

This is an Open Access document downloaded from ORCA, Cardiff University's institutional repository: <https://orca.cardiff.ac.uk/id/eprint/168831/>

This is the author's version of a work that was submitted to / accepted for publication.

Citation for final published version:

Yin, Jiyuan, Xiao, Wenjiao, Wang, Tao, Fowler, Mike, Kerr, Andrew C. , Sun, Min, Strachan, Rob, Huang, He, Zhang, Ji'en, Chen, Wen and Tao, Zaili 2024. Maturation from oceanic arcs to continental crust: Insights from Paleozoic magmatism in West Junggar, NW China. *Earth-Science Reviews* 253 , 104795. 10.1016/j.earscirev.2024.104795

Publishers page: <http://dx.doi.org/10.1016/j.earscirev.2024.104795>

Please note:

Changes made as a result of publishing processes such as copy-editing, formatting and page numbers may not be reflected in this version. For the definitive version of this publication, please refer to the published source. You are advised to consult the publisher's version if you wish to cite this paper.

This version is being made available in accordance with publisher policies. See <http://orca.cf.ac.uk/policies.html> for usage policies. Copyright and moral rights for publications made available in ORCA are retained by the copyright holders.



Maturation from oceanic arcs to continental crust: insights from Paleozoic magmatism in West Junggar, NW China

Jiyuan Yin ^{1*,2}, Wenjiao Xiao ³, Tao Wang ¹, Mike Fowler ⁴, Andrew C. Kerr ⁵,
Min Sun ⁶, Rob Strachan ⁴, He Huang ^{1*}, Ji'en Zhang ⁷, Wen Chen ¹, Zaili Tao

¹ SinoProbe Laboratory, MNR Key Laboratory of Isotope Geology, Institute of
Geology, Chinese Academy of Geological Sciences, Beijing 100037, China

² State Key Laboratory of Continental Dynamics, Northwest University, Xi'an
710069, China

³ Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi
,830011, China

⁴ School of the Environment, Geography and Geosciences, University of Portsmouth,
Burnaby Building, Burnaby Road, Portsmouth PO1 3QL, UK

⁵ School of Earth and Environmental Sciences, Cardiff University, Cardiff, Wales
CF10 3AT, United Kingdom

⁶ Department of Earth Sciences, the University of Hong Kong, Pokflam Road, Hong
Kong, China

⁷ State Key Laboratory of Lithospheric Evolution, Institute of Geology and
Geophysics, Chinese Academy of Sciences, Beijing 100029, China

*Corresponding authors: Jiyuan Yin (yinjiyuan1983@163.com); He Huang
(huanghecugb@126.com)

Abstract

Understanding the processes involved in the transformation of juvenile basaltic oceanic arc crust into mature continental crust remains a key challenge in Earth sciences. In this contribution, we present a comprehensive synthesis of in situ zircon U-Pb age and Hf-O isotope data for Paleozoic intrusions within the West Junggar oceanic arc, NW China. Our study reveals four distinct pulses of magmatic activity: Early Cambrian to Early Ordovician (515 to 486 Ma); Late Ordovician to Middle Devonian (445 to 392 Ma); Early Carboniferous (343 to 310 Ma) and Late Carboniferous to Middle Permian (309 to 259 Ma). These pulses have varied spatial and temporal distributions. All magmatic rocks display consistently high zircon Hf and whole-rock Nd isotope values, but substantial variations in zircon O isotopes. There are two groups of intrusions: those with high zircon $\delta^{18}\text{O}$ ($>6.5\%$) and those with mantle-like zircon $\delta^{18}\text{O}$ (ca. 5.5%). The high zircon $\delta^{18}\text{O}$ intrusions are predominantly concentrated in the southern West Junggar and their Hf and Nd isotopes indicate the involvement of supracrustal material and juvenile basaltic crust in their petrogenesis. Binary mixing calculations indicate a contribution from the supracrustal rocks ranging from 10% to 50%. The intrusions with mantle-like zircon $\delta^{18}\text{O}$ are found primarily in northern West Junggar with a small amount occurring in southern West Junggar. The intrusions record a variety of magma sources and processes as demonstrated by Hf-O isotope and geochemical data. These data indicate partial melting of metasomatized depleted mantle, mixing of depleted mantle and juvenile crust, and partial melting of trapped juvenile oceanic crust or mafic lower crust. Hf model ages reveal significant crustal growth in the West Junggar, characterized by three distinct episodes of crust formation occurring at approximately 656-684 Ma, 524-536 Ma, and 441-471 Ma, involving periodic remelting of igneous material derived from a depleted mantle source. This newly-formed crust maintains a mantle-like oxygen isotope composition despite being repeatedly sampled by magmas for up to 0.26 Ga. Since the timing of crustal growth occurred independently of the major magmatic pulses, the latter reflect primarily reworking and remelting processes.

Two significant episodes of magmatic activity, the late Silurian to early Devonian and the late Carboniferous to early Permian, preserve a signature of ocean ridge subduction. High-temperature magmatism during these periods promoted extensive melting of the mafic lower crust, oceanic crust, and supracrustal rocks, leading to the compositional transformation from basaltic to felsic continental crust. This comprehensive compilation provides valuable insights into granite petrogenesis, crustal evolution, and the diverse processes involved in the maturation of oceanic arc crust and its contribution to continental crust formation and evolution.

Key words: Zircon Hf–O isotope; crustal growth; crustal maturation; intra-oceanic arc; Central Asian Orogenic Belt

1. Introduction

Juvenile continental crust is derived predominantly from subduction-derived intra-oceanic arc magmatism (e.g., Rudnick, 1995). However, intra-oceanic arcs are primarily basaltic (Holbrook et al., 1999) and the bulk composition of continental crust is andesitic (Pearcy et al., 1990; Rudnick, 1995). This apparent contradiction suggests that additional processes are required to transform basaltic oceanic arc crust into mature continental crust. A range of models has been proposed to explain this transformation (Rudnick, 1995; Tatsumi, 2005), for example (1) crust formation from mantle-derived andesitic magmas (e.g., Kelemen, 1995; Rapp et al., 1999); (2) melting of recycled oceanic crust (e.g., Tatsumi, 1981; Kelemen, 1995); (3) relamination of buoyant, subducting crustal material (Hacker et al., 2011; Behn et al., 2011; Kelemen and Behn, 2016); (4) fractional crystallization of basaltic magmas and/or remelting of basaltic arc crust and subsequent delamination of mafic lower crustal material (e.g., Kay and Kay, 1993; Jull and Kelemen, 2001; Tatsumi and Kogiso, 2003); (5) chemical weathering and crustal recycling (Lee et al. 2008, Liu and Rudnick, 2011).

Intra-oceanic arcs are constructed on ocean crust without pre-existing continental

crust (Stern, 2010). However, recent seismic velocity profiling of modern oceanic arcs has demonstrated that they can act as sites for the generation of granitic continental crust within an oceanic setting, thus acting as fundamental contributor to continental growth (Takahashi et al., 2008; Kopp et al., 2011; Crawford et al., 2003; Saito and Tani, 2017). However, all components of the arc, including juvenile sediment, mafic lower crust, recycled oceanic crust, and mantle-derived basaltic magma, exhibit similar “depleted” radiogenic isotope signatures (Bindeman et al., 2005; Tang et al., 2019) since they are derived from elementally-depleted upper mantle. Therefore, in young and juvenile intra-oceanic arcs, it can be challenging to distinguish a recycled crustal source for granitoids solely based on radiogenic isotopes. Nevertheless, accurately identifying the sources of granitic rocks formed in intra-ocean arc systems is crucial for understanding magma genesis and crustal differentiation of oceanic arcs. Zircon, known for its exceptional retention of the magmatic O isotope ratios, displays a narrow $\delta^{18}\text{O}$ range ($5.3 \pm 0.6\text{‰}$) (2SD) when in equilibrium with pristine mantle-derived melts (Valley et al., 1998). Even slight deviations from the mantle $\delta^{18}\text{O}$ value provide significant evidence of changes in the O isotopic compositions of their host rocks caused by surficial processes or by contamination with $\delta^{18}\text{O}$ -modified material (Valley et al., 2005).

In this study, we present a comprehensive synthesis of Hf-O isotopic data obtained from Paleozoic granitoids within the remnants of the West Junggar oceanic arc, NW China. Our petrogenetic interpretations give a comprehensive overview of granite petrogenesis during the evolution of oceanic arc crust. The results enable the identification of four distinct genetic mechanisms for the Paleozoic intrusions, highlighting the diverse processes involved in the crustal maturation of an oceanic arc system. This compilation significantly enhances our understanding of crustal maturation within an oceanic arc setting.

2. Geological setting

The Central Asian Orogenic Belt (CAOB) is the largest accretionary orogenic

116 belt in the world. It is bounded by the Siberian Craton to the north and the
117 Tarim-North China Craton to the south (Fig.1a; Şengör et al., 1993; Jahn et al., 2004;
118 Windley et al., 2007; Xiao et al., 2009, 2015; Wang et al., 2023a, b). This orogenic
119 belt was formed by the successive lateral accretion of multiple arcs, seamounts,
120 oceanic plateaus, accretionary complexes, and microcontinental blocks (e.g., Windley
121 et al., 2007; Xiao et al., 2008; Safonova et al., 2017; Tao et al., 2022). It preserves
122 significant evidence for accretionary orogenesis and Phanerozoic continental growth
123 (Jahn et al., 2000; Wang et al., 2009; Tang et al., 2019; Wang et al., 2023b). The West
124 Junggar is located in the southwestern CAOB, is surrounded by the Tianshan Orogen
125 to the south, the Altai Orogen to the north, the Kazakhstan Plate to the west, and the
126 Junggar Basin to the east. The West Junggar contains extensive Paleozoic
127 accretionary complexes and subduction-related arc magmatic rocks (Geng et al., 2009;
128 Zhang et al., 2011; 2021; Tang et al., 2010; Yin et al., 2010; 2013a; 2015a). It has
129 been proposed to have no Precambrian basement (Feng et al., 1989; Han et al., 1999;
130 Chen and Jahn, 2004; Choulet et al., 2012a) and to have resulted entirely from
131 processes of intra-oceanic subduction-accretion during the Paleozoic (Buckman and
132 Aitchison, 2004; Xiao et al., 2008; Zhang et al., 2011; 2021). Tectonically, West
133 Junggar is divided into northern and southern parts by the Xiemisitai Fault (Fig.1b).

134 The northern West Junggar mainly comprises two E-W trending magmatic arcs,
135 the Zharma-Sawur arc in the north and the Boshchekul-Chingiz arc in the south
136 (Fig.1b). In the Boshchekul-Chingiz arc, most of the ophiolites were formed mainly
137 between 472 and 520 Ma (Zhu and Xu, 2006; Zhang and Guo, 2010; Zhao et al., 2013;
138 Zhao and He, 2014; Ao et al., 2022). The Zharma-Sawur volcanic arc occupies the
139 Tarbagatay and Sawur mountains and is mainly composed of Devonian-early
140 Carboniferous subduction-related volcanic rocks (Fig.1b, Chen et al., 2010a, b; Yin et
141 al., 2017 and references therein). The Zharma-Sawur volcanic arc was formed either
142 by southward subduction of the Irtysh-Zaisan Ocean (Chen et al., 2010a, b; 2015; Yin
143 et al., 2015b) or northward subduction of Junggar Ocean during the Early
144 Carboniferous (Chen et al., 2017). The Boshchekul-Chingiz volcanic arc comprises
145 the Xiemisitai, Saier, and Sharburti mountains (Fig.1b), and is made up of Middle

1 146 Ordovician to Silurian marine volcanic clastic and pyroclastic sediments, as well as
2
3 147 Silurian to Early Devonian calc-alkaline volcanic rocks (Shen et al. 2012; Yang et al.,
4
5 148 2014; Chen et al., 2015; 2019; Yin et al. 2017). It has been proposed that the volcanic
6
7 149 arc formed either by the southward subduction of the Irtysh-Zaisan Ocean (Shen et al.
8
9 150 2012; Yin et al. 2017) or the northward subduction of the Junggar Ocean during the
10
11 151 Early Palaeozoic (Chen et al. 2015).

12 The southern West Junggar is characterized by extensive ophiolitic mélanges and
13
14 152 volcanosedimentary sequences, which are cut across by roughly NE-trending sinistral
15
16 153 strike-slip faults, including the Barleik, Mayile and Dalabute faults from west to east
17
18 154 (Fig.1b). These ophiolitic mélanges form two groups, namely early and late Paleozoic.
19
20 155 The Early Paleozoic ophiolitic mélanges occur in the Barleik, Mayile, and Tangbale
21
22 156 area, and comprise accreted seamounts, ophiolitic fragments, blueschist, amphibolite
23
24 157 blocks, and an accretionary complex (Xu et al. 2012, 2013; Ren et al. 2014; Liu et al.
25
26 158 2016). They are the oldest Supra-Subduction Zone (SSZ) -type ophiolitic mélanges in
27
28 159 the West Junggar and formed in the Early Cambrian to Early Silurian intra-oceanic
29
30 160 arc system, also known as the Barleik-Mayile-Tangbale arc (Ren et al., 2014; Xu et al.,
31
32 161 2012; 2013; Liu et al., 2016; Zhang et al., 2022). The arc comprises
33
34 162 Ordovician-Devonian volcanosedimentary sequences with sporadic slices of Late
35
36 163 Cambrian-Ordovician ophiolitic mélange (Xu et al., 2012, 2013; Ren et al., 2014). The
37
38 164 Late Paleozoic ophiolitic mélanges which crop out the Darbut, Sartuohai, Karamay
39
40 165 and Baijiantan area show Mid-Ocean Ridge Basalt (MORB) and Ocean Island Basalt
41
42 166 (OIB)-type geochemical features. They are proposed to be relicts of a mid-oceanic
43
44 167 ridge (Zhang et al., 1995) or a spreading ridge in a back-arc setting (Zhang et al.,
45
46 168 2011), and of a seamount (Yang et al., 2013; 2015; 2019), respectively. These areas
47
48 169 where late Paleozoic ophiolitic mélanges are exposed are dominated by Early
49
50 170 Carboniferous and minor Devonian subduction-related volcanosedimentary rocks
51
52 171 (Buckman and Aitchison, 2004; An and Zhu, 2009; Shen et al., 2013), which are
53
54 172 mainly distributed on both sides of the Darbut Fault.
55
56 173

57
58
59 174
60
61
62
63
64
65

3. Spatial and temporal distribution of the Paleozoic intrusions

Based on zircon U–Pb ages obtained in this study, as well as those available from previous studies, the West Junggar intrusions can be grouped into four pulses: Early Cambrian Early Ordovician (515 to 486 Ma); Late Ordovician–Middle Devonian (445 to 392 Ma); Early Carboniferous–Late Carboniferous (343 to 310 Ma), Late Carboniferous–Middle Permian (309 to 259 Ma) (Fig.2; Table S1).

3.1 Early Cambrian Early Ordovician (515 to 486 Ma) intrusions

The Early Cambrian to Early Ordovician (515 to 486 Ma) intrusions primarily occur in the Mayile and Barleik Mountain of the southern West Junggar. These rocks intrude into the ultramafic-mafic mélange and are unconformably overlain by middle Silurian greenschist-facies rocks and Early-Middle Devonian volcano-sedimentary strata (Xu et al., 2013; Liu et al., 2016). They are characterized by Early-Middle Cambrian low-K tholeiitic felsic rocks to Late Cambrian medium- and high-K calc-alkaline felsic and mafic rocks (Ren et al., 2014). They typically take the form of small plutons or dikes, consisting of clinopyroxene-hornblende gabbro, gabbro, diorite, trondhjemite, plagiogranite, quartz plagioclase, and porphyritic granite (Xu et al., 2012; 2013; Ren et al., 2014; Zhang et al., 2022). These rocks show notable variations in both major and trace element compositions, including SiO₂ (ranging from 53.0 to 77.4 wt%) and K₂O (ranging from 0.05 to 2.24 wt%), suggesting diverse origins (Zhang et al., 2022 and references therein).

3.2 Late Ordovician–Middle Devonian (445 to 392 Ma) intrusions

The Late Ordovician to Middle Devonian (445 to 392 Ma) intrusions are mainly located in the Boshchekul-Chingiz arc of northern West Junggar (there are but two granodioritic plutons, dated at 444–439 Ma, in southern West Junggar). The 445 to 392 Ma rocks intruded into the Silurian–Devonian volcanic and pyroclastic rocks (Chen et al., 2010a; 2015; 2019; Yin et al., 2017; 2018), and consist predominately of

1 203 K-feldspar granite, alkaline granite, rhyolite-porphyry, felsite, granodiorites, diorite,
2 204 mafic dike, gabbro, and hornblende gabbro. The granodiorites have a calc-alkaline
3 205 character, with elevated Sr (407-532 ppm), low Y (12-15 ppm), Yb (1.5-1.8 ppm), Cr
4 206 (mostly <8 ppm), Co (mostly <11 ppm) and Ni (mostly <4 ppm), along with relatively
5 207 high Sr/Y ratios (31-42) resembling modern adakites (Yin et al., 2017). Alkaline
6 208 granite containing arfvedsonite and aegine-augite has high Zr, Nb and Ga/Al ratios
7 209 and geochemically resembles A-type granites (Chen et al., 2015; Yin et al., 2017).
8 210

17 211 3.3 Early to late Carboniferous (343 to 310 Ma) intrusions

19 212 Based on the rock types and ages, this intrusive period is further subdivided into
20 213 343-321 Ma intrusions in the northern Western Junggar and 332-310 Ma intrusions in
21 214 the southern Western Junggar (Fig.2). The Early Carboniferous (343 to 321 Ma)
22 215 intrusions are predominantly distributed in the Zharma-Sawur volcanic arc within the
23 216 northern West Junggar (Fig.2b). They primarily intruded into late Devonian to Early
24 217 Carboniferous pyroclastic rocks and volcanic rocks. They include gabbro,
25 218 granodiorite, pyroxene diorite, monzonitic granite, adamellite, and K-feldspar granite
26 219 (Han et al., 2006; Zhou et al., 2008; Chen et al., 2010a; Yin et al., 2013b). Many of
27 220 these contain hornblende, and classify as I-type granites in the high-K calc-alkaline
28 221 series. They exhibit weakly peraluminous-metaluminous characteristics, with slight
29 222 negative anomalies of Eu, Nb, Ta, P and Ti (Zhou et al., 2008; Chen et al., 2010b). In
30 223 southern West Junggar, Early to Late Carboniferous (332-310 Ma) intrusions are
31 224 represented mainly by small plutons exposed in the Baogutu, Karamay and Mayile-
32 225 Barleik areas (Chen and Arakawa, 2005; Tang et al., 2010; 2019). These are mainly
33 226 composed of gabbro, diorite and granodiorite. The Karamay suite encompasses a
34 227 range of rock types from gabbroic diorite to granite, which are metaluminous and
35 228 belong to calc-alkaline series. They have negligible to slight negative Eu anomalies
36 229 and marked negative anomalies of Nb, Ta, P and Ti, again classifying as I-type
37 230 granites (Chen and Arakawa, 2005; Geng et al., 2009). In the Baogutu area of
38 231 southern West Junggar, diorite-granodiorite porphyry plutons of Late Carboniferous
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

age (315-310 Ma) are associated with Cu-Au mineralization. These rocks display calc-alkaline compositions, high Sr (346–841 ppm), low Y (9.18–16.5 ppm) and Yb (0.95–1.60 ppm) contents, and relatively high Sr/Y (31–67) ratios, resembling typical adakites (Tang et al., 2010; 2019; Cao et al., 2016).

