2-1-DYL801-36-2-24	-11.959
	JLN-1,JLN-13	-10.700	JLN-11-1-JLN-11-37	-11.328
	JLN-6,JLN-16	-9.800	JLN-15-2-JLN-15-40	-9.530
Huang <i>et al.</i> , 2014	81#-12-81#-26,ZK0-26-1-ZK0-26-3,ZK-1-4-ZK-1-13	-7.516	ZK0-26-3-81#-23	-5.655
Zheng <i>et al.</i> , 2008	03WN58-03WN73	-2.123	03WN71,03WN73	3.958
	03WN60-03WN70	0.002	03WN61,03WN65	5.378
Zhang <i>et al.</i> , 2017a	Plutons-Keketale	-2.547		2.294
Zhao <i>et al.</i> , 2015b	10SC07A,10SC10	-8.850	10SC07A	-7.495
	10SC06A	-8.9	10SC06A	-9.224
	10SC01A,10SC05A	-11.000	10SC05A	-10.356
	10SC01N	-10.500	10SC04A	-10.210
Cheng <i>et al.</i> , 2017	MZ13-3-MZ13-4	-12.720	MZ13-3	-4.326
	MZ13-7-MZ13-14	-12.133	MZ13-7	-4.551



Zhu <i>et al.</i> , 2009	PK01-1-PK01-6	-6.150	PK01-1	5.180
Martínez <i>et al.</i> , 2014	110217-110219	-6.657	106820	5.533
	110210-111383	-4.855	110210	5.075
	110331	-6.350	110331	2.400
	110341	-6.200	110341	-6.267
Wu <i>et al.</i> , 2006	03WN15- 03WN31	-0.523		5.400
	03WN01- 03WN13	-1.338		3.400
	03WN33- 03WN51	-0.758		3.500
Huang <i>et al.</i> , 2015	QL09-02-QL09-18	-4.350		0.775
Li <i>et al.</i> , 2015b	SH-04-SH-43,YJ-3-1	-9.840	SH-04,SH-29-A,YJ-3,YJ-3	-7.328
Gou <i>et al.</i> , 2015	W8011 -W8053	-6.780	W8011-W8017	-2.414
Xu <i>et al.</i> , 2015	13MG-11-13MG-14	-11.685	13MG-11	-9.377
	11TJ-58-11TJ-62,DL-29-DL-31	-11.347	11TJ-66	-6.227
	13HST-1-13HST-24	-11.291	13NWH-13	-12.071
Liao <i>et al.</i> , 2018	SK14-02-SK14-06	3.650	SK14-02-SK14-06	13.775
	SK15-02-SK15-09	1.088	SK15—01-SK15—09	7.540
Qian <i>et al.</i> , 2017	TS-1-1-TS-4-1	-12.500	TS-1-1-TS-4-10	-11.421
Song <i>et al.</i> , 2018a	ZX14-Zx15-4	-9.387	zx14,zxa33	-8.066
Zhang <i>et al.</i> , 2017c	CJ304-3-4,*06220	-10.325	CJ-1,CJ-2	-10.756
	JF-7,*06173	-10.253	JF-12	-10.211
Huang <i>et al.</i> , 2017	Y05-2-Y06-1,Y11-Y12	-10.868	Y-21	-10.660
	Y03-Y06-2,Ysd-3-1-Ysd-4	-9.568	YSD-1	-9.122
Zhao <i>et al.</i> , 2016b	06MES-10A- 06MES-14C	-9.071	06MES-10A, 06MES-14A	-6.065
	06SZJ-06, 06DZS-02	-10.850	06SZJ-06B	-6.232
	06DZS-01A- 06DZS-10B	-10.500	DZS-01A	-9.700
Zhao <i>et al.</i> , 2017b	B1307-1-B1405-1	-4.300	B1310-1,B1403-1	2.400
Fu <i>et al.</i> , 2015	X01-1-X01-7	-4.607	ZJ18-3	-4.055
Xia <i>et al.</i> , 2014	XW01-XW07	-4.300	XW01	1.644
	DT01-DT09	-0.800	DT01-DT09	5.172
Wang <i>et al.</i> , 2015b	10ZYS-05	-12.500	10ZYS05	-8.736
Gao <i>et al.</i> , 2014a	10SC09-10SC55	-10.317	10SC55A	-10.156
	10SC05 -10SC63	-10.633	10SC51	-9.617
	10SC15-10SC17,FCH1-FCH12	-10.183	10SC17	-8.225



Table S-4. Major and tracer element compositions and calculated parameters of the granites from Kekeagashi, Tiemuerte, Jiaertasi, Chaganxile, and Sareshuoke plutons.