3.4 Late Carboniferous–Middle Permian (309 to 259 Ma) intrusions

The Late Carboniferous to Middle Permian (309-259 Ma) intrusions are widely distributed in the West Junggar and not constrained by the tectonic boundaries. The timing of magmatic activity suggests that the intrusive rocks in southern West Junggar (309-259 Ma) were formed at a similar time to those in northern West Junggar (303-263 Ma, Figs. 2b and 2c). However, the southern West Junggar intrusions show a broader spatial distribution and greater compositional complexity. Late Carboniferous-Middle Permian (309 to 259 Ma) intrusions from the southern West Junggar consist of charnockite and alkali-feldspar granite, monzogranite, K-feldspar granite, granodiorite and dioritic dikes (Chen and Arakawa, 2005; Han et al., 2006; Geng et al., 2009; Tang et al., 2010; 2019; Yin et al., 2010; 2013a; 2021). Among these rocks, the alkali-feldspar granites are the most extensively exposed in southern West Junggar. They contain diagnostic minerals such as arfvedsonite, hastingsite and iron-rich biotite and exhibit high alkali, $\text{FeO}^{\text{T}}/\text{MgO}$, Zr, and Ga/Al, as well as low CaO contents with marked negative Eu, Sr, and Ba anomalies, indicating their close affinity with A-type granites (Chen and Jahn, 2004; Chen and Arakawa, 2005; Geng et al., 2009; Tang et al., 2012; Yin et al., 2021). The dioritic dikes display high MgO (3.1-7.4 wt.%), Cr (22-311 ppm) and Ni (32-199 ppm) contents, with geochemical features similar to those of sanukite (Yin et al., 2010; 2013a; 2015). Late Carboniferous–Middle Permian (303-263 Ma) intrusions from the northern West Junggar mainly comprise K-feldspar granites and alkali granites (Han et al., 2006; Zhou et al., 2008; Chen et al., 2010a, b; Yin et al., 2013b). These rocks have high alkalis, $\text{FeO}^{\text{T}}/\text{MgO}$, Zr, and Ga/Al, low CaO and Al_2O_3 contents, and significant negative anomalies of Eu, Sr, Ba, Nb, Ta, P and Ti, indicating their close association

with A-type granites (Zhou et al., 2008; Chen et al., 2010b).

4. Analytical methods

Zircon Hf isotope methods

Determinations of *in situ* Hf isotope ratios were conducted using a Neptune Plus MC-ICP-MS (Thermo Fisher Scientific, Germany) in combination with a Geolas HD excimer ArF laser ablation system (Coherent, Göttingen, Germany) that was hosted at the Wuhan Sample Solution Analytical Technology Co., Ltd, Hubei, China and Nanjing FocuMS Technology Co. Ltd, Nanjing, China. A “wire” signal smoothing device is included in this laser ablation system, by which smooth signals are produced even at very low laser repetition rates down to 1 Hz (Hu et al. 2015). Helium was used as the carrier gas within the ablation cell and was merged with argon (makeup gas) after the ablation cell. Small amounts of nitrogen were added to the argon makeup gas flow for the improvement of sensitivity of Hf isotopes (Hu *et al.* 2012). Compared to the standard arrangement, the addition of nitrogen in combination with the use of the newly designed X skimmer cone and Jet sample cone in Neptune Plus improved the signal intensity of Hf, Yb and Lu by a factor of 5.3, 4.0 and 2.4, respectively. All data were acquired on zircon in single spot ablation mode at a spot size of 44 μm . The energy density of laser ablation that was used in this study was $\sim 7.0 \text{ J cm}^{-2}$. Each measurement consisted of 20 s of acquisition of the background signal followed by 50 s of ablation signal acquisition. Detailed operating conditions for the laser ablation system and the MC-ICP-MS instrument and analytical method are the same as description by Hu *et al.* (2012).

The major limitation to accurate *in situ* zircon Hf isotope determination by LA-MC-ICP-MS is the very large isobaric interference from ^{176}Yb and, to a much lesser extent ^{176}Lu on ^{176}Hf . It has been shown that the mass fractionation of Yb (β_{Yb}) is not constant over time and that the β_{Yb} that is obtained from the introduction of solutions is unsuitable for *in situ* zircon measurements (Woodhead *et al.* 2004). The under- or over-estimation of the β_{Yb} value would undoubtedly affect the accurate correction of ^{176}Yb and thus the determined $^{176}\text{Hf}/^{177}\text{Hf}$ ratio. We applied the directly obtained β_{Yb} value from the zircon sample itself in real-time in this study. The $^{179}\text{Hf}/^{177}\text{Hf}$ and $^{173}\text{Yb}/^{171}\text{Yb}$ ratios were used to calculate the mass bias of Hf (β_{Hf}) and

Yb (β_{Yb}), which were normalized to $^{179}\text{Hf}/^{177}\text{Hf} = 0.7325$ and $^{173}\text{Yb}/^{171}\text{Yb} = 1.132685$ (Fisher *et al.* 2014) using an exponential correction for mass bias. Interference of ^{176}Yb on ^{176}Hf was corrected by measuring the interference-free ^{173}Yb isotope and using $^{176}\text{Yb}/^{173}\text{Yb} = 0.79639$ (Fisher *et al.* 2014) to calculate $^{176}\text{Yb}/^{177}\text{Hf}$. Similarly, the relatively minor interference of ^{176}Lu on ^{176}Hf was corrected by measuring the intensity of the interference-free ^{175}Lu isotope and using the recommended $^{176}\text{Lu}/^{175}\text{Lu} = 0.02656$ (Blichert-Toft *et al.* 1997) to calculate $^{176}\text{Lu}/^{177}\text{Hf}$. We used the mass bias of Yb (β_{Yb}) to calculate the mass fractionation of Lu because of their similar physicochemical properties. Off-line selection and integration of analyte signals, and mass bias calibrations were performed using ICPMSDataCal (Liu *et al.* 2010).

In order to ensure the reliability of the analytical data, three international zircon standards of Plešovice, 91500 and GJ-1 were analyzed simultaneously with the actual samples. Plešovice is used for external standard calibration to further optimize the analysis and test results. 91500 and GJ-1 were used as the second standard to monitor the quality of data correction. The external precision (2SD) of Plešovice, 91500 and GJ-1 is better than 0.000020. During the period of data acquisition, Plešovice was also processed for Hf isotopes, which gave a ratio of 0.282484 ± 0.000016 (2SD) for $^{176}\text{Hf}/^{177}\text{Hf}$, in agreement with the recommended value (0.282482 ± 0.000013 (2SD)) (Sláma *et al.*, 2008). At the same time, in order to monitor the test data of the high Yb/Hf ratio zircon, the internationally-used high Yb/Hf ratio standard sample Temora 2 was used to monitor the test data of the high Yb/Hf ratio zircon. The Hf isotopic compositions of Plešovice, 91500 and GJ-1 have been reported by Zhang *et al.* (2020).

Zircon O isotope methods

Zircon oxygen isotopes were measured using the Cameca IMS-1280 SIMS at Guangzhou Institute of Geochemistry, Chinese Academy of Sciences (GIG-CAS). The detailed analytical procedures were similar to those described by Yang *et al.* (2018). The $^{133}\text{Cs}^+$ primary ion beam with an intensity of $\sim 2\text{nA}$ was accelerated at 10 kV and focused to an area of $10\text{ }\mu\text{m}$ on the sample surface and the size of analytical spots is about $20\text{ }\mu\text{m}$ in diameter ($10\text{ }\mu\text{m}$ beam diameter + $10\text{ }\mu\text{m}$ raster). Oxygen isotopes

were measured in multi-collector mode using two off-axis Faraday cups. Total analytical time per spot was about 3.5 min, including 30 s of pre-sputtering, 120 s of automatic tuning of the secondary beam, and 64 s of analysis. The measured oxygen isotopic data were corrected for instrumental mass fractionation (IMF) using the Penglai zircon standard ($\delta^{18}\text{O}$ VSMOW = 5.3‰) (Li et al., 2010b, Yang et al., 2018), which was analyzed once every five unknowns, using the sample-standard bracketing (SSB) method. The internal precision of a single analysis generally was better than 0.2‰ (1 σ standard error) for the $^{18}\text{O}/^{16}\text{O}$ ratio. As discussed by Kita et al. (2009), internal precision for a single spot (commonly < 0.1‰, 1 σ) is not a good index of analytical quality for stable isotope ratios measured by SIMS. Therefore, the external precision, measured by the reproducibility of repeated analyses of Penglai standard, is 0.38‰ (2SD, n = 45). Forty measurements of the Qinghu zircon standard during the course of this study yielded a weighted mean of $\delta^{18}\text{O} = 5.41 \pm 0.30\text{‰}$ (2SD), which is consistent within errors with the reported value of $5.3 \pm 0.3\text{‰}$ (Li et al., 2010a; 2013).

5. Zircon Hf-O isotopic data

This study provides a comprehensive compilation of published in situ zircon U–Pb ages and Hf-O isotopic data from the intrusions in the West Junggar. A total of 67 plutons are included for Hf-O isotopic data, including 32 sets of new, unpublished U-Pb-Hf-O isotope data. The compiled zircon Hf-O isotopic dataset is organized on the basis of GPS position, rock type, age and tectonic location given above and summarized in Table 1 and Table S2.

All magmatic rocks exhibit consistently high Hf isotope ratios, with zircon $\epsilon\text{Hf}(t)$ ranging from +10 to +16 (Figs. 3a-c). However, the Hf model ages show significant heterogeneity, varying from 800-390 Ma ($T_{\text{DM}2}$) (Figs. 4a-c). The Early Cambrian-Early Ordovician (515 to 485 Ma) intrusions have older model ages, ranging from 800 to 600 Ma, while those of the intrusive rocks from other periods are relatively young (600-390 Ma) (Figs. 5a-d). The zircon $\delta^{18}\text{O}$ values of all magmatic rocks span a range of +4.1‰ to +10.3‰ (Figs. 3d-f, Figs. 6a-c and Table 1). In more

detail, the magmatic rocks in northern West Junggar have lower average zircon $\delta^{18}\text{O}$, ranging from +5.1 to +6.3‰ (Fig. 3e and Fig. 6b), resembling mantle-like or slightly higher values (mantle $\delta^{18}\text{O} = 5.3 \pm 0.6\text{‰}$, 2σ as reported by Valley et al. 1998), except for two samples that are higher ($\sim 7.5\text{‰}$). In contrast, the magmatic rocks (>310 Ma) in southern West Junggar have lower average zircon $\delta^{18}\text{O}$ ranging from 4.4 to 6.7‰ (Fig. 3f and Table 1), thus including slightly lower than mantle values. However, the majority of the magmatic rocks (<310 Ma) from southern West Junggar exhibit high average zircon $\delta^{18}\text{O}$ (7.7-10.3‰) with only a few low values ($<6.3\text{‰}$), suggesting a range of source compositions (Fig. 3f and Table 1) that includes materials that have interacted under surface conditions.

6. Discussion

6.1 Magma sources of the intrusions in West Junggar

In section 5 it was noted that West Junggar magmatic rocks have consistent positive Hf isotope ratios while exhibiting variable zircon $\delta^{18}\text{O}$, ranging from slightly below to far above mantle compositions. Accordingly, we have classified the West Junggar magmatic rocks into two distinct groups: high zircon $\delta^{18}\text{O}$ intrusions ($>6.5\text{‰}$) and mantle-like zircon $\delta^{18}\text{O}$ intrusions (Figs. 3d-f). Such variations likely reflect the composition of their sources, discussed below in the light of elemental and radiogenic isotope constraints.

6.1.1 Origin of mantle-like zircon $\delta^{18}\text{O}$ intrusions

Mantle-like zircon $\delta^{18}\text{O}$ intrusions have distinct temporal and spatial distribution patterns (Fig. 7a) and are predominantly found in northern West Junggar, with a few occurrences in southern West Junggar. Consequently, we will examine their respective sources based on their spatial distribution.

Northern West Junggar

There are three distinct episodes of magmatism in northern West Junggar: Late Silurian-Early Devonian (445 to 392 Ma), Early Carboniferous (343 to 321 Ma), and Late Carboniferous-Middle Permian (307 to 263 Ma) (Fig.2b). Apart from a small amount of gabbro, hornblende gabbro and diorite, the predominant rock types among these intrusions are granodiorite, alkali-feldspar granite, monzogranite and K-feldspar granite. All three have consistently low initial Sr isotopic ratios [$(^{87}\text{Sr}/^{86}\text{Sr})_i = 0.7035\text{--}0.7046$] and high $\epsilon\text{Nd}(t)$ values (+5.1 to +7.5) (Zhou et al., 2008; Chen et al., 2010b; 2015; Yin et al., 2017). They also have high and uniform average zircon $\epsilon\text{Hf}(t)$ values ranging from +11.6 to +14.8, with average T_{DM2} model ages from 404 Ma to 598 Ma (Table 1). However, their sources controversial with proposed models that involve: (1) partial melting of metasomatized depleted mantle (Chen et al., 2010b, Zhou et al., 2008), (2) mixing of depleted mantle and juvenile crust (Zheng et al., 2020), (3) partial melting of trapped juvenile oceanic crust (Gao et al., 2014), and (4) partial melting of juvenile mafic lower crust (Yin et al., 2017).

The gabbros and hornblende gabbros are characterized by moderate SiO_2 (42.0–52.4 wt.%), MgO (5.0–7.2 wt.%), $\text{Mg}^\#$ (52–53), Cr (124–159 ppm) and Ni (58–87 ppm). Along with high whole-rock Nd and zircon Hf isotopic values (Yin et al., 2017), these features are consistent with partial melting of depleted mantle. However, their zircon O isotope values (5.7 to 6.3‰) extend to slightly higher than those of the mantle, suggesting significant metasomatism by subducted slab fluids or sediment melts. The diorites and granodiorites are characterized by high Sr (407–532 ppm) and low Y (12.2–14.7 ppm), Yb (1.5–1.8 ppm), Cr (mostly <8 ppm) and Ni (mostly <4 ppm) contents, as well as relatively high Sr/Y (31–42) ratios, which are similar to adakites, distinguishing them from adakitic rocks derived from subducting slabs (Defant and Drummond, 1990; Yin et al., 2017). Furthermore, their relatively low Nb/Ta ratios and negative Nb-Ta anomalies suggest that they were most likely formed through partial melting of amphibolite within the garnet stability field and they also differ from those of adakitic rocks derived from thickened lower crust (Chung et al., 2003; Yin et al., 2017). Taking into account the zircon O isotopic composition (5.7–6.2‰), it is likely that these diorites and granodiorites are generated through the

partial melting of juvenile, unthickened basaltic lower crust.

The largest exposed granitoid plutons are characterized by high SiO₂ (>65 wt.%), low MgO (<1.0 wt.%), Mg[#] (<40), Cr (<10 ppm) and Ni (<5 ppm) contents (Zhou et al., 2008; Chen et al., 2010b; 2015; Yin et al., 2017), indicating the absence of mantle components in their source. Additionally, their relatively low Sr contents (<100 ppm) and high Yb (>20 ppm) and Y (>2 ppm) contents, which are not typical of adakitic rocks, further distinguish them from magmas formed by the melting of (mafic) oceanic crust. The average zircon $\delta^{18}\text{O}$ values of these granitoid plutons (5.1-6.3‰) are similar to those of diorites and granodiorites, suggesting a potential common source, most likely the juvenile basaltic lower crust.

Southern West Junggar

Mantle-like zircon $\delta^{18}\text{O}$ intrusions are less common in southern West Junggar (Fig.7a) and occur during the Early Cambrian-Early Ordovician and Early to Late Carboniferous. The Early Cambrian-Early Ordovician intrusions are found in the Mayile and Barleik Mountains. They are less than 500 m in diameter and are extensively deformed. Early to Late Carboniferous intrusions primarily consist of the West and East Karamay plutons, as well as several small dioritic plutons in the Baogutu area. The Early Cambrian-Early Ordovician intrusions consist of gabbro, diorite, granodiorite, trondhjemite and tonalite. They display consistent average zircon $\epsilon\text{Hf(t)}$ values ranging from +10.1 to +13.7, zircon $\delta^{18}\text{O}$ values from 4.4 to 5.4‰, and T_{DM2} model ages from 0.60 to 0.79 Ga (Zhang et al., 2022 and Table 1). However, they have variable major and trace element compositions, such as SiO₂ (53.0-77.4 wt.%) and K₂O (0.05-2.2 wt.%), suggesting different origins. One group of dioritic rocks has an adakitic signature of intermediate SiO₂ (53.3-65.6 wt.%), high Al₂O₃ (13.1-22.2 wt.%) and Sr (mostly >350 ppm) with low Y (3.8-17.3 ppm) and high Sr/Y (21-102) (Zhang et al., 2022). These rocks also display moderate Mg[#] (43-58), Cr (mostly >30 ppm) and Ni (mostly >10 ppm), similar to those of typical adakites in subduction zones (Defant and Drummond, 1990; Martin et al., 2005; Xu et al., 2012;

2013; Zhang et al., 2022). These may well have formed by partial melting of subducted oceanic crust with garnet $\pm$ amphibole as residual minerals. Conversely, other dioritic rocks have relatively low Sr (<300 ppm) and Sr/Y (<17), and therefore do not have adakitic signatures. Their high $Mg^\#$ (53-58), Cr (mostly >30 ppm) and Ni (mostly >18 ppm), along with positive Hf isotope values (+13.4), mean that these rocks are more likely to be derived from partial melting of depleted mantle. Related gabbros have lower zircon $\delta^{18}O$ (4.2‰ to 4.7‰) than typical mantle values, suggesting that the depleted mantle source was hydrated by high-temperature hydrothermal fluids (Grimes et al., 2013; Zhang et al., 2022). The trondhjemitic rocks have high SiO_2 (72.6-77.4 wt%), low MgO (mostly <0.65 wt.%), Cr (<10 ppm) and Sr (58-176 ppm), as well as high Y (18-33 ppm) (Ren et al., 2014). However, they also have mantle-like zircon $\delta^{18}O$ values (4.5-5.3‰, Zhang et al., 2022) similar to normal arc rhyolites, suggesting derivation by partial melting of arc basalt in the lower crust.

Early to Late Carboniferous dioritic rocks in the Baogutu area are characterized by high Sr (346-841 ppm), low Y (9.2-16.5 ppm) and Yb (1.0-1.6 ppm) and relatively high Sr/Y (31-67), which also resemble typical adakites (Tang et al., 2010). They have relatively high $Mg^\#$ (mostly >50), Cr (mostly >50 ppm) and Ni (mostly >30 ppm), along with high Th/La (>0.15) and zircon $\delta^{18}O$ (6.1-6.6‰) that exceed mantle values (Tang et al., 2010; Cao et al., 2016 and Table 1). These combined characteristics suggest a complicated petrogenesis involving melting of oceanic crust (adakitic signature) and subducted sediments (high $\delta^{18}O$ and Th/La) followed by interaction with the mantle wedge (high $Mg^\#$, Cr and Ni). The Late Carboniferous Karamay intrusions encompass a range of rock types from gabbroic diorite to granite. They have variable SiO_2 (53.4-70.1 wt.%), high $Mg^\#$ (41-63), Cr (mostly >50 ppm) and Ni (mostly >30 ppm), along with positive zircon $\epsilon Hf(t)$ from +14.4 to +13.6 (Chen and Arakawa, 2005; Tang et al., 2019; and this study). In accord with the logic outlined above, these features indicate that they are derived from depleted mantle sources. Furthermore, they are significantly depleted high field strength elements (HFSE), and enriched in light rare earth elements (LREE) and large ion lithophile elements (LILE)

1 471 These features, in combination with significantly higher zircon $\delta^{18}\text{O}$ (+5.8-6.7‰) than
2
3 472 the mantle, suggest that their depleted mantle source had undergone metasomatism by
4
5 473 subducted slab fluids or sediments.
6

7 474 In summary, the Early Cambrian-Early Ordovician and Early to Late
8
9 475 Carboniferous intrusions in West Junggar are derived from partial melting of several
10
11 476 different sources, including depleted mantle, subducted oceanic crust and sediments,
12
13 477 and basaltic lower crust. These relationships are critically constrained by their zircon
14
15 478 Hf-O isotope relationships (Figs. 3 and 8).
16

17 479 18 19 20 480 6.1.2 Origin of high zircon $\delta^{18}\text{O}$ intrusions 21

22 481 The high zircon $\delta^{18}\text{O}$ intrusions in southern West Junggar, composed primarily
23
24 482 of charnockites and alkali-feldspar granites, were formed during 307-269 Ma (Fig. 3f;
25
26 483 Fig.7a). These intrusions display low $(^{87}\text{Sr}/^{86}\text{Sr})_i$ ratios ranging from 0.7024 to 0.7045
27
28 484 and high $\epsilon\text{Nd}(t)$ values from +5.1 to +8.9 (e.g., Han et al., 1999; Chen and Jahn, 2004;
29
30 485 Chen and Arakawa, 2005; Geng et al., 2009; Zheng et al., 2020). Their average zircon
31
32 486 $\epsilon\text{Hf}(t)$ values and Hf model ages are also relatively juvenile, ranging from +10.6 to
33
34 487 +14.4 and from 0.4 to 0.6 Ga, respectively (e.g., Geng et al., 2009; Gao et al., 2014;
35
36 488 Table 1). Based on these isotopic data, it has been proposed that these granites are
37
38 489 either derived from (a) the juvenile basaltic lower crust (Chen and Jahn, 2004; Chen
39
40 490 and Arakawa, 2005; Geng et al., 2009) (b) by mixing between depleted mantle and
41
42 491 juvenile crust (Zheng et al., 2020) or (c) mantle-derived magmas (Han et al., 1999).
43
44

45 492 Experimental work has established that $\text{Mg}^\#$ is a useful discriminant between
46
47 493 melts from the crust and those involving mantle components. Melts derived from the
48
49 494 basaltic (and felsic) lower crust consistently have low $\text{Mg}^\#$ (<40) regardless of the
50
51 495 degree of melting, whereas $\text{Mg}^\# > 40$ can only be achieved with the involvement of a
52
53 496 mantle component (Rapp and Watson, 1995). The high zircon $\delta^{18}\text{O}$ intrusions are
54
55 497 characterized by low $\text{Mg}^\#$ values (<33), as well as low Cr (average 10 ppm) and Ni
56
57 498 (average 5 ppm) (Chen and Arakawa, 2005; Geng et al., 2009; Yin et al., 2021),
58
59 499 which indicates an absence of mantle in their source. However, the high average $\delta^{18}\text{O}$
60
61
62
63
64
65

values (+7.7‰ to +10.3‰) strongly suggest that their formation cannot be attributed solely to the melting of juvenile basaltic lower crust, since their source must contain a significant proportion of supracrustal material (Valley, 2003).

Previous studies have demonstrated that these intrusions contain a substantial number of Early Carboniferous inherited zircon cores (Geng et al., 2009; Tang et al., 2019), similar to the ages of Early Carboniferous volcanic rocks (Geng et al., 2011) and detrital zircon ages found in early-late Carboniferous sedimentary rocks in southern West Junggar (Choulet et al., 2012). Importantly, these volcanic and sedimentary rocks also have highly depleted Nd-Hf isotopic compositions (Geng et al., 2011; Choulet et al., 2012), consistent with being the source for the high zircon $\delta^{18}\text{O}$ intrusions. These have a metaluminous to weakly peraluminous character with an aluminum saturation index below 1.1, and they lack aluminum-saturated minerals such as cordierite and muscovite. Based on $\text{Al}_2\text{O}_3/(\text{MgO}+\text{FeO}^{\text{T}})$ and $\text{CaO}/(\text{MgO}+\text{FeO}^{\text{T}})$, Yin et al. (2021) argue that the source of these intrusions was comprised of metagraywackes rather than metapelites. Binary mixing calculations for Hf-O isotopes suggest that 10-50% supracrustal rocks were involved in their petrogenesis (Figs. 8a-c).

6.2 Implications for growth of the continental crust

The CAOBS represents one of the largest and most complex accretionary orogenic belts of the Phanerozoic (Sengör et al., 1993; Windley et al., 2007). Previous work on its granitoid rocks commonly relied on whole-rock Nd isotopic data to elucidate significant continental growth during the Phanerozoic (Jahn et al., 2000; Wang et al., 2009; Wang et al., 2023b), however, whole-rock isotopes can often obscure crucial petrogenetic processes (Kemp et al., 2007; Kröner et al., 2013; 2017). Recent isotopic evidence suggests that most of the granites comprise mixtures of materials from various sources (Tang et al., 2019; Yin et al., 2021).

Whole-rock Nd and zircon Hf model ages are commonly employed to recognize recycling and estimate the time when a portion of new crust was initially extracted

1 529 from the mantle (Dhuime et al., 2012). However, individual model ages may not
2 530 accurately represent the true age of crustal formation, as the crustal material analysed
3
4 531 may be a mixture of reworked and newly generated juvenile material (Kemp et al.,
5
6 532 2006; Hawkesworth et al., 2010). Hence, relying solely on Nd-Hf isotopic data to
7
8 533 estimate crustal growth ages and differentiate between recycled and juvenile
9
10 534 components can be highly controversial and unreliable.

11
12 535 Oxygen isotope ratios of igneous rocks are sensitive indicators of sedimentary
13
14 536 input, as exemplified by the elevated $\delta^{18}\text{O}$ values observed in
15
16 537 metasedimentary-derived granites (Kemp et al., 2007; Hopkinson et al., 2017).
17
18 538 Therefore, by combining microanalysis of U-Pb, O and Hf isotopes in zircon,
19
20 539 uncertainty regarding the proportion of new and reworked crust can be reduced,
21
22 540 providing valuable insights into granite genesis, crustal growth and evolution (e.g.,
23
24 541 Hawkesworth and Kemp, 2006; Kemp et al., 2006; 2007) As described above, the
25
26 542 West Junggar dataset was subdivided on the basis of $\delta^{18}\text{O}$ values, considering zircon
27
28 543 domains with $\delta^{18}\text{O} < 6.5\text{‰}$ as being derived from magmas with minimal supracrustal
29
30 544 input, while those with $\delta^{18}\text{O} > 6.5\text{‰}$ formed from hybrid magmas with a mixed source
31
32 545 containing a supracrustal component.

33
34 546 On an $\epsilon\text{Hf}(t)$ –time diagram and Hf model age histogram (Fig. 5), zircons with
35
36 547 $\delta^{18}\text{O} < 6.5\text{‰}$ delineate three prominent linear trends intersecting the depleted mantle
37
38 548 growth curve at 670 ± 14 Ma and 456 ± 15 Ma for the southern West Junggar and 530 ± 6
39
40 549 Ma for the northern West Junggar, respectively. It is suggested that each linear trend
41
42 550 records periodic, closed-system remelting of igneous material that was extracted from
43
44 551 a depleted mantle reservoir at 670 ± 14 Ma, 530 ± 6 Ma, and 456 ± 15 Ma (Fig. 5 and Fig.
45
46 552 7b). Therefore, although West Junggar experienced several discrete intrusive events,
47
48 553 the three episodes of crust generation recorded by zircon were not synchronous with
49
50 554 these episodes (Fig. 5). The newly-added material retained a predominantly
51
52 555 mantle-like oxygen isotope composition despite residing in the crust for up to 0.26 Ga
53
54 556 and being repeatedly sampled by magmas during this period. Importantly, in southern
55
56 557 West Junggar, even the intrusions with $\delta^{18}\text{O} > 6.5\text{‰}$ exhibit comparable Hf model
57
58 558 ages (473 ± 7 Ma) to those with $\delta^{18}\text{O} < 6.5\text{‰}$ (456 ± 15 Ma) (Fig. 5 and Fig. 7b),
59
60
61
62
63
64
65

1 559 indicating a rapid recycling process without the addition of ancient basement material.
2 560 Therefore, in the context of orogenic belt evolution, it is evident that all intrusions can
3
4 561 be traced back to mantle-derived materials from the early Paleozoic. This observation
5
6 562 suggests significant crustal growth during this period. However, it is crucial to
7
8 563 emphasise that the peak periods of magmatic activity do not coincide with the ages of
9
10 564 crustal growth, but represent the timing of crustal reworking and remelting processes
11
12 565 (Fig. 9).
13

14 566 Continental crustal growth refers to the continuous addition and formation of
15
16 567 new crustal material at the Earth's surface. This process involves the transfer of
17
18 568 material from the mantle to the crust through a range of geological processes, such as
19
20 569 arc, hotspot, rift-related, and spreading-ridge magmatism (Scholl and von Huene,
21
22 570 2007, 2009; Clift et al., 2009; Cawood et al., 2013). However, many questions
23
24 571 regarding the mechanisms involved in continental crust formation in the CAO
25
26 572 remain unresolved. Three broad mechanisms have been proposed: lateral growth
27
28 573 (Sengör et al., 1993; Xiao et al., 2008), vertical growth (Han et al., 1999; 2006) or a
29
30 574 combination of both (Jahn et al., 2000; 2004).
31
32

33 575 In this study, we have identified three episodes of crustal growth in the West
34
35 576 Junggar through a comprehensive analysis of Hf model ages of intrusive rocks. The
36
37 577 first phase occurred between 656-684 Ma. During this period, the Junggar
38
39 578 intra-oceanic arc had not formed, and this phase of crustal growth might therefore be
40
41 579 associated with the generation of MORB-type oceanic crust at a mid-ocean ridge. The
42
43 580 second phase took place between 524-536 Ma. Many studies of Cambrian island arc
44
45 581 magmatism, accretionary complexes and metamorphic rocks indicate that initial
46
47 582 subduction in the western Paleo-Asian Ocean likely occurred between 530-520 Ma
48
49 583 (Reng et al., 2014; Zhang et al., 2022). Consequently, the timing of crustal growth in
50
51 584 the second phase is consistent with the onset of subduction in the Paleo-Asian Ocean,
52
53 585 suggesting a significant role for oceanic subduction in crustal growth. During
54
55 586 subduction of oceanic crust, the flux of water and other volatiles from the subducting
56
57 587 slab causes melting in the overlying mantle wedge along with minor contributions
58
59 588 from the subducting slab and associated sediments (Currie et al., 2007; Scholl and von
60
61
62
63
64
65

Huene, 2009; Spencer et al., 2017). The resultant magma ascends into the overlying crust, forming a magmatic arc that signifies the genesis of continental crust. Similarly, the third and final phase of crustal growth (441-471 Ma) is likely associated with continuing subduction processes in the western Paleo-Asian Ocean. Hence, subduction-related geological processes play a key role in the growth of continental crust in the West Junggar.

6.3 Implications for crustal maturation and evolution of the oceanic arc

Granitic magmatism is considered to be the main driver of continental maturation and evolution (Kemp et al., 2007). In West Junggar, a significant number of dioritic to granitoid rocks clearly illustrate the production of continental crust in an oceanic arc setting. Since oceanic arc crust is primarily composed of basalt which originates from the mantle, this requires additional processes to transform juvenile basaltic intra-oceanic arc crust into mature continental crust.

As discussed in the Section 3, there are four main pulses of granitic magmatism. Although rocks from all pulses exhibit depleted mantle-like zircon Hf isotopic compositions and whole-rock Nd isotopic compositions, they display distinct whole-rock geochemical compositions and zircon $\delta^{18}\text{O}$ values (Chen and Arakawa, 2005; Geng et al., 2009; Tang et al., 2019 and this study; Table 1). These differences shed light on the temporal and spatial evolution of magma sources during crustal evolution. Firstly, the partial melting of subducting oceanic crust can generate granodioritic magma, promoting crustal maturation (e.g., Tatsumi, 1981; Kelemen, 1995). This mechanism was more common in the Archean due to the high geothermal gradient (Martin, 1999), but some modern geological processes, such as ridge subduction and young ocean subduction, can also induce partial melting of subducted oceanic crust in the Phanerozoic (Defant and Drummond, 1990; Thorkelson and Bretsprecher, 2005). Late Cambrian and Late Carboniferous adakitic rocks found in the West Junggar were formed in this way (Tang et al., 2010; Zhang et al., 2022). Secondly, remelting of basaltic arc crust can lead to crustal differentiation and

1 618 maturation (e.g., Jull and Kelemen, 2001; Hawkesworth and Kemp, 2006). The
2 619 intrusive rocks in the northern West Junggar and a few in the southern West Junggar
3
4 620 have depleted whole-rock Nd and zircon Hf isotopic compositions, as well as
5
6 621 mantle-like zircon oxygen isotopic compositions. However, as discussed in Section
7
8 622 6.1.2, they are geochemically subtly different from adakites and were more likely
9
10 623 formed through the partial melting of juvenile basaltic lower crust. Lastly, the
11
12 624 maturation of oceanic arc crust typically involves contributions from chemical
13
14 625 weathering residues and supracrustal rocks (Lee et al., 2008; Tang et al., 2019). Most
15
16 626 of the intrusive rocks in the southern West Junggar exhibit depleted mantle-like
17
18 627 Hf-Nd isotopic signatures, indicating minimal or no involvement of old continental
19
20 628 components, but their high zircon oxygen isotope values indicate that the late
21
22 629 Carboniferous to middle Permian crustal maturation of the Junggar ocean arc is
23
24 630 related to chemical weathering and crustal recycling. Hence, our results indicate that
25
26 631 the transformation of juvenile basaltic intra-oceanic arc crust into mature continental
27
28 632 crust in the West Junggar involves multiple processes, such as partial melting of
29
30 633 subducting oceanic crust, melting of juvenile basaltic lower crust, and melting of
31
32 634 supracrustal rocks. As described in Section 6.2, crustal growth in West Junggar, in the
33
34 635 sense of separation from mantle sources, mainly occurred between 670-456 Ma.
35
36

37 636 Despite this major period of crustal growth between 670 and 456 Ma,
38
39 637 significant “crustal maturation” also took place after this time, thus intra-oceanic
40
41 638 crustal growth and maturation is an episodic rather than continuous process. As
42
43 639 previously described, four periods of magmatic activity have been identified in the
44
45 640 West Junggar region: Early Cambrian to Early Ordovician (515 to 486 Ma); Late
46
47 641 Ordovician to Middle Devonian (445 to 392 Ma); Early Carboniferous to Late
48
49 642 Carboniferous (343 to 310 Ma) and Late Carboniferous to Middle Permian (309 to
50
51 643 259 Ma). The first phase of magmatic activity (i.e., Early Cambrian to Early
52
53 644 Ordovician), within the Paleo-Asian Oceanic arc system, followed subduction
54
55 645 initiation that most likely occurred during the Early Cambrian (>515 Ma) (Fig. 10a).
56
57 646 This early magmatic activity is evidenced by the SSZ-type ophiolites (516 Ma) and
58
59 647 the oldest arc plutons (515–509 Ma) intruding the ophiolites (Xu et al., 2012; Ren et
60
61
62
63
64
65

al., 2014; Zhang et al., 2022). During the subduction process, the differentiation of arc basalts and partial melting of the subducted oceanic crust and arc mafic crust led to the formation of the felsic continental crust (Zhang et al., 2022). Intrusive rocks of the third phase of magmatic activity (Early Carboniferous to Late Carboniferous) are predominantly exposed in the Sawur region of West Junggar. They are primarily composed of calc-alkaline volcanic rocks and I-type granitic intrusions, accompanied by a minor occurrence of gabbros and mafic volcanic rocks displaying arc-related geochemical characteristics (Fig. 10c; Chen et al., 2010b; Yin et al., 2015b). Therefore, magmatic activity and crustal evolution during this period are closely associated with the subduction processes in the oceanic arc.