Sample	SiO ₂	Al ₂ O ₃	TFe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	MnO	P ₂ O ₅	TiO ₂	LOI	total	A/CNK	A/NK	Mg [#]	K ₂ O+Na ₂ O
	%	%	%	%	%	%	%	%	%	%	%	%				%
Kekeagashi@01	71.4	15.08	2.02	0.91	1.26	3.18	3.75	0.09	0.13	0.3	1.14	99.26	1.3	1.62	0.5	6.93
Kekeagashi@02	72.81	14.42	1.17	0.69	1.12	3.19	3.76	0.06	0.12	0.17	0.86	98.37	1.27	1.55	0.3	6.95
Kekeagashi@03	71.78	15.08	1.53	0.71	1.32	3.33	3.56	0.13	0.13	0.23	1.06	98.86	1.28	1.61	0.38	6.89
Kekeagashi@04	71.89	14.64	1.66	0.54	1.1	3.2	3.81	0.08	0.14	0.23	1.01	98.3	1.28	1.56	0.39	7.01
Tiemuerte@01	67.97	14.79	3.86	1.44	0.28	2.35	7.23	0.10	0.07	0.58	0.71	99.38	1.21	1.26	0.60	9.58
Tiemuerte@02	67.85	15.26	3.05	0.71	0.45	1.92	7.86	0.06	0.07	0.45	1.11	98.79	1.22	1.31	0.44	9.78
Tiemuerte@03	68.21	15.22	3.06	1.02	0.48	2.69	7.05	0.08	0.09	0.41	0.73	99.04	1.18	1.26	0.43	9.74
Tiemuerte@04	66.84	13.90	5.53	0.79	0.38	1.78	6.55	0.14	0.06	0.81	1.07	97.85	1.30	1.39	0.81	8.33
Jiaertasi@01	67.02	14.84	4.97	0.72	1.34	3.69	3.58	0.07	0.17	0.63	0.99	98.02	1.2	1.49	0.4	7.27
Jiaertasi@02	69.46	15.33	2.22	0.38	1.13	3.59	4.99	0.04	0.08	0.31	0.67	98.2	1.15	1.35	0.2	8.58
Jiaertasi@03	67.28	15.4	3.98	0.65	1.24	3.62	4.4	0.07	0.17	0.59	0.92	98.32	1.19	1.44	0.36	8.02
Jiaertasi@04	65.27	15.6	4.66	0.77	1.73	3.68	4.16	0.07	0.2	0.69	1.22	98.05	1.14	1.48	0.43	7.84
Chaganxile@01	73.08	13.60	2.47	0.28	0.43	3.31	3.94	0.04	0.02	0.21	0.99	98.37	1.29	1.40	0.26	7.25
Chaganxile@02	72.19	13.46	1.88	0.49	0.80	3.67	4.36	0.04	0.03	0.19	0.63	97.74	1.10	1.25	0.12	8.03
Chaganxile@03	71.00	13.52	2.25	0.21	1.14	3.32	4.14	0.04	0.03	0.23	0.75	96.63	1.12	1.36	0.13	7.46
Chaganxile@04	71.68	13.68	2.10	0.22	0.84	3.56	4.42	0.04	0.03	0.20	0.68	97.45	1.12	1.28	0.11	7.98
Sareshuoke@01	73.59	13.45	2.31	0.61	1.09	3.33	3.85	0.03	0.04	0.15	-0.02	98.43	1.16	1.39	0.17	7.18
Sareshuoke@02	73.95	13.14	2	0.45	1.18	3.28	3.81	0.03	0.05	0.16	0.45	98.5	1.13	1.38	0.18	7.09
Sareshuoke@03	72.96	13.54	2.54	0.58	1.14	3.39	3.81	0.03	0.04	0.19	0.25	98.47	1.15	1.39	0.2	7.2
Sareshuoke@04	72.53	13.46	3.4	0.87	1.06	3.42	3.79	0.04	0.04	0.17	-0.04	98.74	1.15	1.38	0.17	7.21
Sample	Na ₂ O/K ₂ O	[Li]	[Be]	[Sc]	[V]	[Cr]	[Co]	[Ni]	[Cu]	[Zn]	[Ga]	[Ge]	[As]	[Rb]	[Sr]	[Y]
		μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g
Kekeagashi@01	1.57	78.8	0.07	10.1	30	254	8	146	11.1	37	16.35	0.18	<0.2	64.7	165	36.3
Kekeagashi@02	2.73	53.5	0.08	6	18	210	5.5	123.5	8.4	21	13.85	0.19	<0.2	65.5	168	33.9
Kekeagashi@03	2.18	68.9	0.07	8.5	23	212	7	127.5	11.3	27	15.3	0.24	<0.2	56.4	175	38
Kekeagashi@04	1.93	66.1	0.07	8.2	23	236	7	135.5	10.1	28	15.2	0.23	<0.2	60.4	173	39.9
Tiemuerte@01	0.61	38.4	0.12	22.4	33	124	6	62.6	10.8	72	18.20	0.36	0.70	155	83.1	22.0
Tiemuerte@02	0.63	37.9	0.18	17	23	132	5.8	70.4	12	54	16.75	0.32	2.00	149	79.9	14.1
Tiemuerte@03	0.88	26.9	0.15	18.1	27	109	5.4	58.1	15.6	50	17.10	0.42	0.90	149	88.1	17.3
Tiemuerte@04	0.32	53.9	0.20	29.4	39	128	7.9	65.8	16	98	20.20	0.44	1.30	157	73.8	19.7
Jiaertasi@01	0.74	118.5	0.86	11.3	32	265	8.9	140	10.4	105	26.4	0.28	8.9	154.5	191	45.7
Jiaertasi@02	1.62	74.1	0.35	4.6	15	247	6.3	134.5	8.1	55	22.1	0.2	3.4	138	227	51.2
Jiaertasi@03	0.91	111.5	0.7	9.4	33	261	9.4	141	10.2	108	26.5	0.24	13.8	108	230	52.7
Jiaertasi@04	0.79	131	1	10.4	33	213	8.5	109.5	10.1	107	27.4	0.33	6.5	116	237	57.4
Chaganxile@01	1.34	8.7	0.28	4	21	560	5.5	171.5	9.4	63	22.70	0.28	0.70	98.8	144	30.8
Chaganxile@02	1.95	5.1	0.22	3.6	8	324	5.5	176	8	65	24.40	0.34	<0.2	83	137	30.6
Chaganxile@03	1.48	5.7	0.25	4.1	8	288	5.1	154	7	74	24.70	0.35	0.50	75.7	119	25.1
Chaganxile@04	1.70	6	0.23	4	9	286	4.9	149.5	7	61	24.50	0.34	0.40	65.4	136	30.4
Sareshuoke@01	1.44	12.1	0.01	2	14	994	3.5	71.9	16.3	15	13.8	0.23	1	95.2	173.5	24.3
Sareshuoke@02	1.64	12.7	0.01	2.6	14	787	3.3	41.7	10.7	12	13.8	0.23	1.2	106.5	122.5	29.6