The most extensive outcrop areas in West Junggar are associated with Late Ordovician to Middle Devonian and late Carboniferous to middle Permian periods of magmatic activity. Therefore, they are most closely linked to crustal maturation of West Junggar intra-oceanic arc crust. A-type granites from the latter period were formed under high-temperature conditions (up to 906°C) and low-pressure settings (Geng et al., 2009). Their coexistence with charnockites, adakites, MORB, OIB, Nb-enriched dikes and sanukitoid dikes also indicates high-temperature magmatism (Geng et al., 2009; Tang et al., 2010; 2012; Yin et al., 2010; 2013a; 2015a; Zhang et al., 2011). Similarly, the late Silurian to early Devonian A-type granites were also generated under high-temperature conditions (up to 940°C) and low-pressure settings (~1.0 GPa) (Yin et al., 2017) and are associated with adakites, mafic dikes, hornblende gabbro, basaltic andesite and andesite.

In both cases the inferred tectonic setting involves ocean ridge subduction (e.g., Geng et al., 2009; Tang et al., 2010; 2012; Yin et al., 2010; 2013a; 2015a; Yin et al., 2017; Zhang et al., 2011; 2021) which could have provided the heat energy for the maturation process(es). Significantly, the orogenic architecture of West Junggar aligns with the diagnostic features of sub-parallel trench-ridge interaction, analogous to those observed in modern California that include: double magmatic belts, a young oceanic crust separating a former accretionary complex from its associated magmatic arc (Fig. 10b; Fig. 10d; Zhang et al., 2021). In Japan, ridge subduction has occurred

approximately every 100 Myr over the last 450 Myr. West Junggar, as an important part of the CAOBS, could therefore have experienced multiple ridge subductions at a rate similar to Japan. In this scenario, with the opening of a slab window and the upwelling of asthenospheric mantle, the overriding mantle within the slab window would become hotter and less hydrated (Sisson et al., 2003; Thorkelson et al., 2011). Advected heat would promote extensive melting of the mafic lower crust, oceanic crust and supracrustal rocks, producing the observed granitoids and driving the compositional transformation from juvenile basaltic intra-oceanic arc crust to mature continental crust. Consequently, our results suggest that supracrustal recycling via intracrustal remelting, consequent upon ridge subduction and generation of a slab window, played a critical role in driving crustal maturation and evolution of the oceanic arc crust from basaltic to felsic.

Conclusions

- (1) Based on zircon U-Pb ages, the West Junggar intrusions can be grouped into four temporal pulses. The first occurred from the Early Cambrian to Early Ordovician (515-486 Ma) and is concentrated in the Mayile and Barleik Mountain regions of southern West Junggar. The second spans the Late Ordovician to Middle Devonian (445-392 Ma) and is primarily found in the Boshchekul-Chingiz arc of northern West Junggar, with a single granodioritic pluton dated at 444-439 Ma in the southern West Junggar. The third pulse, during the Early Carboniferous (343-321 Ma) and the Early to late Carboniferous (332-310 Ma), is predominantly observed in the Zharma-Sawur volcanic arc of northern West Junggar and in the Baotutu and Keramay of southern West Junggar, respectively. The fourth magmatic pulse in the Late Carboniferous to Middle Permian (307-259 Ma) is preserved throughout West Junggar, unrestricted by tectonic boundaries.
- (2) All the magmatic rocks in the Western Junggar exhibit similar whole-rock Nd isotope and zircon Hf isotope values, but have marked variations in zircon oxygen isotopes. Accordingly, they can be classified into high zircon $\delta^{18}\text{O}$ intrusions and

mantle-like zircon $\delta^{18}\text{O}$ intrusions. The high zircon $\delta^{18}\text{O}$ intrusions formed relatively late, during the 307-259 Ma episode, and require the involvement of supracrustal components. Modelling using binary mixing indicates that 10-50% supracrustal rocks mixed with juvenile basaltic lower crust. The intrusions with mantle-like zircon $\delta^{18}\text{O}$ have diverse magma sources. In northern West Junggar, they occur during different magmatic episodes and originate from a variety of processes including partial melting of metasomatized depleted mantle, mixing of depleted mantle with juvenile crust, partial melting of trapped juvenile oceanic crust, and partial melting of juvenile mafic lower crust. However, the dominant granitoid plutons in the northern West Junggar lack direct mantle input and are likely derived from juvenile basaltic lower crust. In southern West Junggar, the mantle-like zircon $\delta^{18}\text{O}$ intrusions occur less frequently but also exhibit a range of sources. These include partial melting of subducted oceanic crust with garnet $\pm$ amphibole as residual minerals, partial melting of depleted mantle and partial melting of arc basaltic lower crust.

(3) Hf model ages reveal three different episodes of crustal growth in the West Junggar. These episodes do not coincide with major magmatic pulses, at approximately 656-684 Ma, 524-536 Ma, and 441-471 Ma, which show distinct spatial and temporal variations. The subduction-related geological processes play a key role in the three-stage growth of continental crust in the West Junggar.

(4) The West Junggar region exhibits a complex process of crustal maturation in an oceanic arc setting. The transformation from juvenile basaltic intra-oceanic arc crust to mature continental crust is episodic and involves partial melting of subducting oceanic crust, melting of juvenile basaltic lower crust and melting of supracrustal rocks.

(5) Two of the episodes of magmatic activity, the late Ordovician to middle Devonian and the late Carboniferous to middle Permian, are closely linked to crustal maturation. Associated high-temperature magmatism during these periods, represented by A-type granites, adakites and other rock associations, suggests the influence of ocean ridge subduction. Ridge subduction, with the opening of a slab

window and the upwelling of asthenospheric mantle, may therefore promote extensive melting of the mafic lower crust, oceanic crust, and supracrustal rocks, driving the compositional transformation from basaltic to felsic continental crust.

Acknowledgments

We are grateful to Editor-in-Chief Yildirim Dilek and two anonymous reviewers for their constructive suggestions and comments that significantly improved the manuscript. We thank Yichao Chen, Yang Yu, Gaoxue Yang, Yaqi Yang and Zongying Huang for useful discussions on the geological problems of NW China. We also appreciate the assistance of Xiaoping Xia and Zexian Cui in the zircon O isotope analyses. This study was supported by the National Key Research and Development Project (Grant no. 2019YFA0708601), National Science Foundation of China (grant nos. 41888101, 4231101056 and 42127801), the China Geological Survey (Grant no. DD20230213), , the Opening Foundation of State Key Laboratory of Continental Dynamics, Northwest University (Grant no. 22LCD01). This is a contribution to IGCP 662.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

References

- An, F., Zhu Y.F., 2009. SHRIMP U–Pb zircon ages of tuff in Baogutu formation and their geological significances: *Acta Petrologica Sinica* 25, 1437–1445 (in Chinese with English abstract)
- Ao, S.J., Xiao, W.J., Han, C.M., Mao, Q.G., Wan, B., Zhang, J.E., Zhang, Z.Y., Song, D.F., Tan, X.B., 2022. Status and Prospect of Research on Ophiolites in the Southern Margin of the Central Asian Orogenic Belt. *Earth Science*, 47(9): 3107-3126 (in Chinese with English abstract)

- Behn, M.D., Kelemen, P.B., Hirth, G., Hacker, B.R., Massonne, H., 2011. Diapirs as the source of the sediment signature in arc lavas. *Nature Geoscience* 4, 641– 646
- Bindeman, I.N., Eiler, J.M., Yogodzinski, G.M., Tatsumi, Y., Stern, C.R., Grove, T.L., Portnyagin, M., Hoernle, K., Danyushevsky, L.V., 2005. Oxygen isotope evidence for slab melting in modern and ancient subduction zones. *Earth and Planetary Science Letters* 235, 480– 496
- Blichert-Toft, J., Chauvel, C. and Albarède, F., 1997. Separation of Hf and Lu for high-precision isotope analysis of rock samples by magnetic sector-multiple collector ICP-MS, *Contributions to Mineralogy and Petrology*, 127, 248–260.
- Buckman, S., Aitchison, J.C., 2004. Tectonic evolution of Paleozoic terranes in West Junggar, Xinjiang, NW China. In: Malpas, J., Fletcher, C.J.N., Aitchison, J.C. (Eds.), *Aspects of the Tectonic Evolution of China*. Special Publication, Geological Society of London, 101–129
- Cao, M.J., Qin, K.Z., Li, G.M., Evans, N.J., Hollings, P., Jin, L.Y., 2016. Genesis of ilmenite-series I-type granitoids at the Baogutu reduced porphyry Cu deposit, western Junggar, NW-China. *Lithos* 246–247, 13–30
- Cawood, P.A., Hawkesworth, C.J., Dhuime, B., 2013. The continental record and the generation of continental crust. *Geological Society of America Bulletin* 125, 14– 32
- Chen, B., and Arakawa, Y., 2005. Elemental and Nd-Sr isotopic geochemistry of granitoids from the West Junggar foldbelt (NW China), with implications for Phanerozoic continental growth. *Geochimica et Cosmochimica Acta* 69, 1307– 1320
- Chen, B., and Jahn, B.M., 2004. Genesis of post-collisional granitoids and basement nature of the Junggar Terrane, NW China: Nd-Sr isotope and trace element evidence. *Journal of Asian Earth Sciences* 23, 691–703
- Chen, J.F., Han, B.F., Ji, J.Q., Zhang, L., Xu, Z., He, G.Q., Wang, T., 2010a. Zircon U–Pb ages and tectonic implications of Paleozoic plutons in northern West Junggar, North Xinjiang, China. *Lithos* 115, 137–152
- Chen, J.F., Han, B.F., Zhang, L., 2010b. Geochemistry, Sr–Nd isotopes and tectonic

796 implications of two generations of Late Paleozoic plutons in northern West
 797 Junggar, Northwest China. *Acta Petrologica Sinica* 26 (8), 2317–2335 (in
 798 Chinese with English abstract)
 799 Chen, J.F., Han, B.F., Zhang, L., Xu, Z., Liu, J.L., Qu, W.J., Li, C., Yang, J.H., Yang,
 800 Y.H., 2015. Middle Paleozoic initial amalgamation and crustal growth in the
 801 West Junggar (NW China): constraints from geochronology, geochemistry and
 802 Sr–Nd–Hf–Os isotopes of calc-alkaline and alkaline intrusions in the Xiemisitai–
 803 Saier Mountains. *Journal of Asian Earth Sciences* 113, 90–109
 804 Chen, J.F., Ma, X., Simon, A., Du, H.Y., Han, B.F., Liu, J.L., Liu, B., 2019. Late
 805 Ordovician to early Silurian calc-alkaline magmatism in the Xiemisitai
 806 Mountains, northern West Junggar: a response to the subduction of the
 807 Junggar-Balkhash Ocean. *International Geology Review* 61, 2000–2020
 808 Chen, Y.C., Xiao, W.J., Windley, B.F., Zhang, J.E., Zhou, K.F., Sang, M., 2017.
 809 Structures and detrital zircon ages of the Devonian–Permian Tarbagatay
 810 accretionary complex in west Junggar, China: imbricated ocean plate stratigraphy
 811 and implications for amalgamation of the CAOBS. *International Geology Review*,
 812 59, 1097–1115.
 813 Choulet, F., Cluzel, D., Faure, M., Lin, W., Wang, B., Chen, Y., Wu, F.Y., and Ji, W.B.,
 814 2012. New constraints on the pre-Permian continental crust growth of Central
 815 Asia (West Junggar, China) by U–Pb and Hf isotopic data from detrital zircon.
 816 *Terra Nova* 24, 189–198
 817 Chung, S.L., Liu, D.Y., Ji, J.Q., Chu, M.F., Lee, H.Y., Wen, D.J., Lo, C.H., Lee, T.Y.,
 818 Qian, Q., Zhang, Q., 2003. Adakites from continental collision zones: Melting of
 819 thickened lower crust beneath southern Tibet. *Geology* 31, 1021–1024
 820 Clift, P.D., Vannucchi, P., Morgan, J.P., 2009. Crustal redistribution, crust–mantle
 821 recycling and Phanerozoic evolution of the continental crust. *Earth Science*
 822 *Reviews* 97, 80–104
 823 Crawford, W.C., Hildebrand, J.A., Dorman, L.M., Webb, S.C., Wiens, D.A., 2003.
 824 Tonga ridge and Lau Basin crustal structure from seismic refraction data. *Journal*
 825 *of Geophysical Research* 108 (B4), 2195

Currie, C.A., Beaumont, C., Huisman, R.S., 2007. The fate of subducted sediments: a case for backarc intrusion and underplating. *Geology* 35, 1111–1114

Defant, M.J., Drummond, M.S., 1990. Derivation of some modern arc magmas by melting of young subducted lithosphere. *Nature* 347, 662–665

Dhuime, B., Hawkesworth, C.J., Cawood, P.A., Storey, C.D., 2012. A Change in the Geodynamics of Continental Growth 3 Billion Years Ago. *Science* 335, 1334–1336

Fisher, C.M., et al., 2014, Guidelines for reporting zircon Hf isotopic data by LA-MC-ICPMS and potential pitfalls in the interpretation of these data, *Chemical Geology*, 363, 125–133.

Gao, R., Xiao, L., Pirajno, F., Wang, G.C., He, X.X., Yang, G., Yan, S.W., 2014. Carboniferous–Permian extensive magmatism in the West Junggar, Xinjiang, northwestern China: its geochemistry, geochronology, and petrogenesis. *Lithos* 204, 125–143

Geng, H.Y., Sun, M., Yuan, C., Xiao, W.J., Zhao, G.C., Zhang, L.F., Wong, K., and Wu, F.Y., 2009, Geochemical, Sr-Nd and zircon U-Pb-Hf isotopic studies of Late Carboniferous magmatism in the West Junggar, Xinjiang: Implications for ridge subduction? *Chemical Geology* 266, 364–389

Geng, H.Y., Sun, M., Yuan, C., Zhao, G.C., Xiao, W.J., 2011. Geochemical and geochronological study of early Carboniferous volcanic rocks from the West Junggar: Petrogenesis and tectonic implications. *Journal of Asian Earth Sciences* 42, 854–866

Hacker, B.R., Kelemen, P.B., Behn, M.D., 2011. Differentiation of the continental crust by relamination. *Earth and Planetary Science Letters* 307, 501–516

Han, B.F., He, G.Q., Wang, S.G., 1999. Postcollisional mantle-derived magmatism, underplating and implications for basement of the Junggar Basin. *Science in China. Series D, Earth Sciences* 42, 113–119

Han, B.F., Ji, J.Q., Song, B., Chen, L.H., Zhang, L., 2006. Late Paleozoic vertical growth of continental crust around the Junggar Basin, Xinjiang, China (Part I): timing of postcollisional plutonism. *Acta Petrologica Sinica* 22, 1077–1086 (in

Chinese with English abstract)

Hawkesworth, C.J., Dhuime, B., Pietranik, A.B., Cawood, P.A., Kemp, A.I.S., Storey, C.D., 2010. The generation and evolution of the continental crust. *Journal of the Geological Society, London* 167, 229–248

Hawkesworth, C.J., Kemp, A.I.S. 2006. Evolution of the continental crust. *Nature* 443, 811–817

Holbrook, W.S., Lizarralde, D., McGeary, S., Bangs, N., Diebold, J., 1999. Structure and composition of the Aleutian island arc and implications for continental crustal growth. *Geology* 27, 31–34

Hopkinson, T.N., Harris, N.B.W., Warren, C.J., Spencer, C.J., Roberts, N.M.W., Horstwood, M.S.A., Parrish, R.R., and EIMF, 2017. The identification and significance of pure sediment-derived granites. *Earth and Planetary Science Letters* 467, 57–63

Hu, Z.C., Liu, Y.S., Gao, S., Liu, W., Yang, L., Zhang, W., Tong, X., Lin, L., Zong, K.Q., Li, M., Chen, H. and Zhou, L., 2012. Improved in situ Hf isotope ratio analysis of zircon using newly designed X skimmer cone and Jet sample cone in combination with the addition of nitrogen by laser ablation multiple collector ICP-MS, *Journal of Analytical Atomic Spectrometry*, 27, 1391–1399.

Hu, Z.C., Zhang, W., Liu, Y.S., Gao, S., Li, M., Zong, K.Q., Chen, H.H. and Hu, S.H., 2015. “Wave” Signal-Smoothing and Mercury-Removing Device for Laser Ablation Quadrupole and Multiple Collector ICPMS Analysis: Application to Lead Isotope Analysis. *Analytical Chemistry*, 87(2), 1152–1157.

Jahn, B.M., Windley, B., Natal'in, B., Dobretsov, N., 2004. Phanerozoic continental growth in Central Asia. *Journal of Asian Earth Sciences* 23, 599–603.

Jahn, B.M., Wu, F.Y., Chen, B., 2000. Granitoids of the Central Asian Orogenic Belt and continental growth in the Phanerozoic. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh* 91, 181–193

Jull, M., Kelemen, P.B., 2001. On the conditions for lower crustal convective instability. *Journal of Geophysical Research: Solid Earth* 106, 6423–6446

Kay, R.W., Kay, S.M., 1993. Delamination and delamination magmatism.

886 Tectonophysics 219, 177–189

887 Kelemen, P.B., 1995. Genesis of high Mg andesites and the continental crust.
888 Contributions to Mineralogy and Petrology 120, 1–19

889 Kelemen, P.B., Behn, M.D., 2016. Formation of lower continental crust by
890 relamination of buoyant arc lavas and plutons. Nature Geoscience 9, 197–205

891 Kemp, A.I., Hawkesworth, C.J., Paterson, B.A., and Kinny, P.D., 2006. Episodic
892 growth of the Gondwana supercontinent from hafnium and oxygen isotopes in
893 zircon. Nature 439, 580–583

894 Kemp, A.I.S., Hawkesworth, C.J., Foster, G.L., Paterson, B.A., Woodhead, J.D., Hergt,
895 J.M., Gray, C.M., and Whitehouse, M.J., 2007. Magmatic and crustal
896 differentiation history of granitic rocks from Hf-O isotopes in zircon. Science
897 315, 980–983

898 Kita, N.T., Ushikubo, T., Fu, B.X., Valley, J.W., 2009. High precision SIMS oxygen
899 isotope analyses and the effect of sample topography. Chemical Geology 264,
900 43–57.