Sareshuoke@03	1.33	14	0.01	2.8	16	1160	4.2	59.3	14.5	14	14.4	0.27	1.2	118	156.5	27.6
Sareshuoke@04	1.01	14	0.01	2.6	18	1540	4.8	98.1	20.4	16	13.95	0.26	1.5	102	174.5	29.9
Sample	[Zr]	[Nb]	[Mo]	[Ag]	[Cd]	[In]	[Sn]	[Sb]	[Cs]	[Ba]	[La]	[Ce]	[Pr]	[Nd]	[Sm]	[Eu]
	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g
Kekeagashi@01	62.8	11.8	0.97	0.04	0.03	0.02	4.3	0.1	8.91	390	50	110	13.35	51.2	9.75	1.64
Kekeagashi@02	54.6	11.6	0.79	0.03	0.02	0.011	2.5	0.09	7.21	410	50.8	111	13.25	52.9	10.1	1.67
Kekeagashi@03	60	12.6	1.49	0.03	0.05	0.015	3.3	0.09	8.35	460	54.5	121.5	14.3	57	10.9	1.83
Kekeagashi@04	56.8	14.8	0.88	0.04	0.03	0.017	3.5	0.09	7.92	500	56.4	128	15.35	59.6	11.6	1.82
Tiemuerte@01	52.6	9.6	0.52	0.03	<0.02	0.14	11.9	0.08	6.78	250	57.3	121.5	13.85	48.5	11.45	0.92
Tiemuerte@02	37.6	6.4	0.62	0.03	0.03	0.10	8.9	0.11	5.56	240	66.8	141.5	15.65	53.9	11.75	0.86
Tiemuerte@03	50.6	7.6	0.67	0.04	0.02	0.11	9.3	0.09	5.24	280	69.1	147.5	17.10	61.2	13.50	0.99
Tiemuerte@04	41.4	8.2	0.71	0.06	0.05	0.20	16.1	0.14	9.27	240	65.4	140.0	15.75	55.1	12.35	1.02
Jiaertasi@01	39.2	7.6	3.37	0.08	0.04	0.098	16.1	0.57	44.7	570	75.2	172.5	19.6	75.5	16.5	2.03
Jiaertasi@02	40.4	10.4	1.57	0.06	0.02	0.036	8.1	0.34	20.2	570	57.5	119	14.7	54.9	13.4	1.38
Jiaertasi@03	41	10.2	3.19	0.08	0.04	0.093	15.2	0.66	40	520	61.9	132	16.2	66.2	14.4	1.81
Jiaertasi@04	44.1	9.8	2.08	0.07	0.03	0.103	16.9	0.52	31.6	550	68.8	148.5	19.1	73	15.7	2.16
Chaganxile@01	36.3	11.7	2.10	0.02	<0.02	0.10	11.3	0.31	2.07	350	34.3	74.3	8.41	33.2	6.76	1.56
Chaganxile@02	44.1	11.0	2.36	0.04	0.05	0.08	9.8	0.27	1.45	320	31.6	70.5	8.52	34.5	7.62	1.40
Chaganxile@03	41.6	10.7	2.75	0.07	0.06	0.09	10.8	0.27	1.43	310	29.0	66.6	7.43	29.9	6.39	1.36
Chaganxile@04	39.5	12.4	2.29	0.06	0.04	0.10	12.3	0.32	1.59	280	32.2	69.9	8.47	33.8	7.29	1.54
Sareshuoke@01	69.4	9.9	2.69	<0.01	<0.02	<0.005	0.9	0.17	2.18	400	78.3	171.5	19.5	70.8	15	0.83
Sareshuoke@02	81.2	14.4	2.26	<0.01	0.03	<0.005	0.8	0.16	2.22	460	37.1	77.8	9.32	33.7	7.06	0.71
Sareshuoke@03	59	13.1	3.22	<0.01	0.03	0.005	1	0.18	2.35	440	51.8	115	14.2	53.3	12.15	0.79
Sareshuoke@04	75.2	11.9	4.02	<0.01	0.03	<0.005	1	0.22	2.29	310	74	163	18.65	68.4	14.35	0.83
Sample	[Gd]	[Tb]	[Dy]	[Ho]	[Er]	[Tm]	[Yb]	[Lu]	[Hf]	[Ta]	[W]	[Ti]	[Pb]	[Bi]	[Th]	[U]
	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g
Kekeagashi@01	8.03	1.13	6.55	1.26	3.67	0.52	3.41	0.5	2.4	1.11	0.7	0.84	18	0.07	15.6	4.8
Kekeagashi@02	8.09	1.17	6.59	1.28	3.54	0.53	3.35	0.5	2.2	1.09	0.5	0.79	19.6	0.08	19.1	5.6
Kekeagashi@03	8.56	1.26	7.08	1.43	3.96	0.59	3.68	0.56	2.6	1.22	1.1	0.82	20.2	0.07	16.4	5.2
Kekeagashi@04	8.92	1.29	7.36	1.48	4.04	0.6	3.89	0.61	2.8	1.37	0.7	0.82	19.3	0.07	18.15	5.7
Tiemuerte@01	4.64	0.69	4.17	0.79	2.31	0.34	2.44	0.35	1.70	0.62	1.4	1.76	30	0.12	9.3	2.8
Tiemuerte@02	3.38	0.47	2.82	0.52	1.52	0.23	1.69	0.24	1.20	0.46	1.7	1.75	30.4	0.18	7.3	2.1
Tiemuerte@03	4.04	0.59	3.45	0.62	1.78	0.27	1.90	0.29	1.40	0.49	1.3	1.54	27.9	0.15	8.6	2.5
Tiemuerte@04	4.31	0.64	3.82	0.72	2.14	0.31	2.18	0.32	1.60	0.57	2.4	1.98	30.6	0.20	8.8	2.6
Jiaertasi@01	8.74	1.34	8.44	1.7	5.01	0.68	4.41	0.28	1.4	0.63	0.9	0.71	20.3	0.86	10.4	4.3
Jiaertasi@02	9.35	1.41	8.95	1.84	5.37	0.73	4.96	0.35	1.8	0.67	0.4	0.66	20.9	0.35	7.6	3.8
Jiaertasi@03	9.87	1.5	9.34	1.95	5.7	0.78	5.25	0.33	1.8	0.71	1.1	0.75	16.1	0.7	8.8	5
Jiaertasi@04	10.6	1.63	10	2.08	6.25	0.85	5.59	0.36	2	0.74	0.9	0.81	18.3	1	10.4	5.4
Chaganxile@01	7.11	1.04	6.24	1.24	3.60	0.51	3.18	0.28	1.20	0.79	0.9	0.65	11.8	0.28	10.1	3.5
Chaganxile@02	6.80	1.00	6.01	1.21	3.54	0.50	3.14	0.35	1.80	0.77	0.8	0.66	12	0.22	9.5	3.2
Chaganxile@03	5.85	0.83	5.10	1.02	2.93	0.41	2.63	0.25	1.20	0.75	0.9	0.69	11.8	0.25	7.4	2.8
Chaganxile@04	6.74	0.97	6.00	1.21	3.46	0.50	3.11	0.28	1.40	0.89	0.7	0.74	12.1	0.23	7.9	2
Sareshuoke@01	5.71	0.87	4.82	0.94	2.52	0.38	2.39	0.36	1.7	0.82	1.6	0.49	20.5	0.01	11.5	4.3
Sareshuoke@02	6.72	1	6.06	1.21	3.3	0.51	3.15	0.5	2.4	1.14	1.4	0.5	16.9	0.01	12.8	4.8



Sareshuoke@03	5.61	0.89	5.28	1.11	3.25	0.47	3.2	0.49	2.1	1.22	1.9	0.48	18.3	0.01	11.6	4.2
Sareshuoke@04	6.56	1.02	5.84	1.2	3.35	0.5	3.26	0.49	2.3	0.87	2.4	0.48	21	0.01	11.2	3.8

Table S-5-1 U-Pb dating for standard materials during analysis.

Sample	Th ($\mu\text{g/g}$)	U ($\mu\text{g/g}$)	Th/U	Ratio						Age (Ma)	
				$^{207}\text{Pb}/^{206}\text{Pb}$	1 σ	$^{207}\text{Pb}/^{235}\text{U}$	1 σ	$^{206}\text{Pb}/^{238}\text{U}$	1 σ	$^{207}\text{Pb}/^{235}\text{U}$	1 σ
TEMORA 1	59.28101	116.4969	0.508863	0.052001	0.00252	0.47856	0.023996	0.066778	0.0007	418.3894	4.099275
TEMORA 1	51.10731	153.2785	0.333428	0.05649	0.001815	0.522611	0.017997	0.067078	0.0006	417.7887	3.499381
TEMORA 1	88.91066	174.7345	0.508833	0.05601	0.001613	0.518607	0.015997	0.067078	0.0006	418.2893	3.399399
TEMORA 1	72.65438	139.0397	0.522544	0.050791	0.00242	0.468548	0.022996	0.066778	0.0006	418.1903	3.799328
TEMORA 1	107.3015	196.1904	0.546925	0.05609	0.001311	0.516604	0.012998	0.066778	0.0005	416.5873	3.299416
TEMORA 1	92.9975	258.5148	0.359738	0.05539	0.000706	0.510597	0.006999	0.066978	0.0003	417.5885	2.099629
TEMORA 1	41.9119	162.4739	0.257961	0.052492	0.001815	0.482565	0.016997	0.066678	0.0006	417.0879	3.499381
TEMORA 1	61.32443	118.5403	0.51733	0.05659	0.001916	0.522611	0.018997	0.066978	0.0007	417.0879	3.999292
TEMORA 1	47.02046	128.7574	0.365186	0.049001	0.002621	0.449526	0.024996	0.066478	0.0007	418.0891	3.799328
TEMORA 1	122.6272	230.9286	0.531018	0.053691	0.001311	0.494579	0.012998	0.066778	0.0005	417.4884	2.899487

Table S-5-2 Major and trace element compositions for standard materials during analysis

Sample	SiO ₂	Al ₂ O ₃	TFe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	MnO	P ₂ O ₅	TiO ₂	Li	Be	Sc	V	Cr
GBPG-1	65.12	15.75	5.92	2.57	2.90	3.57	2.26	0.07	0.08	0.70	19.4	0.80	14.4	99	188
GBPG-1	65.21	15.78	5.93	2.59	2.91	3.59	2.27	0.07	0.08	0.71	19.0	0.70	14.0	112	175
GBPG-1	65.18	15.77	5.92	2.57	2.91	3.58	2.27	0.07	0.08	0.71	19.6	1.00	13.7	99	185
GBPG-1	65.15	15.75	5.93	2.59	2.91	3.56	2.26	0.07	0.08	0.70	19.2	0.75	13.5	100	182
GBPG-1	65.13	15.79	5.92	2.57	2.90	3.59	2.26	0.07	0.08	0.71	19.4	0.70	14.2	107	175
GSR-1	72.83	13.4	2.14	0.42	1.55	3.13	5.01	0.06	0.09	0.29	131	12.4	6.1	24	2.7
GSR-1	72.87	13.39	2.16	0.42	1.53	3.12	5.00	0.06	0.09	0.29	124.6	12.12	6.8	23	2.70
GSR-1	72.77	13.45	2.16	0.42	1.53	3.13	5.01	0.06	0.08	0.28	138.3	12.32	6.8	22	2.80
GSR-1	72.66	13.35	2.13	0.41	1.55	3.11	5.03	0.06	0.09	0.29	137.4	12.31	6.3	24	2.90
GSR-1	72.81	13.36	2.16	0.42	1.54	3.14	4.97	0.06	0.09	0.30	137.7	12.15	7.0	23	2.90
Sample	Co	Ni	Cu	Zn	Ga	Ge	As	Rb	Sr	Y	Zr	Nb	Mo	Ag	Cd
GBPG-1	20.5	58.2	28.2	84	18.40	1.09	0.16	57.1	364	18.3	251.00	10.20	1.50	0.05	0.22
GBPG-1	20.6	58.6	27.4	78	18.75	1.12	0.19	62.6	366	17.9	238.80	10.80	1.70	0.05	0.20
GBPG-1	18.1	55.4	29.0	76	19.05	1.05	0.18	58.6	363	19.3	228.20	9.20	2.00	0.03	0.10
GBPG-1	19.0	56.6	26.2	84	19.30	1.16	0.18	61.0	362	20.6	226.00	10.30	1.95	0.05	0.10
GBPG-1	20.5	58.0	28.4	80	18.80	1.08	0.19	60.4	373	18.8	231.70	10.20	1.65	0.04	0.20
GSR-1	3.4	2.5	1.6	28	19.00	2.33	0.24	466.0	106	67.6	167.00	43.50	3.50	0.06	0.03
GSR-1	3.6	2.6	1.6	24	19.00	2.59	0.25	484.7	114	71.1	173.50	41.80	3.56	0.07	0.03
GSR-1	3.6	2.7	1.5	26	19.19	2.92	0.20	483.2	106	69.6	150.30	40.60	3.70	0.06	0.03
GSR-1	3.4	2.5	1.5	28	19.80	2.41	0.29	477.0	101	70.1	172.90	43.10	3.63	0.07	0.03
GSR-1	3.7	2.6	1.8	26	19.31	2.58	0.31	480.9	100	68.8	163.40	43.40	3.49	0.07	0.03
Sample	In	Sn	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho
GBPG-1	0.05	0.92	0.05	0.30	860	54.0	98.9	11.22	41.7	6.70	1.73	4.75	0.69	3.30	0.63
GBPG-1	0.04	0.72	0.07	0.25	872	49.5	97.4	12.81	42.9	5.52	1.69	4.71	0.67	3.08	0.70
GBPG-1	0.04	0.88	0.70	0.35	888	49.5	99.7	11.43	37.1	6.74	1.76	4.82	0.71	2.97	0.65
GBPG-1	0.04	0.90	0.79	0.30	872	46.9	97.0	12.42	40.6	6.51	1.72	4.83	0.56	3.42	0.66
GBPG-1	0.04	0.91	0.74	0.30	890	52.6	101.4	13.92	42.5	5.50	1.70	4.80	0.71	3.14	0.70
GSR-1	0.02	1.22	0.30	38.40	343	54.0	108.0	12.70	47.0	9.70	0.85	9.30	1.65	10.20	2.05
GSR-1	0.02	1.23	0.28	37.50	345	47.3	114.0	12.90	44.6	9.86	0.82	9.60	1.61	9.76	2.01
GSR-1	0.02	1.16	0.29	38.00	342	55.6	100.1	12.50	49.4	9.21	0.86	8.90	1.66	9.94	2.00
GSR-1	0.02	1.19	0.32	38.30	354	45.2	101.7	12.60	49.7	10.13	0.87	9.40	1.63	9.60	2.06
GSR-1	0.02	1.31	0.29	38.20	348	45.6	97.9	12.30	48.4	10.03	0.82	9.00	1.57	9.91	2.00



Sample	Er	Tm	Yb	Lu	W	Tl	Pb	Bi	Th	U	Ta	Hf
GBPG-1	1.85	0.31	1.92	0.32	0.31	0.30	14.60	0.04	11.9	0.90	0.40	5.9
GBPG-1	1.81	0.30	1.88	0.34	0.33	0.38	14.90	0.06	11.1	0.90	3.83	5.2
GBPG-1	1.88	0.32	1.98	0.32	0.35	0.39	14.00	0.10	11.4	0.90	4.00	6.4
GBPG-1	1.86	0.32	2.09	0.34	0.27	0.30	14.20	0.04	11.1	0.90	4.20	5.0
GBPG-1	1.85	0.27	2.20	0.33	0.29	0.40	13.70	0.07	10.8	0.80	3.90	6.0
GSR-1	6.50	1.06	7.40	1.15	8.40	1.93	31.00	0.60	54.0	19.00	7.20	5.9
GSR-1	6.10	1.03	7.57	1.18	8.66	1.96	29.17	0.59	55.8	18.41	7.21	5.7
GSR-1	6.90	1.02	6.99	1.16	8.37	1.98	29.78	0.58	52.5	19.88	7.06	6.0
GSR-1	6.20	1.03	7.59	1.07	8.69	1.91	29.08	0.60	55.6	19.24	7.28	5.5
GSR-1	6.50	1.09	7.00	1.13	8.68	1.96	32.43	0.62	53.4	19.36	7.23	5.8

Table S-5-3 Whole rock Nd isotopic compositions for standard materials during analysis

Sample	$^{143}\text{Nd}/^{144}\text{Nd}$	2σ
BCR-1	0.512661	6
BCR-1	0.512663	8
BCR-1	0.512663	8
BCR-1	0.512661	6
BCR-1	0.512662	4
La Jolla	0.511861	6
La Jolla	0.511862	6
La Jolla	0.511863	8
La Jolla	0.511862	6
La Jolla	0.511864	8

Table S-5-4 Whole rock Hf isotopic compositions for standard materials during analysis.