901 Kopp, H., Weinzierl, W., Becel, A., Charvis, P., Evain, M., Flueh, E.R., Gailler, A.,
902 Galve, A., Hirn, A., Kandilarov, A., Klaeschen, D., Laigle, M., Papenberg, C.,
903 Planert, L., Roux, E., Trail, T., Thales, T., 2011. Deep structure of the central
904 lesser Antilles island arc: relevance for the formation of continental crust. Earth
905 and Planetary Science Letters 304, 121–134

906 Kröner, A., Kovach, V., Alexeiev, D., Wang, K.-L., Wong, J., Degtyarev, K., Kozakov,
907 I., 2017. No excessive crustal growth in the Central Asian Orogenic Belt: further
908 evidence from field relationships and isotopic data. Gondwana Research 50,
909 135–166

910 Kröner, A., Kovach, V., Belousova, E., Hegner, E., Armstrong, R., Dolgoplova, A.,
911 Seltmann, R., Alexeiev, D.V., Hoffmann, J.E., Wong, J., Sun, M., Cai, K., Wang,
912 T., Tong, Y., Wilde, S.A., Degtyarev, K.E., Rytsk, E., 2014. Reassessment of
913 continental growth during the accretionary history of the Central Asian Orogenic
914 Belt. Gondwana Research 25, 103–125

915 Lee, C.T.A., Morton, D.M., Little, M.G., Kistler, R., Horodyskyj, U.N., Leeman, W.P.,

- 1 916 Agranier, A., 2008. Regulating continent growth and composition by chemical
2 weathering. *Proceedings of the National Academy of Sciences of the United*
3
4 918 *States of America* 105, 4981–4986
5
6 919 Li, X.H., Li, W.X., Li, Q.L., Wang, X.C., Liu, Y., Yang, Y.H., 2010a. Petrogenesis and
7
8 920 tectonic significance of the ~850 Ma Gangbian alkaline complex in South China:
9
10 921 Evidence from in situ zircon U-Pb dating, Hf-O isotopes and whole-rock
11
12 922 geochemistry. *Lithos* 114, 1–15
13
14 923 Li, X.H., Long, W.G., Li, Q.L., Liu, Y., Zheng, Y.F., Yang, Y.H., Chamberlain, K.R.,
15
16 924 Wan, D.F., Guo, C.H., Wang, X.C., Tao, H., 2010b. Penglai Zircon Megacrysts:
17
18 925 A Potential New Working Reference Material for Microbeam Determination of
19
20 926 Hf-O Isotopes and U-Pb Age. *Geostandards and Geoanalytical Research* 34,
21
22 927 117–134.
23
24 928 Li, X.H., Tang, G.Q., Gong, B., Yang, Y.H., Hou, K.J., Hu, Z.C., Li, Q.L., Liu, Y., Li,
25
26 929 W.X., 2013. Qinghu zircon: A working reference for microbeam analysis of U-Pb
27
28 930 age and Hf and O isotopes. *Chinese Science Bulletin* 58, 4647–4654
29
30 931 Liu, B., Han, B.F., Xu, Z., Ren, R., Zhang, J.R., Zhou, J., Su, L., and Li, Q.L., 2016.
31
32 932 The Cambrian initiation of intraoceanic subduction in the southern Paleo-Asian
33
34 933 Ocean: Further evidence from the Barleik subduction-related metamorphic
35
36 934 complex in the West Junggar region, NW China. *Journal of Asian Earth Sciences*
37
38 935 123, 1–21
39
40 936 Liu, X.M., Rudnick, R.L., 2011. Constraints on continental crustal mass loss via
41
42 937 chemical weathering using lithium and its isotopes. *Proceedings of the National*
43
44 938 *Academy of Sciences of the United States of America* 108, 20873–20880
45
46 939 Liu, Y.S., Gao, S., Hu, Z.C., Gao, C.G., Zong, K.Q. and Wang, D.B., 2010.
47
48 940 Continental and oceanic crust recycling-induced melt-peridotite interactions in
49
50 941 the Trans-North China Orogen: U-Pb dating, Hf isotopes and trace elements in
51
52 942 zircons of mantle xenoliths. *Journal of Petrology*, 51(1–2): 537–571.
53
54 943 Martin, H., 1999. The adakitic magmas: modern analogues of Archaean granitoids.
55
56 944 *Lithos* 46, 411–429
57
58 945 Martin, H., Smithies, R.H., Rapp, R., Moyen, J.F., Champion, D., 2005. An overview
59
60
61
62
63
64
65

946 of adakite, tonalite-trondhjemite-granodiorite (TTG), and sanukitoid:
 947 relationships and some implications for crustal evolution. *Lithos* 79, 1–24
 948 Percy, L.G., Debari, S.M., Sleep, N.H., 1990. Mass balance calculations for two
 949 sections of island arc crust and implications for the formation of continents. *Earth*
 950 *and Planetary Science Letters* 96, 427–442
 951 Rapp, R.P., Shimizu, N., Norman, M.D., and Applegate, G.S., 1999. Reaction between
 952 slab-derived melts and peridotite in the mantle wedge: Experimental constraints
 953 at 3.8 GPa. *Chemical Geology* 160, 3335–3356
 954 Rapp, R.P., Watson, E.B., 1995. Dehydration Melting of Metabasalt at 8–32 kbar:
 955 Implications for Continental Growth and Crust-Mantle Recycling. *Journal of*
 956 *Petrology* 36, 891–931
 957 Ren, R., Han, B.F., Xu, Z., Zhou, Y.Z., Liu, B., Zhang, L., Chen, J.F., Su, L., Li, J., Li,
 958 X.H., and Li, Q.L., 2014. When did the subduction first initiate in the southern
 959 Paleo-Asian Ocean: New constraints from a Cambrian intra-oceanic arc system
 960 in West Junggar, NW China. *Earth and Planetary Science Letters* 388, 222–236
 961 Rudnick, R.L., 1995. Making continental crust. *Nature* 378, 573–578
 962 Safonova, I., Kotlyarov, A., Krivonogov, S., Xiao, W.J., 2017. Intra-oceanic arcs of
 963 the Paleo-Asian Ocean. *Gondwana Research* 50, 167–194
 964 Saito, S., Tani, K., Transformation of juvenile Izu–Bonin–Mariana oceanic arc into
 965 mature continental crust: An example from the Neogene Izu collision zone
 966 granitoid plutons, Central Japan. *Lithos* 277, 228–240
 967 Şengör, A.M.C., Natal'in, B.A., Burtman, U.S., 1993. Evolution of the Altaid tectonic
 968 collage and Paleozoic crustal growth in Eurasia. *Nature* 364, 209–304.
 969 Scholl, D.W., von Huene, R., 2007. Crustal recycling at modern subduction zones
 970 applied to the past—issues of growth and preservation of continental basement
 971 crust, mantle geochemistry, and supercontinent reconstruction. *Geological*
 972 *Society of America Memoir* 200, 9–32
 973 Scholl, D.W., von Huene, R., 2009. Implications of estimated magmatic additions and
 974 recycling losses at the subduction zones of accretionary (non-collisional) and
 975 collisional (suturing) orogens. *Geological Society, London, Special Publications*

- 976 318, 105–125
- 977 Shen P., Pan, H.D., Xiao, W.J., Li, X.H., Dai, H.W., Zhu, H.P., 2013. Early
978 Carboniferous intra-oceanic arc and back-arc basin system in the West Junggar,
979 NW China. *International Geology Review* 55, 1991–2007
- 980 Shen, P., Shen, Y.C., Li, X.H., Pan, H.D., Zhu, H.P., Meng, L., Dai, H.W., 2012.
981 Northwestern Junggar Basin, Xiemisitai Mountains, China: a geochemical and
982 geochronological approach. *Lithos* 140, 103–118
- 983 Sláma, J., Košler, J., Condon, D.J., Crowley, J.L., Gerdes, A., Hanchar, J.M.,
984 Horstwood, M.S.A., Morris, G.A., Nasdala, L., Norberg, N., Schaltegger,
985 U., Schoene, B., Tubrett, M.M., Whitehouse, M.J., 2008. Plešovice zircon
986 -A new natural reference material for U–Pb and Hf isotopic microanalysis.
987 *Chemical Geology* 249, 1–35.
- 988 Sisson, V.B., Pavlis, T.L., Roeske, S.M., Thorkelson, D.J., 2003. An overview of
989 ridge-trench interaction in modern and ancient settings. In: Sisson, V.B., Roeske,
990 S.M., Pavlis, T.L. (Eds.), *Geology of a Transpressional Orogen Developed during*
991 *Ridge-Trench Interaction along the North Pacific Margin*. The Geological
992 Society of America, Colorado, pp. 1–18
- 993 Spencer, C.J., Roberts, N.M.W., Santosh, M., 2017. Growth, destruction, and
994 preservation of Earth's continental crust. *Earth Science Reviews* 172, 87–106
- 995 Stern, R.J., 2010. The anatomy and ontogeny of modern intra-oceanic arc systems.
996 Geological Society, London, Special Publications 338, 7–34
- 997 Takahashi, N., Kodaira, S., Tatsumi, Y., Kaneda, Y., Suyehiro, K., 2008. Structure and
998 growth of the Izu-Bonin-Mariana arc crust: 1. Seismic constraint on crust and
999 mantle structure of the Mariana arc–back-arc system. *Journal of Geophysical*
1000 *Research* 113, B01104
- 1001 Tang, G.J., Wang, Q., Wyman, D.A., Li, Z.X., Xu, Y.G., Zhao, Z.H., 2012. Recycling
1002 oceanic crust for continental crustal growth: Sr–Nd–Hf isotope evidence from
1003 granitoids in the western Junggar region, NW China. *Lithos* 128–131, 73–83
- 1004 Tang, G.J., Wang, Q., Wyman, D.A., Li, Z.X., Zhao, Z.H., Jia, X.H., Jiang, Z.Q., 2010.
1005 Ridge subduction and crustal growth in the Central Asian Orogenic Belt:

1 1006 evidence from Late Carboniferous adakites and high-Mg diorites in the western
2 1007 Junggar region, northern Xinjiang (west China). *Chemical Geology* 277, 281–
3
4 1008 300
5
6 1009 Tang, G.J., Wang, Q., Wyman, D.A., Li, Z.X., Zhao, Z.H., Jia, X.H., and Jiang, Z.Q.,
7
8 1010 2010. Ridge subduction and crustal growth in the Central Asian Orogenic Belt:
9
10 1011 Evidence from Late Carboniferous adakites and high-Mg diorites in the western
11
12 1012 Junggar region, northern Xinjiang (west China). *Chemical Geology* 277, 281–
13
14 1013 300
15
16 1014 Tang, G.J., Wang, Q., Wyman, D.K., and Dan, W., 2019. Crustal maturation through
17
18 1015 chemical weathering and crustal recycling revealed by Hf-O-B isotopes. *Earth*
19
20 1016 and Planetary Science Letters 524, 115709
21
22 1017 Tao, Z.L., Yin, J.Y., Chen, W., Chen, Y.L., Sun, J.B., Xu, Z.H., 2022. Zircon U-Pb
23
24 1018 Ages and Tectonic Implications of Late Paleozoic Volcanic Rocks in the Western
25
26 1019 Tianshan, North Xinjiang, China. *Journal of Earth Science*, 33(3): 736–752
27
28 1020 Tatsumi and Kogiso, 2003. The subduction factory: its role in the evolution of the
29
30 1021 Earth's crust and mantle. Geological Society, London, Special Publications 219,
31
32 1022 55–80
33
34 1023 Tatsumi, Y., 1981. Melting experiments on a high-magnesian andesite. *Earth and*
35
36 1024 Planetary Science Letters 54, 357–365
37
38 1025 Tatsumi, Y., 2005. The subduction factory; how it operates in the evolving Earth. *GSA*
39
40 1026 Today 15, 4–10
41
42 1027 Thorkelson, D.J., Bretsprecher, K., 2005. Partial melting of slab window margins:
43
44 1028 genesis of adakitic and non-adakitic magmas. *Lithos* 79, 25–41
45
46 1029 Thorkelson, D.J., Madsen, J.K., Sluggett, C.L., 2011. Mantle flow through the
47
48 1030 Northern Cordilleran slab window revealed by volcanic geochemistry. *Geology*
49
50 1031 39, 267–270
51
52 1032 Valley, J.W., 2003. Oxygen isotopes in zircon. *Reviews in Mineralogy and*
53
54 1033 Geochemistry 53, 343–385
55
56 1034 Valley, J.W., Kinny, P.D., Schulze, D.J., Spicuzza, M.J., 1998. Zircon megacrysts from
57
58 1035 kimberlite: oxygen isotope variability among mantle melts. *Contributions to*
59
60
61
62
63
64
65

- 1036 Mineralogy and Petrology 133, 1–11
- 1037 Valley, J.W., Lackey, J.S., Cavosie, A.J., Clechenko, C.C., Spicuzza, M.J., Basei,
1038 M.A.S., Bindeman, I.N., Ferreira, V.P., Sial, A.N., King, E.M., Peck, W.H., Sinha,
1039 A.K., Wei, C.S., 2005. 4.4 billion years of crustal maturation: oxygen isotope
1040 ratios of magmatic zircon. Contributions to Mineralogy and Petrology 150, 561–
1041 580
- 1042 Wang, T., Jahn, B.M., Kovach, V.P., Tong, Y., Hong, D.W., Han, B.F., 2009. Nd–Sr
1043 isotopic mapping of the Chinese Altai and implications for continental growth in
1044 the Central Asian Orogenic Belt. Lithos 110, 359–372.
- 1045 Wang, T., Tong, Y., Huang, H., Zhang, H., Guo, L., Li, Z., Wang, X., Eglington, B., Li,
1046 S., Zhang, J., Donskaya, T.V., Petrov, O., Zhang, L., Song, P., Zhang, X.W., Wang,
1047 C.Y., 2023a. Granitic record of the assembly of the Asian continent.
1048 Earth-Science Reviews 237, 104298.
- 1049 Wang, T., Huang, H., Zhang, J., Wang, C.Y., Cao, G.Y., Xiao, W.J., Yang, Q.Q., Bao,
1050 X.W., 2023b. Voluminous continental growth of the Altaids and its control on
1051 metallogeny. National Science Review 10, nwac283.
- 1052 Windley, B.F., Alexeiev, D., Xiao, W., Kröner, A., Badarch, G., 2007. Tectonic models
1053 for accretion of the Central Asian Orogenic belt. Journal of the Geological
1054 Society 164, 31–47
- 1055 Woodhead, J., Hergt, J., Shelley, M., Eggins, S. and Kemp, R., 2004. Zircon
1056 Hf-isotope analysis with an excimer laser, depth profiling, ablation of complex
1057 geometries, and concomitant age estimation. Chemical Geology, 209(1-2):
1058 121-135.
- 1059 Xiao, W., Han, C., Yuan, C., Sun, M., Lin, S., Chen, H., Li, Z., Li, J., Sun, S., 2008.
1060 Middle Cambrian to Permian subduction-related accretionary orogenesis of
1061 Northern Xinjiang, NW China: implications for the tectonic evolution of central
1062 Asia. Journal of Asian Earth Sciences 32, 102–11
- 1063 Xiao, W.J., Windley, B.F., Sun, S., Li, J.L., Huang, B.C., Han, C.M., Yuan, C., Sun,
1064 M., Chen, H.L., 2015. A tale of amalgamation of three collage systems in the
1065 PermianMiddle Triassic in Central Asia: oroclinal sutures and terminal accretion.

- 1066 Annual Review of Earth and Planetary Sciences 43, 477–507
- 1067 Xiao, W.J., Windley, B.F., Yuan, C., Sun, M., Han, C.M., Lin, S.F., Chen, H.L., Yan,
1068 Q.R., Liu, D.Y., Qin, K.Z., Li, J.L., Sun, S., 2009. Paleozoic multiple
1069 subduction-accretion processes of the southern Altaids. American Journal of
1070 Science 309, 221–270
- 1071 Xu, Z., Han, B.F., Ren, R., Zhou, Y.Z., and Su, L., 2013. Palaeozoic multiphase
1072 magmatism at Barleik Mountain, southern West Junggar, Northwest China:
1073 Implications for tectonic evolution of the West Junggar. International Geology
1074 Review 55, 633–656
- 1075 Xu, Z., Han, B.F., Ren, R., Zhou, Y.Z., Zhang, L., Chen, J.F., Su, L., Li, X.H., and Liu,
1076 D.Y., 2012. Ultramafic–mafic mélange, island arc and post-collisional intrusions
1077 in the Mayile Mountain, West Junggar, China: Implications for Paleozoic
1078 intra-oceanic subduction–accretion process. Lithos 132, 141–161
- 1079 Yang, G.X., Li, Y.J., Santosh, M., Yang, B.K., Zhang, B., Tong, L.L., 2013.
1080 Geochronology and geochemistry of basalts from the Karamay ophiolitic
1081 mélange in West Junggar (NW China): Implications for Devonian–Carboniferous
1082 intraoceanic accretionary tectonics of the southern Altaids. Geological Society of
1083 America Bulletin 125, 401–419
- 1084 Yang, G.X., Li, Y.J., Tong, L.L., Wang, Z.P., Duan, F.H., Xu, Q., Li, H., 2019. An
1085 overview of oceanic island basalts in accretionary complexes and seamounts
1086 accretion in the western Central Asian Orogenic Belt. Journal of Asian Earth
1087 Sciences 179, 385–398
- 1088 Yang, G.X., Li, Y.J., Xiao, W.J., Sun, Y., Tong, L.L., 2014. Petrogenesis and tectonic
1089 implications of the middle Silurian volcanic rocks in northern West Junggar, NW
1090 China. International Geology Review 56, 869–884
- 1091 Yang, G.X., Li, Y.J., Xiao, W.J., Tong, L.L., 2015. OIB-type rocks within West
1092 Junggar ophiolitic mélanges: evidence for the accretion of seamounts. Earth
1093 Science Review 150, 477–496
- 1094 Yang, Q., Xia, X.P., Zhang, W.F., Zhang, Y.Q., Xiong, B.Q., Xu, Y.G., Wang, Q., Wei,
1095 G.J., 2018. An evaluation of precision and accuracy of SIMS oxygen isotope