Sample	$^{176}\text{Hf}/^{177}\text{Hf}$	2σ	$^{178}\text{Hf}/^{177}\text{Hf}$	2σ
AGV-2	0.282976	0.000002	1.46718	0.00001
AGV-2	0.282990	0.000002	1.46725	0.00000
AGV-2	0.282985	0.000003	1.46722	0.00001
AGV-2	0.282986	0.000003	1.46723	0.00001
AGV-2	0.282985	0.000003	1.46722	0.00001
BCR-2	0.282874	0.000002	1.46727	0.00001
BCR-2	0.282871	0.000002	1.46719	0.00001
BCR-2	0.282868	0.000002	1.46725	0.00000
BCR-2	0.282885	0.000002	1.46720	0.00001
BCR-2	0.282864	0.000004	1.46720	0.00001
BHVO-2	0.283102	0.000001	1.46726	0.00001
BHVO-2	0.283096	0.000002	1.46718	0.00001
BHVO-2	0.283090	0.000003	1.46718	0.00001
BHVO-2	0.283093	0.000003	1.46723	0.00001
BHVO-2	0.283093	0.000003	1.46723	0.00001
RGM-2	0.283021	0.000004	1.46720	0.00001
RGM-2	0.283022	0.000004	1.46720	0.00001
RGM-2	0.283020	0.000003	1.46721	0.00001
RGM-2	0.283019	0.000003	1.46721	0.00001
RGM-2	0.283021	0.000004	1.46720	0.00001



Table S-5-5 Zircon Hf isotopic compositions for standard materials during analysis

sample	$^{176}\text{Hf}/^{177}\text{Hf}$	2 σ	$^{176}\text{Yb}/^{177}\text{Hf}$	2 σ	$^{176}\text{Lu}/^{177}\text{Hf}$	2 σ
91500	0.282311	0.000047	0.007184	0.000072	0.000276	0.000001
91500	0.282314	0.000038	0.007089	0.000082	0.000275	0.000001
91500	0.282291	0.000035	0.007341	0.000086	0.000277	0.000001
91500	0.282305	0.000031	0.009413	0.000032	0.000278	0.000000
91500	0.282233	0.000045	0.012642	0.000028	0.000329	0.000000
91500	0.282315	0.000055	0.012684	0.000071	0.000323	0.000000
91500	0.282312	0.000054	0.012487	0.000023	0.000321	0.000000
91500	0.282324	0.000047	0.007172	0.000034	0.000275	0.000001
91500	0.282303	0.000032	0.007185	0.000047	0.000274	0.000001
91500	0.282282	0.000043	0.007202	0.000075	0.000284	0.000001
91500	0.282304	0.000017	0.011595	0.000054	0.000307	0.000001
91500	0.282294	0.000015	0.011217	0.000065	0.000305	0.000001
91500	0.282305	0.000014	0.010637	0.000065	0.000297	0.000001
91500	0.282305	0.000027	0.010437	0.000042	0.000295	0.000000
91500	0.282323	0.000016	0.009545	0.000028	0.000287	0.000000
91500	0.282304	0.000077	0.010275	0.000084	0.000307	0.000000
Mud Tank	0.282484	0.000027	0.001835	0.000033	0.000055	0.000001
Mud Tank	0.282484	0.000047	0.001892	0.000021	0.000054	0.000001
Mud Tank	0.282487	0.000025	0.001912	0.000017	0.000054	0.000001
Mud Tank	0.282483	0.000035	0.001957	0.000036	0.000061	0.000000
Mud Tank	0.282484	0.000033	0.001811	0.000022	0.000051	0.000001
Mud Tank	0.282488	0.000041	0.001963	0.000031	0.000059	0.000000
Mud Tank	0.282475	0.000032	0.001877	0.000024	0.000052	0.000000
Mud Tank	0.282471	0.000041	0.001899	0.000019	0.00006	0.000001
Mud Tank	0.282399	0.000043	0.001921	0.000018	0.000065	0.000001
Mud Tank	0.282455	0.000037	0.001898	0.000036	0.000058	0.000001
Mud Tank	0.282487	0.000035	0.001985	0.000033	0.000057	0.000000
Mud Tank	0.282432	0.000036	0.001899	0.000036	0.000051	0.000001
Mud Tank	0.282387	0.000031	0.00185	0.000039	0.000062	0.000001
Mud Tank	0.282481	0.000052	0.001882	0.000025	0.000064	0.000000
Mud Tank	0.282483	0.000021	0.00185	0.000021	0.000058	0.000000
Mud Tank	0.282483	0.000023	0.001943	0.000038	0.000059	0.000001



Table S-5-6 Zircon O isotopic compositions for standard materials during analysis.

Sample	$^{18}\text{O}/^{16}\text{O}$	1 s.e.	$^{18}\text{O}_R$	$^{18}\text{O}_C$	2 s.e.
91500	0.002017071	0.008729563	10.20	5.97	0.19
91500	0.002017054	0.007740212	10.10	5.89	0.18
91500	0.002017191	0.012069925	10.20	5.98	0.20
91500	0.002017183	0.011332486	10.16	5.95	0.23
91500	0.002017192	0.010963056	10.16	5.96	0.21
91500	0.002017014	0.010450853	10.17	5.96	0.16
91500	0.002017164	0.009839817	10.08	5.91	0.21
91500	0.002017051	0.011551639	10.07	5.90	0.19
91500	0.002017004	0.012035082	10.13	5.94	0.16
91500	0.002017004	0.007740562	10.20	5.98	0.22
91500	0.002017191	0.013136341	10.20	5.98	0.24
PENGLAI	0.002018838	0.009548955	6.8	5.33	0.21
PENGLAI	0.002018794	0.012893091	6.78	5.31	0.29
PENGLAI	0.002018874	0.007266366	6.82	5.35	0.16
PENGLAI	0.002019644	0.012199558	7.2	5.7	0.21
PENGLAI	0.002018236	0.010900021	6.5	5.03	0.23
PENGLAI	0.002018267	0.011877535	6.52	5.05	0.26
PENGLAI	0.002018559	0.010167726	6.66	5.16	0.22
PENGLAI	0.002018433	0.007492875	6.6	5.13	0.13
PENGLAI	0.002018661	0.008254897	6.71	5.24	0.17
PENGLAI	0.002019292	0.012255554	7.03	5.56	0.26
PENGLAI	0.002019344	0.009568334	7.05	5.55	0.18