- 1096 analysis. *Solid Earth Sciences* 3, 81–86
- 1097 Yin, J.Y., Chen, W., Xiao, W.J., Yuan, C., Sun, M., and Cai, K.D., 2018. Petrogenesis
- 1098 and tectonic implications of early Devonian mafic dike-granite association in the
- 1099 northern West Junggar, NW China: *International Geology Review* 60, 87–100
- 1100 Yin, J.Y., Chen, W., Xiao, W.J., Yuan, C., Sun, M., Tang, G.J., Yu, S., Long, X.P., Cai,
- 1101 K.D., Geng, H.Y., Zhang, Y., Liu, X.Y., 2015a. Petrogenesis of Early–Permian
- 1102 sanukitoids from West Junggar, Northwest China: implications for Late Paleozoic
- 1103 crustal growth in Central Asia. *Tectonophysics* 662, 385–397
- 1104 Yin, J.Y., Chen, W., Xiao, W.J., Yuan, C., Windley, B.F., Yu, S., and Cai, K.D., 2017,
- 1105 Late Silurian-early Devonian adakitic granodiorite, A-type and I-type granites in
- 1106 NW Junggar, NW China: Partial melting of mafic lower crust and implications
- 1107 for slab roll-back: *Gondwana Research* 43, 55–73
- 1108 Yin, J.Y., Chen, W., Yuan, C., Yu, S., Xiao, W.J., Long, X.P., Li, J., Sun, J.B., 2015b.
- 1109 Petrogenesis of Early Carboniferous adakitic dikes, Sawur region, northern West
- 1110 Junggar, NW China: implications for geodynamic evolution. *Gondwana Research*
- 1111 27, 1630–1645
- 1112 Yin, J.Y., Chen, Y., Yuan, C., Zhang, Y.Y., Long, X.P., Yu, S., Zhang, Y., Li, J., Sun,
- 1113 J.B., 2013b. Ages and tectonic implication of Late Paleozoic plutons in the West
- 1114 Junggar, North Xinjiang: evidence from LA-ICPMS zircon geochronology.
- 1115 *Geochimica* 42 (5), 415–430 (in Chinese with English abstract)
- 1116 Yin, J.Y., Chen, Y., Yuan, C., Zhang, Y.Y., Long, X.P., Yu, S., Zhang, Y., Li, J., Sun,
- 1117 J.B., 2013b. Ages and tectonic implication of Late Paleozoic plutons in the West
- 1118 Junggar, North Xinjiang: evidence from LA-ICPMS zircon geochronology.
- 1119 *Geochimica* 42 (5), 415–430 (in Chinese with English abstract).
- 1120 Yin, J.Y., Long, X.P., Yuan, C., Sun, M., Zhao, G.C., Geng, H.Y., 2013a. A Late
- 1121 Carboniferous slab window: geochronological and geochemical evidence from
- 1122 mafic to intermediate dykes in West Junggar, NW China. *Lithos* 175–176, 146–
- 1123 162
- 1124 Yin, J.Y., Xiao, W.J., Christopher J. Spencer., Sun, M., Chen, W., Huang, H.Q., Yuan,
- 1125 Chao, Zhang, Y.Y., Tao, Z.L., Huang, H., Xia, X.P., 2021. The role and

- 1126 significance of juvenile sediments in the formation of A-type granites, West
- 1127 Junggar oceanic arc (NW China): zircon Hf-O isotopic perspectives. Geological
- 1128 Society of America Bulletin 133, 1560–1574.
- 1129 Yin, J.Y., Yuan, C., Sun, M., Long, X.P., Zhao, G.C., Geng, H.Y., 2010. Late
- 1130 Carboniferous highMg dioritic dykes in Western Junggar, NW China:
- 1131 geochemical features, petrogenesis and tectonic implications. Gondwana
- 1132 Research 17, 145–152
- 1133 Zhang, C., Huang, X., Zhai, M.G., 1995. The geological characteristics, tectonic
- 1134 settings and ages of ophiolite in Western Junggar, Xinjiang. Collected Papers of
- 1135 Institute of Geology. Chinese Academy of Sciences, Beijing 8, 165–218 (in
- 1136 Chinese)
- 1137 Zhang, J.E., Chen, Y.C., Xiao, W.J., Wakabayashi, J., Windley, B.F., Yin, J.Y., 2021.
- 1138 Sub-parallel ridge-trench interaction and an alternative model for the
- 1139 Silurian-Devonian archipelago in Western Junggar and North-Central Tianshan in
- 1140 NW China. Earth-Science Reviews 217, 103648
- 1141 Zhang, J.E., Xiao, W.J., Han, C.M., Mao, Q.G., Ao, S.J., Guo, Q.Q., Ma, C., 2011. A
- 1142 Devonian to Carboniferous intra-oceanic subduction system in Western Junggar,
- 1143 NW China. Lithos 125, 592–606
- 1144 Zhang, W., Hu, Z.C., 2020. Estimation of Isotopic Reference Values for Pure
- 1145 Materials and Geological Reference Materials. Atomic Spectroscopy,
- 1146 41(3):93-102.
- 1147 Zhang, Y.Y., Guo, Z.J., 2010. New constraints on formation ages of ophiolites in
- 1148 northern Junggar and comparative study on their connection. Acta Petrologica
- 1149 Sinica 26, 421–430 (in Chinese with English abstract)
- 1150 Zhang, Y.Y., Sun, M., Yin, J.Y., Yuan, C., Sun, Z., Xia, X.P., 2022. Subduction
- 1151 initiation of the western Paleo-Asian Ocean linked to global tectonic
- 1152 reorganization: Insights from Cambrian island-arc magmatism within the West
- 1153 Junggar, NW China. Geological Society of America Bulletin 134, 3099–3112
- 1154 Zhao, L., He, G.Q., 2013. Tectonic entities connection between West Junggar (NW
- 1155 China) and East Kazakhstan. Journal of Asian Earth Sciences 72, 25–32.

- 1 1156 Zhao, L., He, G.Q., 2014. Geochronology and geochemistry of the Cambrian (518 Ma)
2
3 1157 Chagantaolegai ophiolite in northern West Junggar (NW China): constraints on
4
5 1158 spatiotemporal characteristics of the Chingiz-Tarbagatai megazone. International
6
7 1159 Geology Review 56, 1181–1196
8
9 1160 Zhao, L., He, G.Q., Zhu, Y.B., 2013. Discovery and its tectonic significance of the
10
11 1161 ophiolite in the south of Xiemisitai Mountain, West Junggar, Xinjiang.
12
13 1162 Geological Bulletin of China 32, 195–205 (in Chinese with English abstract).
14
15 1163 Zheng, B., Han, F.B., Wang, Z.Z., Liu, B., Feng, L.X., 2020. An example of
16
17 1164 Phanerozoic continental crustal growth: The West Junggar Orogenic Belt,
18
19 1165 Northwest China. Lithos 376–377, 105745
20
21 1166 Zhou, T.F., Yuan, F., Fan, Y., Zhang, D.Y., Cooke, D., Zhao, G.C., 2008. Granites in
22
23 1167 the Sawuer region of the west Junggar, Xinjiang Province, China:
24
25 1168 geochronological and geochemical characteristics and their geodynamic
26
27 1169 significance. Lithos 106, 191–206
28
29 1170 Zhu, Y.F., Xu, X., 2006. The discovery of Early Ordovician ophiolite mélangé in
30
31 1171 Taerbahatai Mts., Xinjiang, NW China. Acta Petrologica Sinica 22, 2833–2842
32
33 1172 (in Chinese with English abstract).
34
35
36 1173
37
38
39 1174

1174 **Figure captions**

1175 Fig. 1. (a) Simplified tectonic divisions of the Central Asian Orogenic Belt (after Jahn
1176 et al., 2000); (b) Geological map of the West Junggar region (modified after Yin et al.,
1177 2017). The zircon U-Pb ages, Hf-O isotope data, and other detailed information can
1178 be listed in Table S1.

1179
1180 Fig. 2 Statistics of the zircon ages for the the Paleozoic intrusions in the West Junggar
1181 oceanic arc. Zircon U-Pb ages are listed in Table S1.

1182
1183 Fig.3 Correlation plots between zircon U-Pb age and Hf–O isotopic data for the the
1184 Paleozoic intrusions in the West Junggar oceanic arc. Zircon U-Pb age and Hf-O

isotopic data are listed in Table S2.

Fig.4 Correlation plots between zircon U-Pb ages and Hf model ages (T_{2DM}) for the the Paleozoic intrusions in the West Junggar oceanic arc. Zircon U-Pb age and Hf model age are listed in Table S2.

Fig.5 Histogram of zircon Hf model ages for the the Paleozoic intrusions in the West Junggar oceanic arc. Zircon Hf model ages are given in Table S2.

Fig.6 Histogram of zircon O isotopic data for the the Paleozoic intrusions in the West Junggar oceanic arc. Zircon O isotopic data is given in Table S2.

Fig.7 (a) Zircon O isotope contour map showing the spatial variation of $\delta^{18}O_{zm}$ values for the Paleozoic intrusions in the West Junggar oceanic arc; (b) Hf isotope contour map showing the spatial variation of T_{DM2} for the Paleozoic intrusions in the West Junggar oceanic arc. Zircon Hf-O isotopic data is given in Table 1.

Fig.8 $\delta^{18}O_{zm}-\epsilon Hf(t)$ diagram for the Paleozoic intrusions in the West Junggar oceanic arc. Zircon Hf-O isotopic data is given in Table S2. We assume that $\epsilon Hf(t)$ and oxygen isotope values of juvenile weathered sediment and lower crust are +10 and 16‰ and +16 and 5.3‰ respectively. Hf_{JS}/Hf_{LC} is the ratio of Hf concentration in the juvenile weathered sediment over parental lower crust indicated for each mixing curves, and the small ticks on the curves represent 10% mixing increments by assuming the juvenile lower crust and the juvenile weathered sediment. The field of mantle-derived zircon (Valley, 2003) is shown for comparison. The model calculations were carried out and obtain the 10-50% of sediment addition. The results show that sediments play an important role in the formation of high $\delta^{18}O_{zm}$ intrusions.

Fig.9 Histogram of ages for magmatic zircons from the West Junggar oceanic arc compared with the probability distribution of Hf model ages for zircons with $\delta^{18}O_{zm} <$

6.5%. Zircon U-Pb and Hf model ages are listed in Table S1 and Table S2, respectively.

Fig.10 Tectonic evolution of the Paleozoic multi-arc subduction–accretion system in the West Junggar, NW China (Modified after Xu et al., 2012; Yin et al., 2015; Chen et al., 2017; Zhang et al., 2021). (a) Early Cambrian-early Ordovician subduction accretionary system in the southern West Junggar; (b) Early Silurian-Middle Devonian formation of a slab window in the Boshkuekul-Chingiz arc due to a spreading ridge subduction; (c) Early Carboniferous multi-arc subduction–accretion system in the West Junggar; (d) Late Carboniferous-Middle Permian double-subduction arc systems with a ridge subduction regime in the southern West Junggar. BMT arc system: Barleik-Mayile-Tangbale arc system; SSZ-type OM: SSZ-type ophiolitic mélange; BGT: Baogutu; MG: Miaoergou; CTS: Central Tianshan.

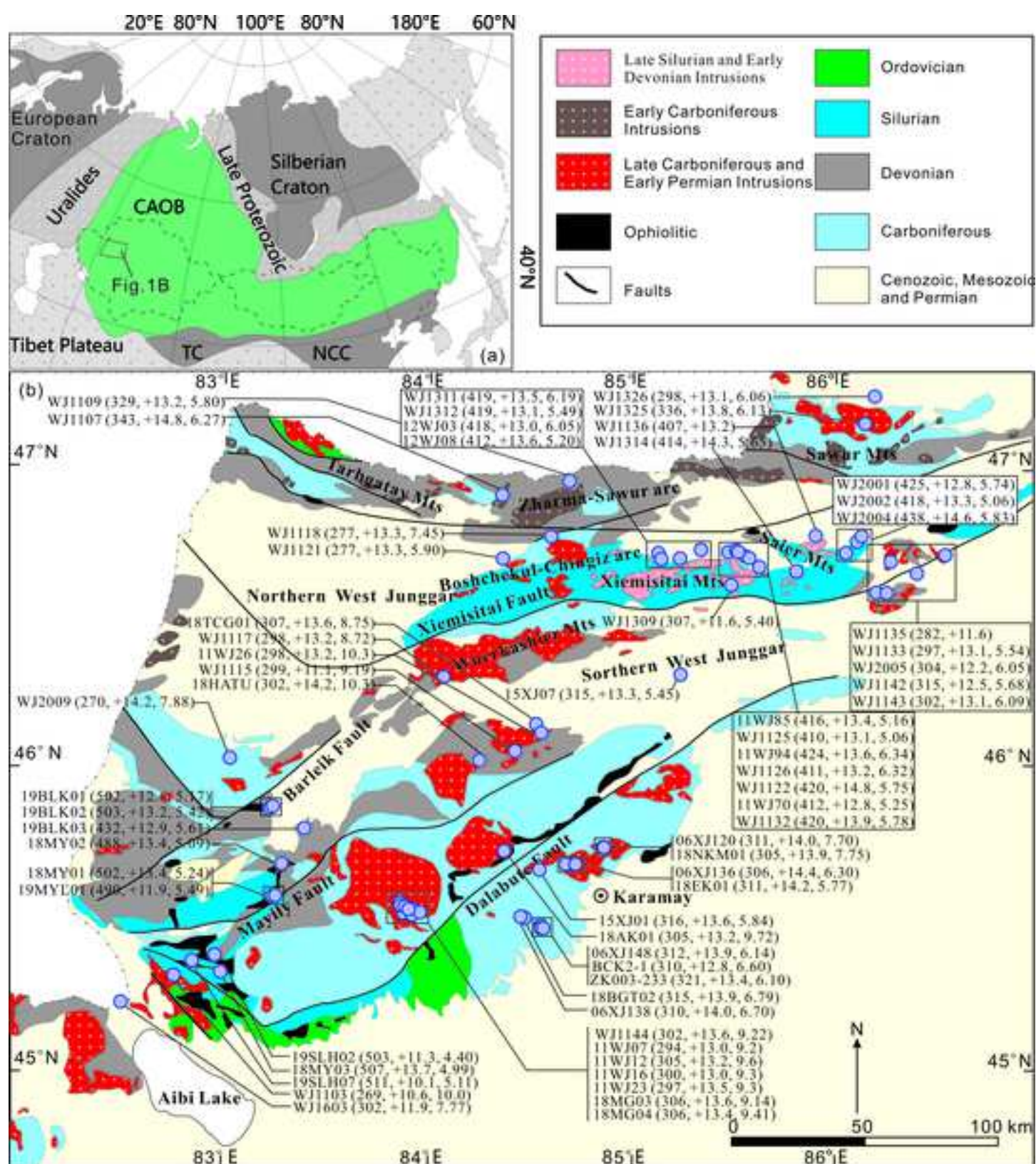
Table captions

Table 1 Summary of sample localities and ages of the intrusions in the West Junggar oceanic arc

Table S1 A summary of the zircon U-Pb, Hf-O isotope data for the Paleozoic intrusions in the West Junggar oceanic arc

Table S2 The zircon Hf-O isotope data for the Paleozoic intrusions in the West Junggar oceanic arc

[Click here to access/download;Figure;Fig. 1 West Junggar.jpg](#)