Supplementary Figures

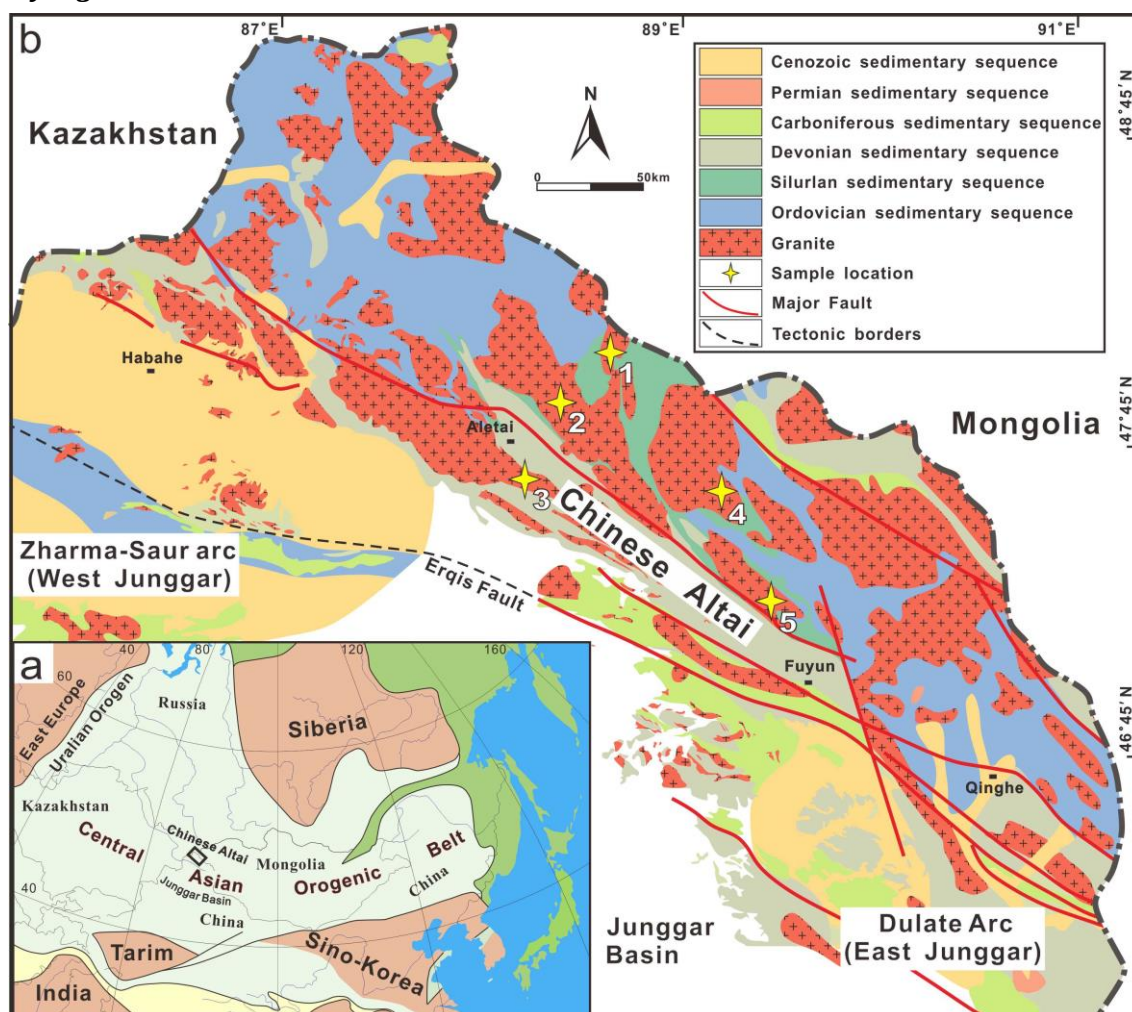


Figure S-1 (a) Location of northern Xinjiang in the Central Asian Orogenic Belt (modified after Zhang *et al.*, 2019); (b) Geological map showing the distribution of the studied granites in the Chinese Altai (modified after Zhang *et al.*, 2019), including: 1. the Kekeagashi pluton, 2. the Tiemuerte pluton, 3. the Jiaertasi pluton, 4. the Chaganxile pluton, and 5. the Sareshuoke pluton.

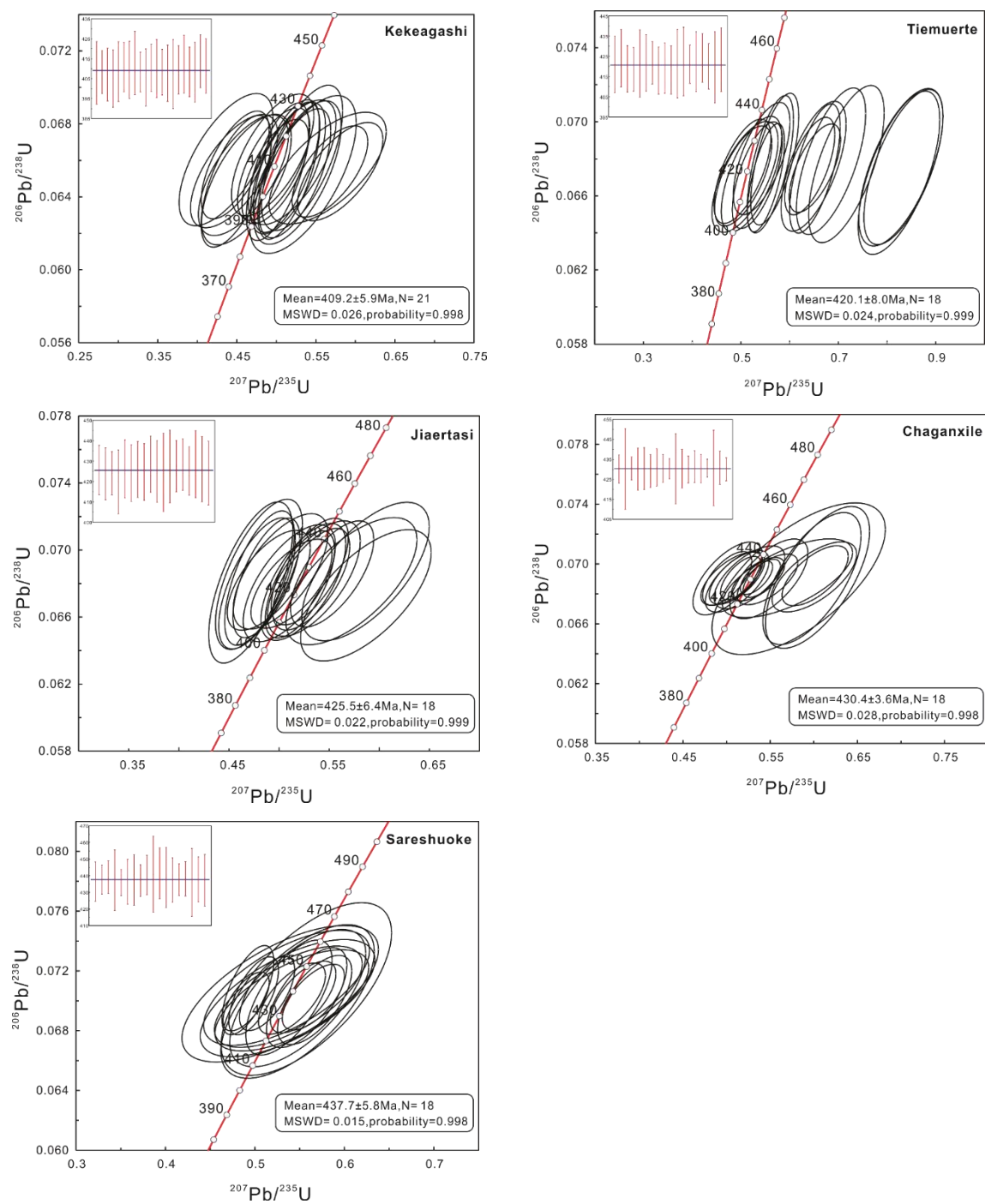
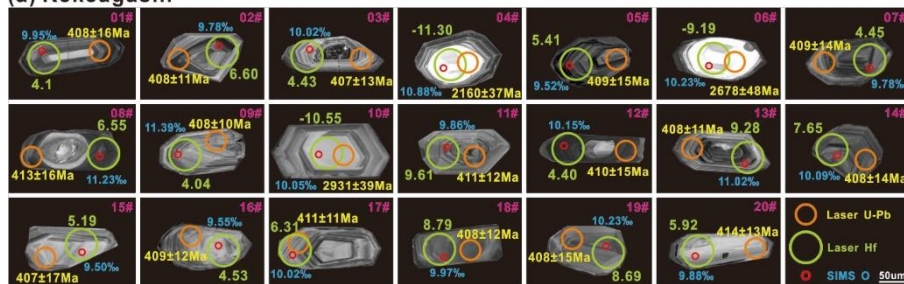


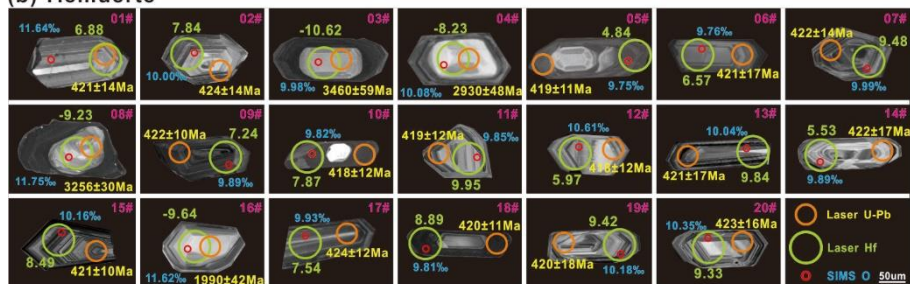
Figure S-2 U – Pb concordia diagrams of the studied granites.



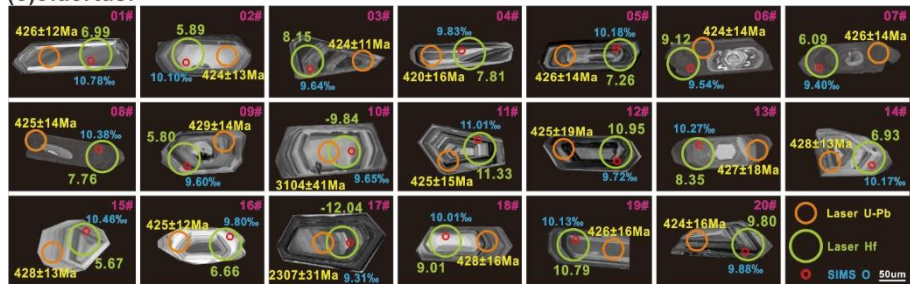
(a) Kekeagashi



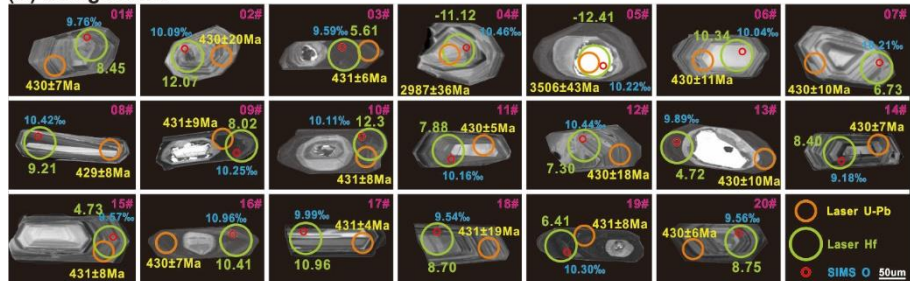
(b) Tiemuerte



(c) Jiaertasi



(d) Chaganxile



(e) Sareshuoke

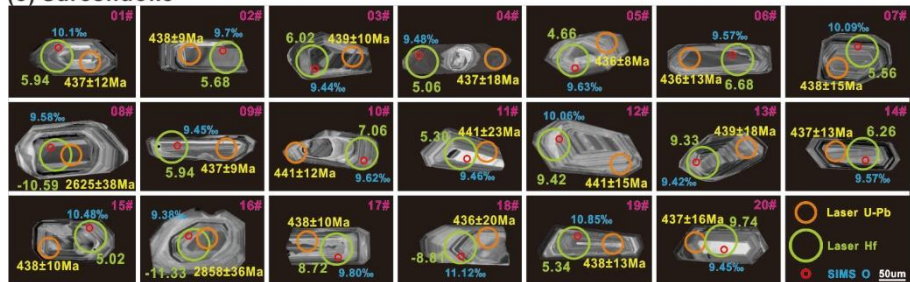


Figure S-3 CL images of zircon grains from the studied granites with analytical spots for age values, $\epsilon_{\text{Hf}}(t)$ values and $\delta^{18}\text{O}$ compositions.