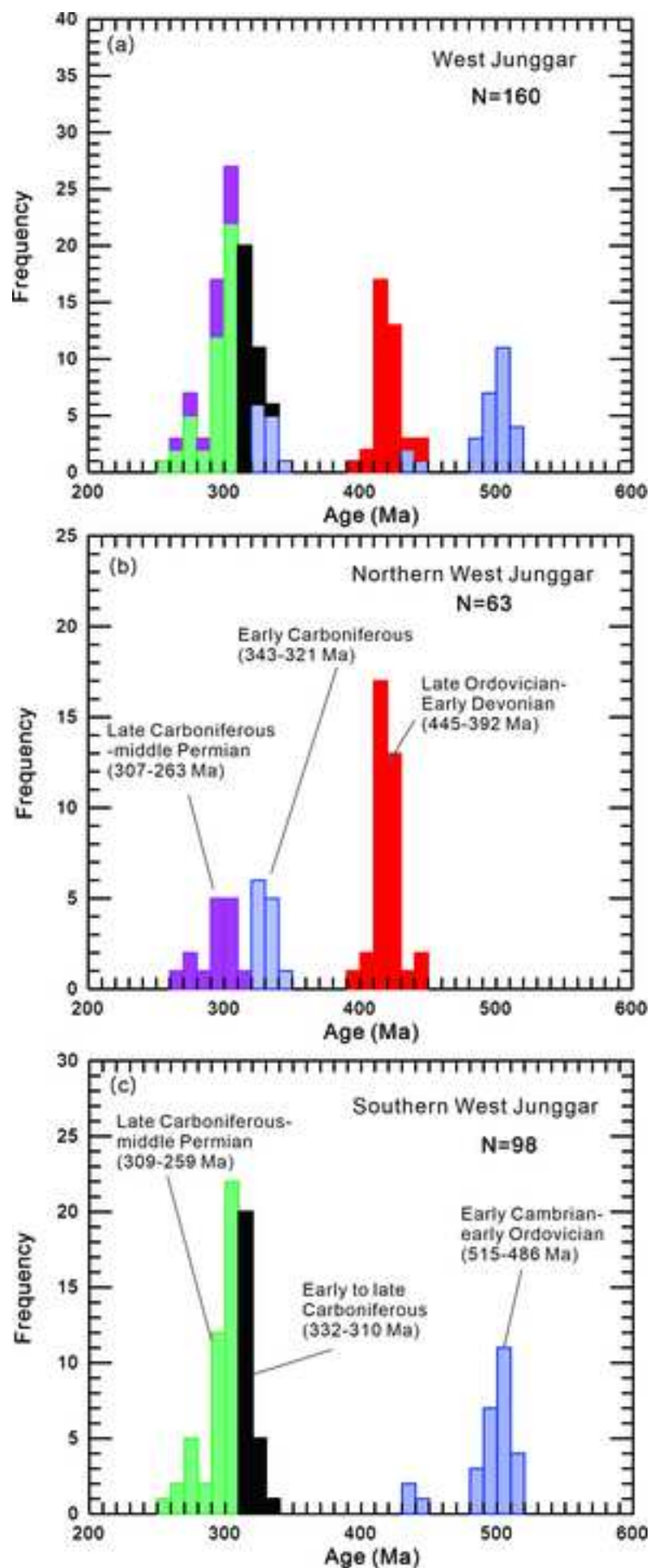


Figure 3

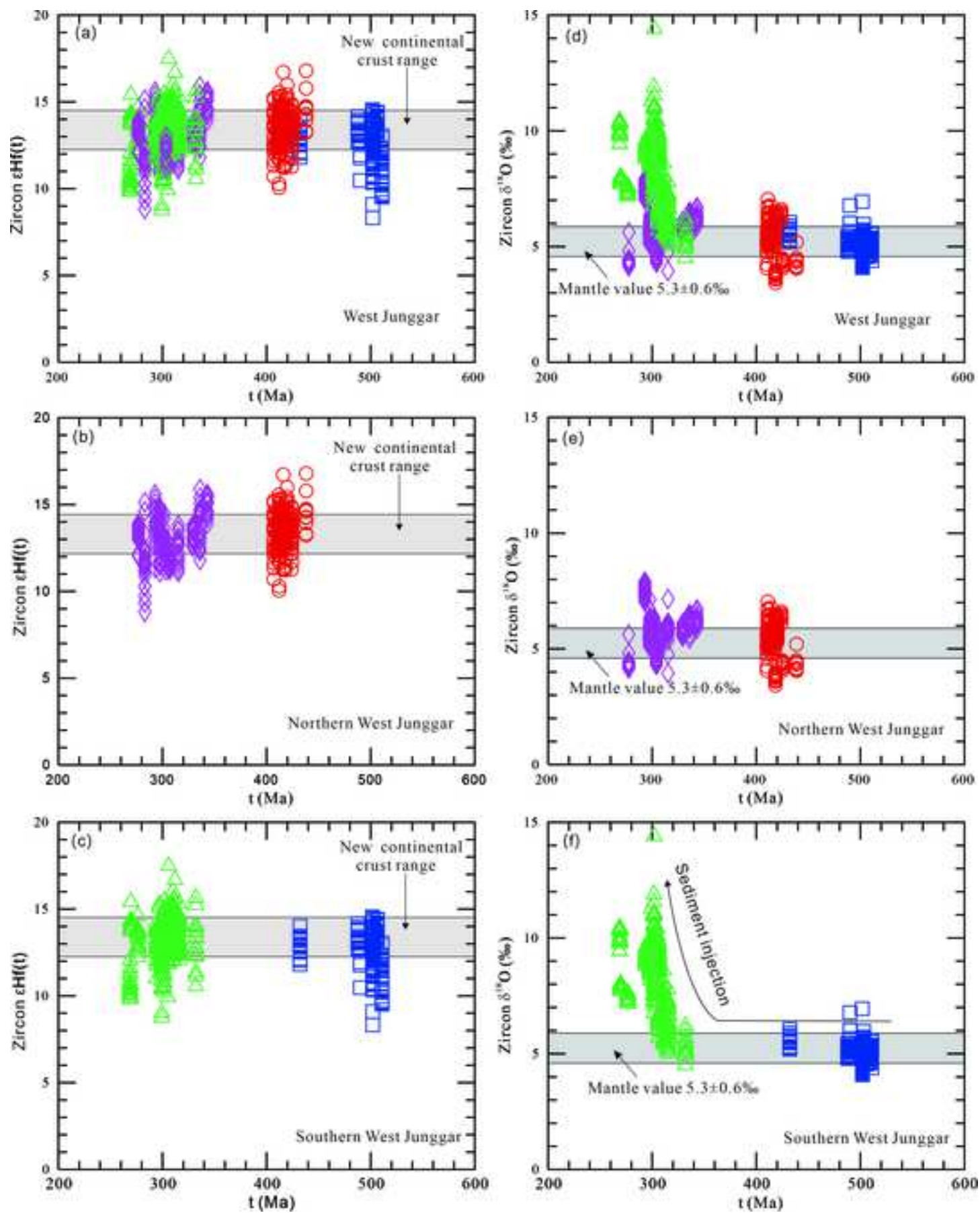
[Click here to access/download;Figure;Fig.3.jpg](#)

Figure 4

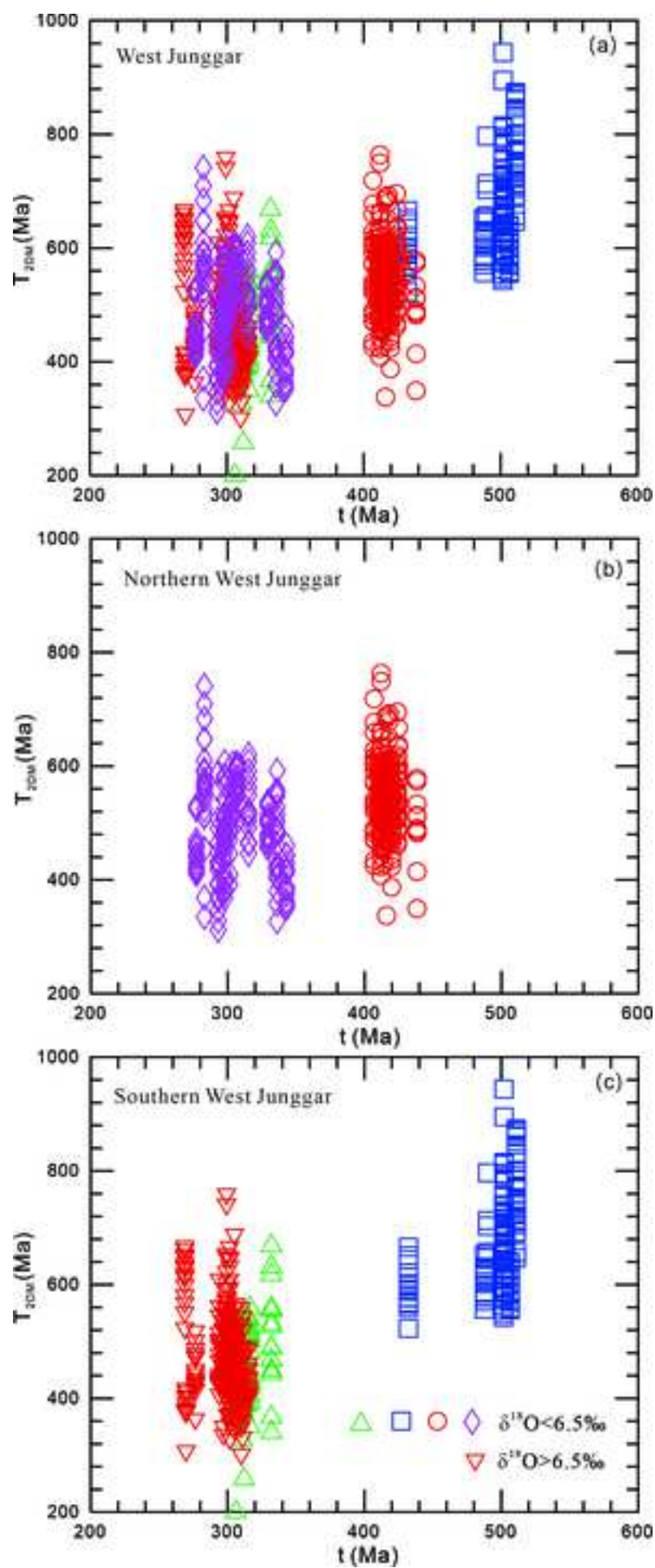
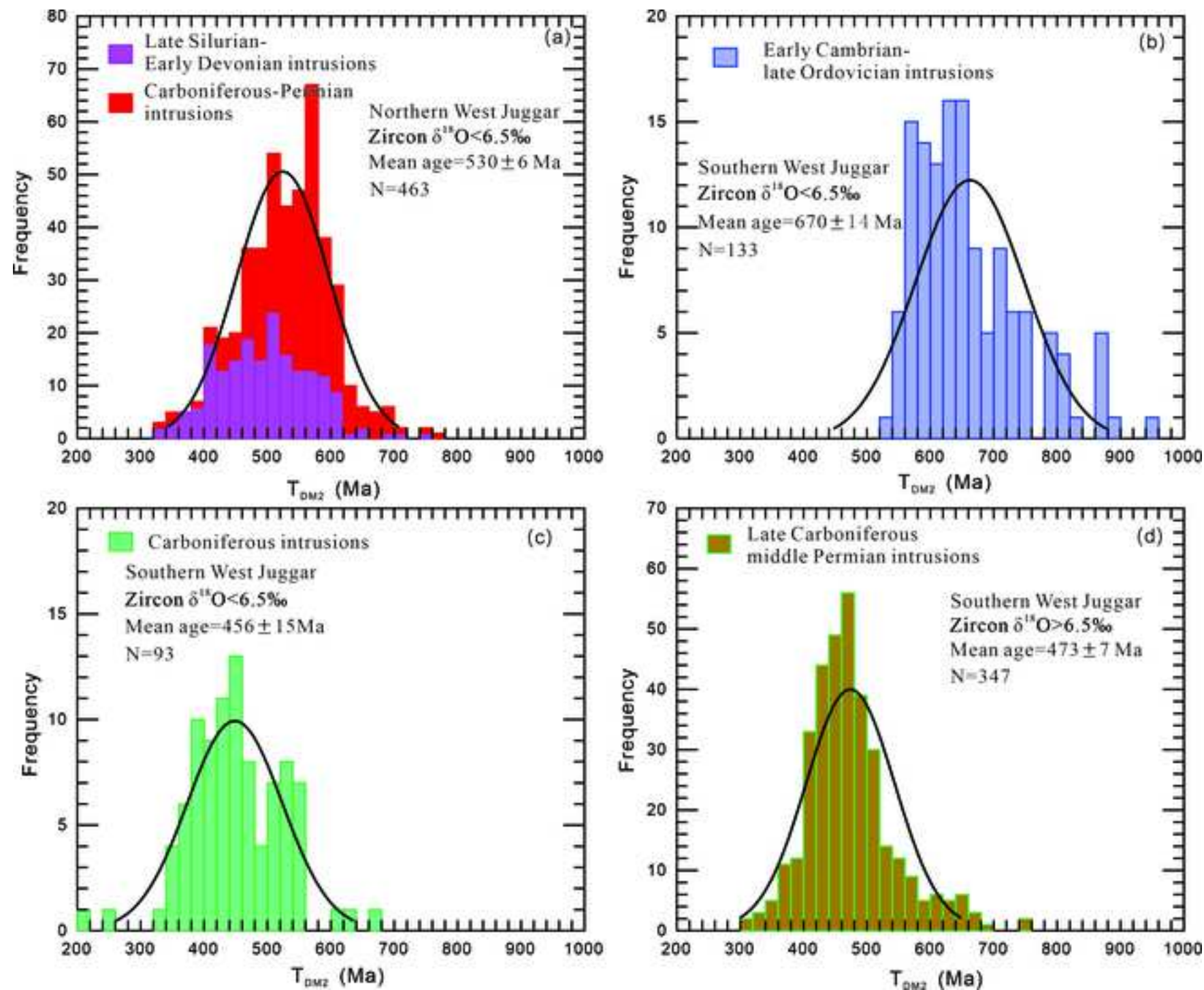


Figure 5

[Click here to access/download;Figure;Fig.5.jpg](#)

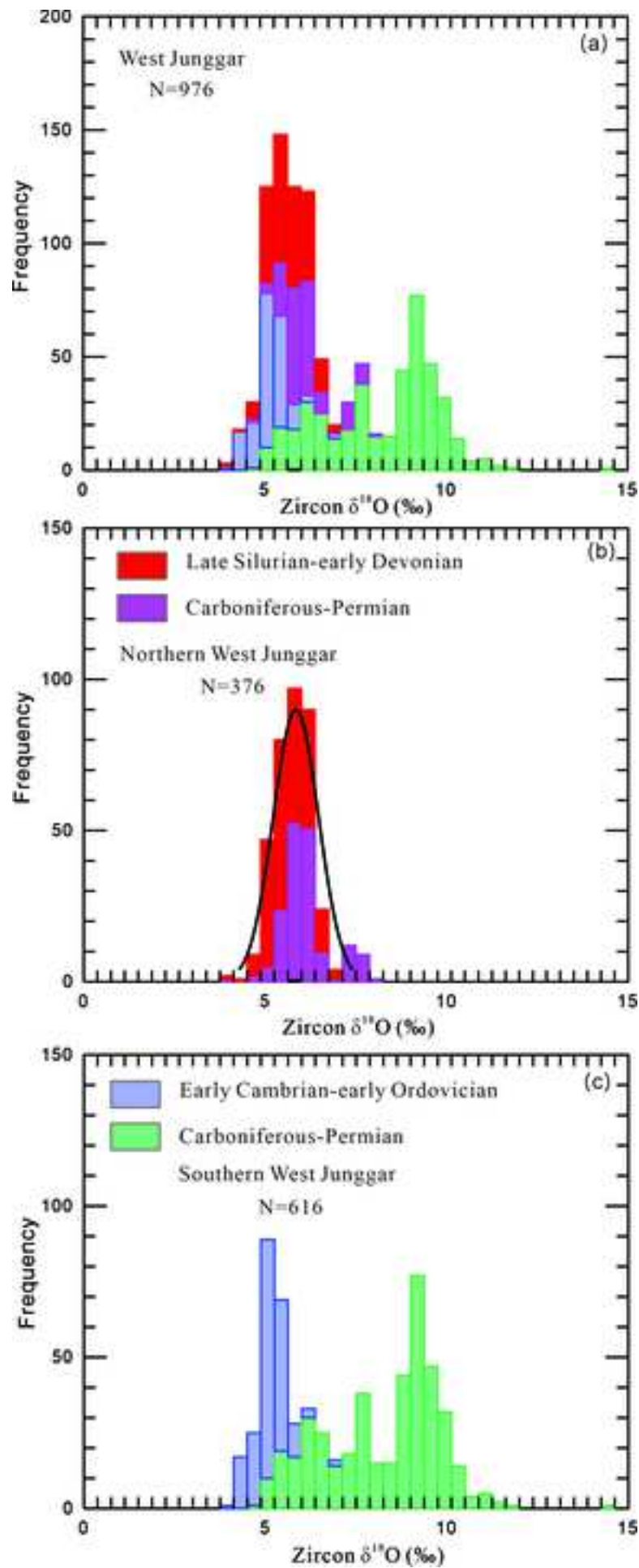
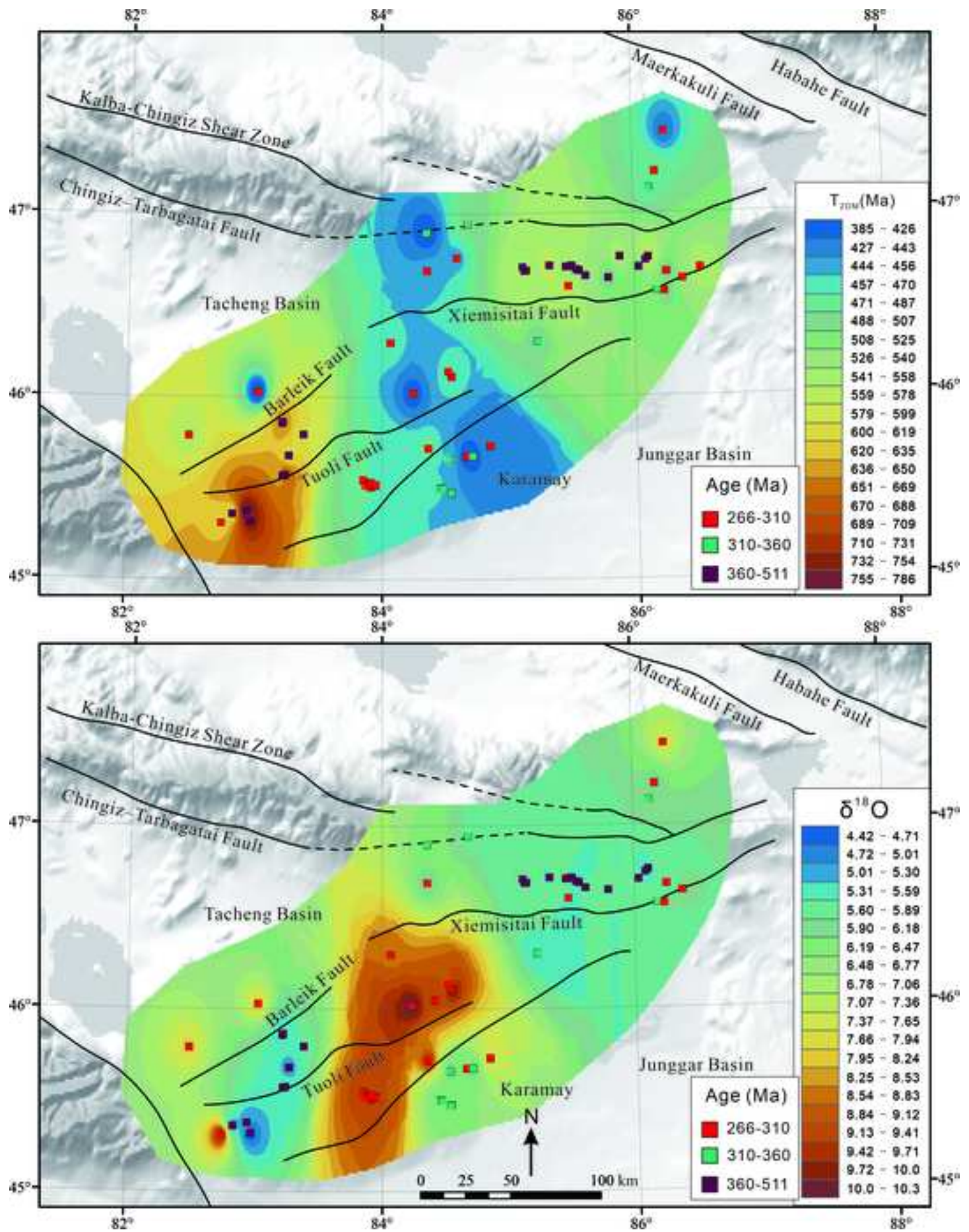


Figure 7

[Click here to access/download;Figure;Fig.7 O isotope mapping new.jpg](#)