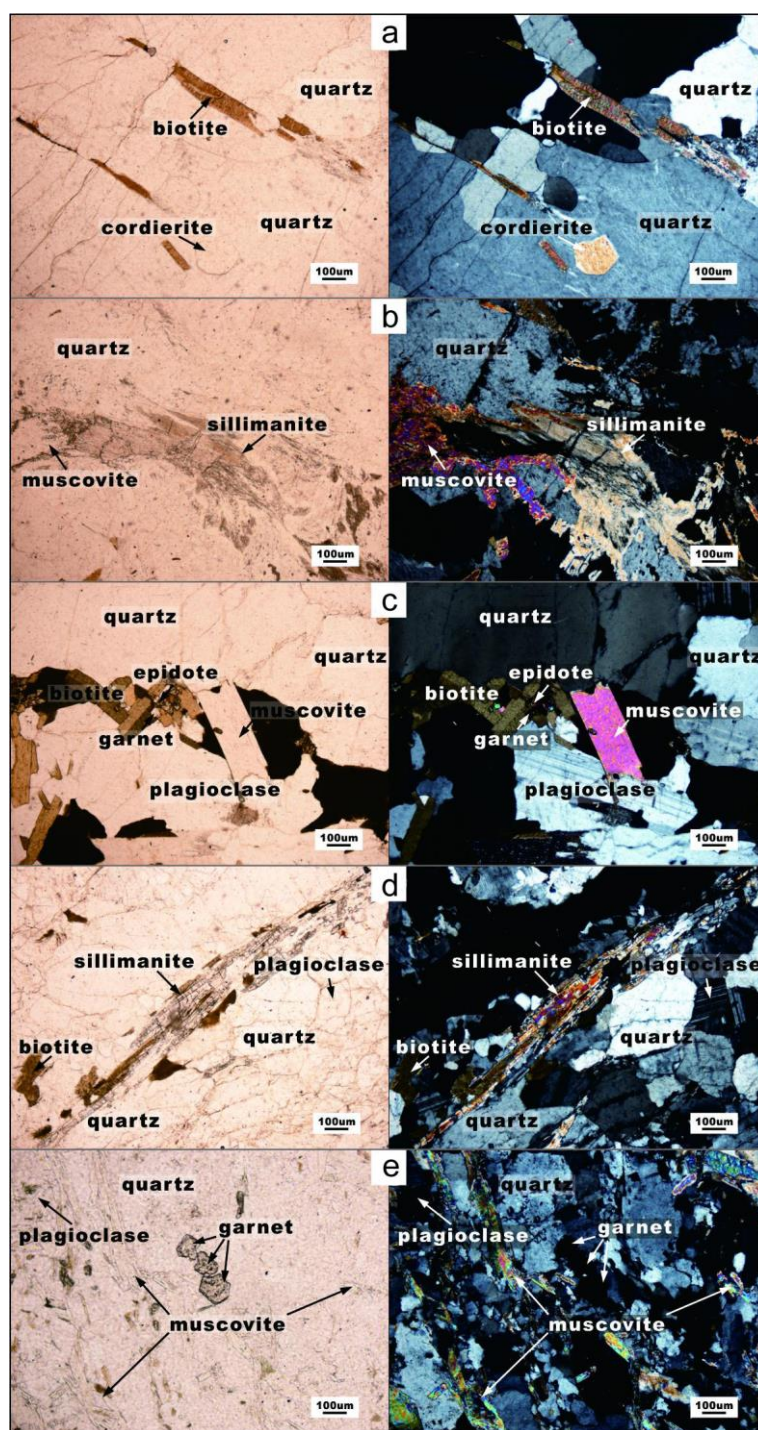


Figure S-4 Photomicrographs from the studied granites of the (a) Kekeagashi, (b) Tiemuerte, (c) Jiaertasi, (d) Chaganxile, and (e) Sareshuoke plutons.

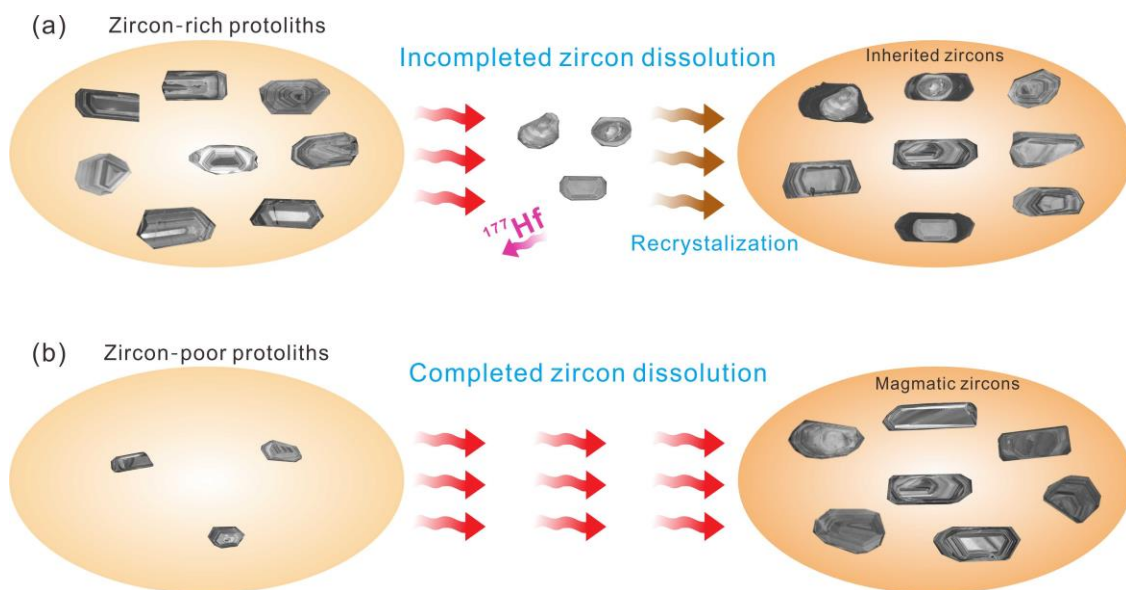


Figure S-5 Schematic diagram suggesting the different melting processes of **(a)** zircon-rich and **(b)** zircon-poor protoliths.

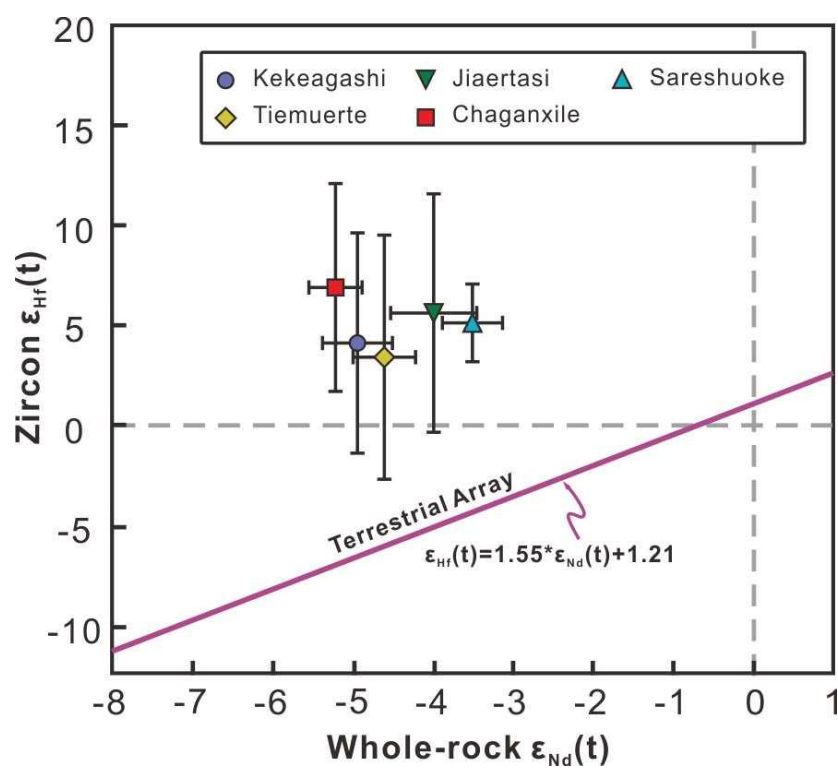


Figure S-6 Crossplot of zircon $\epsilon_{\text{Hf}}(t)$ versus whole-rock $\epsilon_{\text{Nd}}(t)$.

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