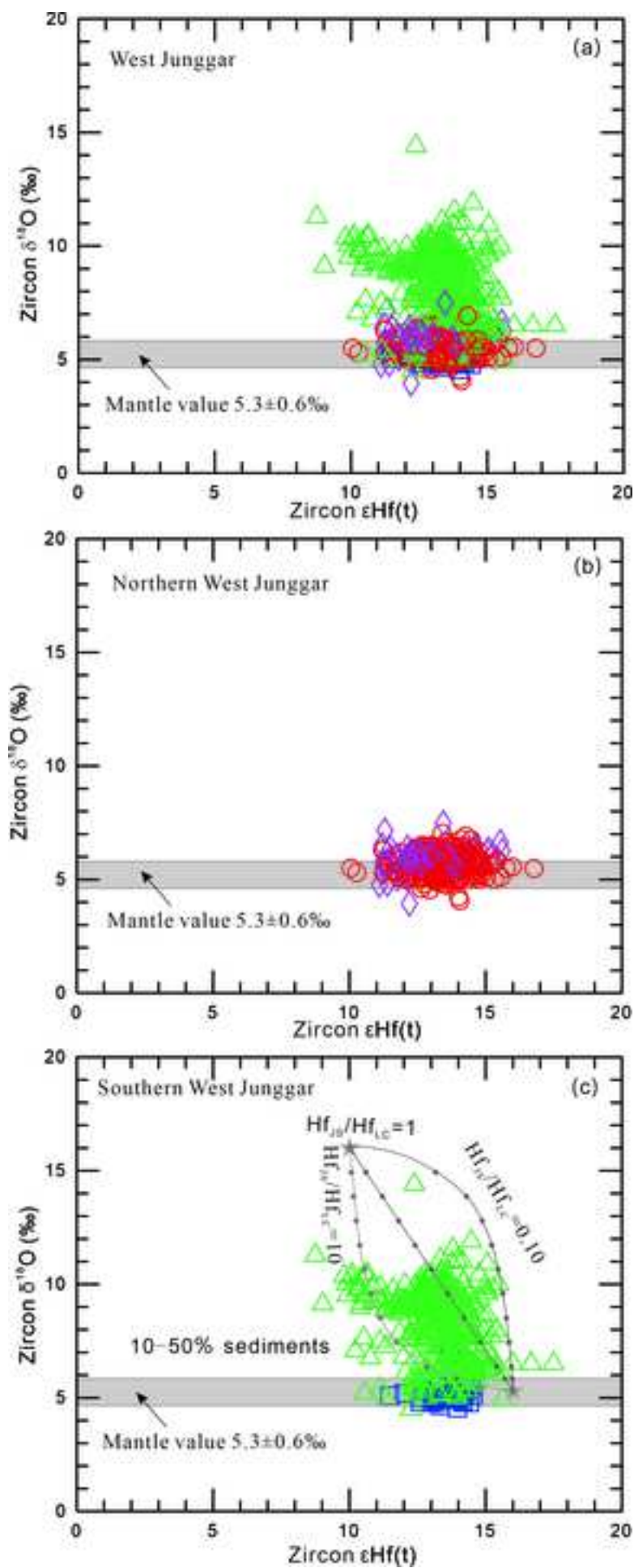
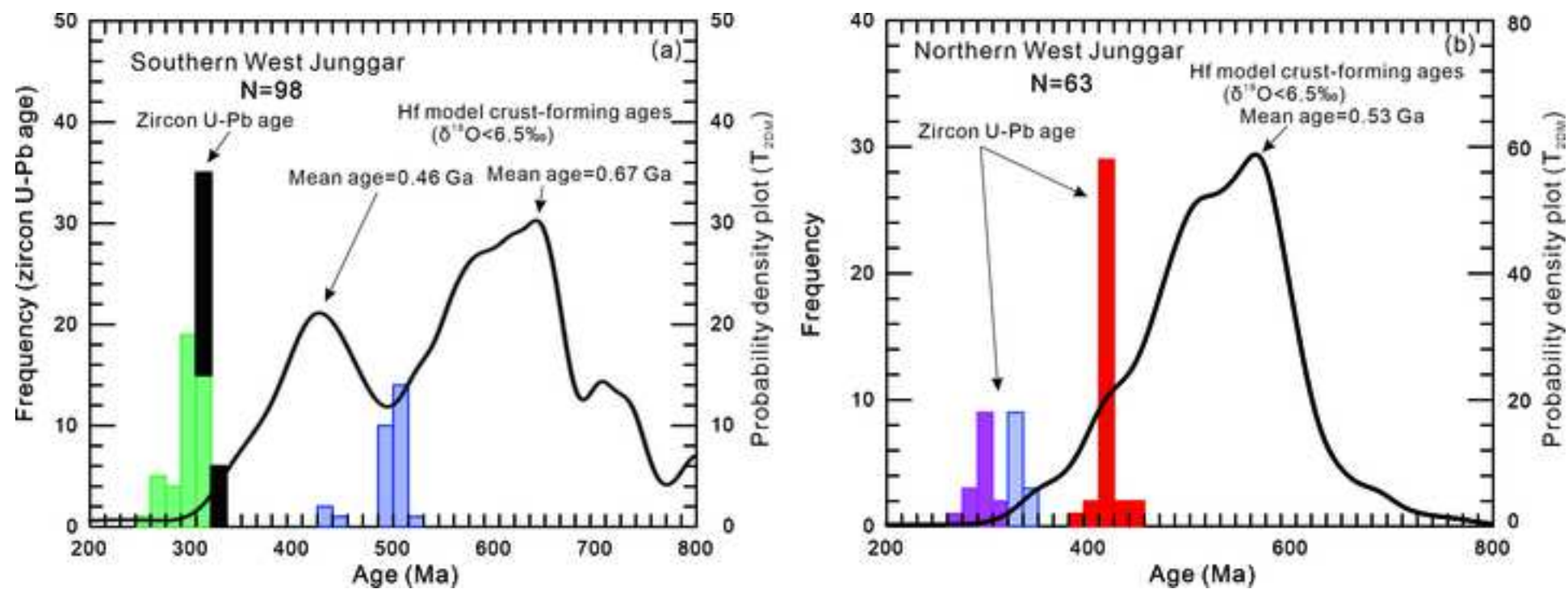


Figure 9



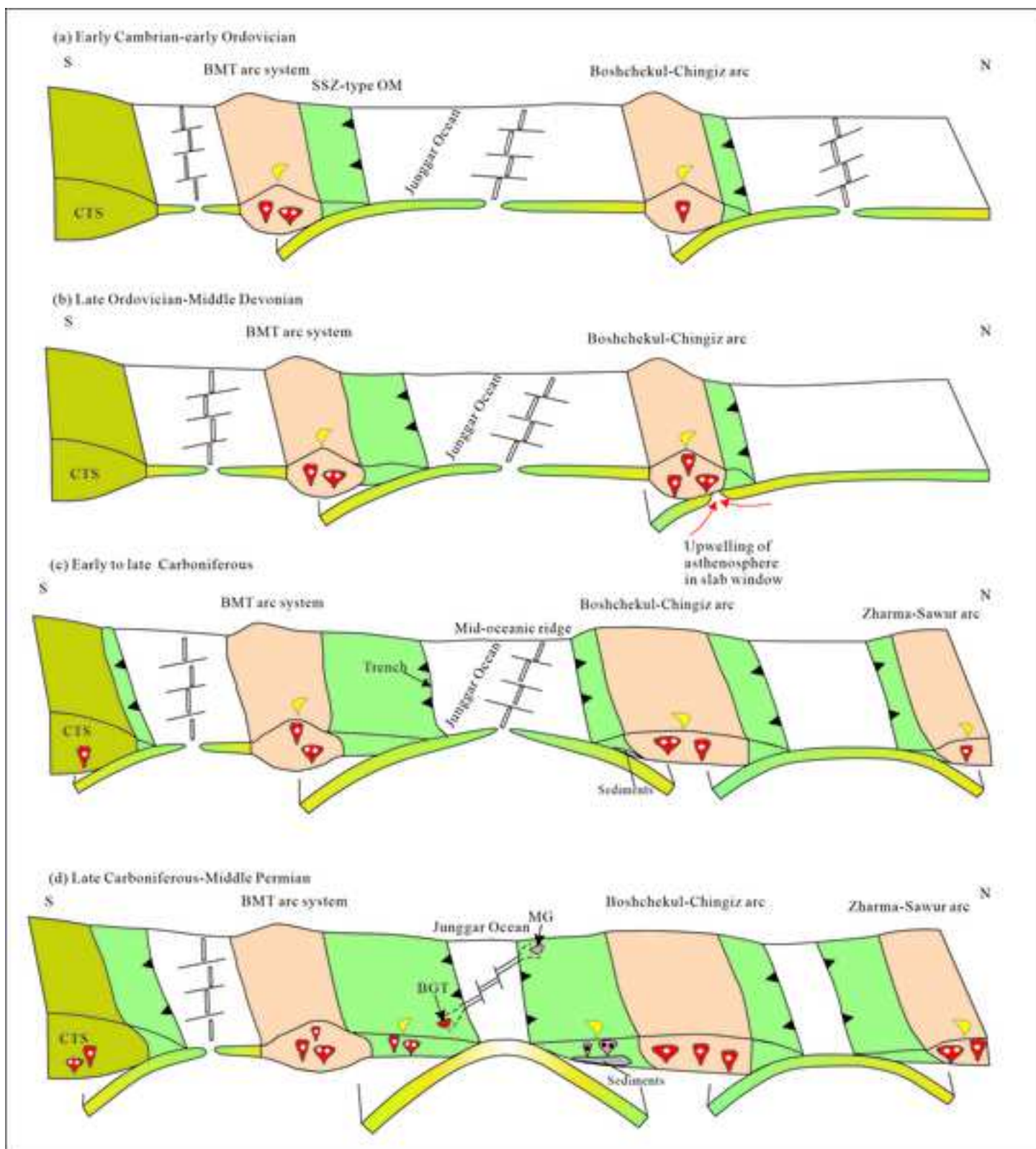


Table 1 Summary of sample localities and ages of the intrusions in the West Junggar oceanic arc

Samples	Locality	Longitude (E)	Latitude (N)	Lithology	Age (Ma)	error
ZK003-233	Baogutu	-	-	Diorite	321	2
BCK2-1	Baogutu	-	-	Granodiorite porphyry	310	2
XMST08	Xiemisitai Mts	85°31'07"	46°42'39"	K-feldspar granite	419	2
XMST14	Xiemisitai Mts	85°31'07"	46°42'39"	Diorite	422	2
XMST02	Xiemisitai Mts	85°31'07"	46°42'39"	Alkaline granite	417	4
XMST01	Xiemisitai Mts	85°30'25"	46°35'05"	K-feldspar granite	420	4
XMST03	Xiemisitai Mts	85°29'09"	46°34'44"	Rhyolite-Porphyry	420	5
HZ	Xiemisitai Mts	85°52'28"	46°36'42"	Rhyolite-Porphyry	414	5
XGSL03	Xiemisitai Mts	85° 29'09"	46° 34'44"	Rhyolitye-porphyry	420	5
TW1	Xiemisitai Mts	83°57'43"	46°19'11"	Granodiorite	411	3
HLSL	Saier Mts	85°48'44"	46°44'16"	Felsite	405	4
CGKL	Saier Mts	85°53'39"	46°45'56"	K-feldspar granite	410	3
HBK	Saier Mts	85°40'42"	46°46'32"	K-feldspar granite	417	5
TLG	Hebukesaier	85° 10'26"	46° 47'11"	Granite	263	6
KLMS	Wuerkashier Mts	84°07'00"	46°17'58"	K-feldspar granite	302	2
SLK	Wuerkashier Mts	84°34'52"	46° 22'45"	K-feldspar granite	290	4
LST	Sawur Mts	85°54"	47°11'15"	K-feldspar granite	321	5
ZQS	Tarbgatay Mts	83° 00'30"	47°06'07"	Granodiorite	325	3
DYS	Tarbgatay Mts	84° 21'16"	46° 53'50"	Pyroxene diorite	333	2
BEG	Tarbgatay Mts	83°04'58"	47°04'23"	Granodiorite	332	3
ABDL	Tarbgatay Mts	83°16'58"	46°59'12"	Monzonitic granite	332	3
QS-1	Xiemisitai Mts			quartz syenite	418	5
D-1	Xiemisitai Mts			diorite	424	5
MG-1	Xiemisitai Mts			monzogranite	418	5
S-1	Xiemisitai Mts			syenite	392	6
HG-1	Xiemisitai Mts			hornblende gabbro	422	5
12XJ37-A	Xiemisitai Mts	85°07'20"	46°38'30"	monzogranite	429	1
12XJ05-B	Xiemisitai Mts	85°10'10"	46°36'40"	Quartz diorite	440	3
12XJ14-A	Xiemisitai Mts	85°10'15"	46°34'20"	Quartz monzodiorite	445	6
KM-9918-3	Keramay	83°45'05"	45°39'06"	K-feldspar granite	296	7
AK154-2	Akebastaw	84° 45'33"	45° 24'39"	K-feldspar granite	305	4
MG 164-2	Miaoergou	83°57'00"	45°31'3"	Chamockite	305	3
MG9811-1	Miaoergou	84° 01'45"	45° 32'45"	Chamockite	296	3
MG 123-2	Miaoergou	83°52'20"	45°30'55"	Chamockite	305	3
MG136-1	Miaoergou	83° 56'26"	45° 29'25"	K-feldspar granite	308	6
MG9951-1	Miaoergou	83°52'33"	45°31'57"	K-feldspar granite	298	4
Gn-71	Sawur Mts			K-feldspar granite	338	4
Gn-40	Tarbgatay Mts			Granodiorite	325	4
Gn-14	Tarbgatay Mts			K-feldspar granite	303	4
KLMY21	Keramay			K-feldspar granite	295	6
KLMY3	Keramay			Granite	318	5
KLMY16	Akebastaw			K-feldspar granite	276	5
MEG5	Miaoergou			Granite	327	7
TGL1	Taergen			K-feldspar granite	287	5
KL-19	Keramay			Quartz diorite	316	3
ALT-49	Barleik Mts			diorite	324	2
ALT-87	Barleik Mts			diorite	321	2
ALT-52	Barleik Mts			diorite	320	2
ALT-74	Barleik Mts			quartz syenite	314	5
ALT-130	Barleik Mts			quartz syenite	282	2
ALT-36	Barleik Mts			quartz syenite	272	2
ALT-101	Barleik Mts			granitic porphyry	274	2
ALT-116	Barleik Mts			granitic porphyry	270	2
ALT-84	Barleik Mts			granitic porphyry	259	5
9LB-50	Saleinuohai Mts	82°56'37.7"	45°22'42.3"	plagiogranite	515	3
09LB-53	Saleinuohai Mts	82°58'43.9"	45°22'20.0"	plagiogranite	514	3
09LB-77	Saleinuohai Mts	82°50'17.4"	45°21'41.6"	plagiogranite	509	2

SLN-19	Saleinuohai Mts	82°55'43.0"	45°23'21.2"	plagiogranite	511	4
09LB-81	Saleinuohai Mts	82°50'4.3"	45°21'29.0"	quartz plagioclase	500	2
LBD-09	Saleinuohai Mts	83°03'36.7"	45°20'35.3"	plagiogranite	493	2
HJK-13	Saleinuohai Mts	82°52'28.8"	45°20'53.7"	carbonated felsic rock	495	9
HJK-14	Saleinuohai Mts	82°58'20.7"	45°19'13.4"	gabbro	498	2
HJK-18	Saleinuohai Mts	82°56'42.1"	45°17'45.0"	porphyritic granite	492	2
D07057	Taergen	83°32'35"	45°45'55"	K-feldspar granite	296	3
AS3	Akebastaw			K-feldspar granite	303	3
MI	Miaoergou			K-feldspar granite	305	2
06XJ145	Baogutu	84°27'10"	45°29'57"	Quartz dioritic porphyry	315	4
06XJ153	Baogutu	84°26'25"	45°23'54"	Dioritic porphyry	314	4
06XJ156	Baogutu	84°26'14"	45°23'24"	Dioritic porphyry	310	3
06XJ182	Keramay			Granodiorite	316	3
12WJ08	Xiemisitai	85°08'31"	46°41'21"	Syenitic porphyry	412	4
11WJ70	Xiemisitai	85°33'45"	46°41'11"	Granite	412	5
11WJ85	Xiemisitai	85°30'01"	46°42'48"	Alkali granite	416	5
12WJ03	Xiemisitai	85°07'46"	46°41'16"	Syenitic granite	418	7
11WJ94	Xiemisitai	85°27'31"	46°42'30"	Syenitic granite	424	6
11WJ07	Miaoergou	83°54'32"	45°30'25"	Aalkali-feldspar granite	294	3
11WJ23	Miaoergou	83°57'00"	45°31'04"	Charnokite	297	4
11WJ26	Hatu	84°32'45"	46°06'39"	Biotite granite	298	4
11WJ06	Miaoergou	83°57'00"	45°30'54"	Charnokite	298	2
11WJ16	Miaoergou	83°51'18"	45°32'31"	Aalkali-feldspar granite	300	5
11WJ12	Miaoergou	83°51'03"	45°32'50"	Charnokite	305	7
06XJ136	Keramay	84°39'43"	45°40'26"	Diorite	306	5
06XJ138	Baogutu	84°27'02"	45°29'56"	Diorite	310	4
06XJ120	Keramay	84°50'54"	45°43'40"	Aalkali-feldspar granite	311	4
06XJ148	Keramay	84°32'25"	45°28'25"	Granodiorite	312	4
15XJ07	Keramay	85°13'33"	46°18'04"	Diorite	315	5
15XJ01	West Keramay	84°31'59"	45°39'33"	Diorite	316	7
06XJ143	Baogutu	84°27'05"	45°29'56"	Gabbro	332	4
WJ2009	Mayile Mts	83°01'27"	46°01'39"	Quartz Monzonite	270	2
19BLK03	Mayile Mts	83°23'08.03"	45°47'43.87"	Granodiorite	432	4
WJ1103	Alashankou	82°44'43"	45°18'33"	Alkali granite	269	2
WJ1115	Bieluagaxi	84°24'52.3"	46°02'56.4"	Granodiorite	299	2
WJ1603	Suyunhe	82°29'13"	45°47'20"	Monzonitic granite	302	2
18BGT02	Baogutu	84°28'07.06"	45°29'51.43"	Diorite	315	2
18EK01	Keramay	84°42'40.62"	45°40'26.45"	Monzonitic granite	311	1
18MG03	Miaoergou	83°56'58.85"	45°31'03.32"	Charnockite	306	1
18MG04	Miaoergou	83°52'18.98"	45°30'54.84"	Charnockite	306	1
WJ1309	Xiemisitai	85°28'23.6"	46°36'6.6"	A-type granite	307	1
WJ1315	Sawur Mts	86°15'21.7"	47°26'36.6"	A-type granite	293	1
WJ1325	Sawur Mts	86°07'45.7"	47°08'4.9"	I-type granite	336	1
WJ1326	Sawur Mts	86°10'32.0"	47°13'27.8"	A-type granite	298	1
WJ2001	Xiemisitai Mts	86°06'45.33"	46°45'31.56"	Rhyolite	425	5
WJ2002	Xiemisitai Mts	86°05'26.09"	46°44'33.85"	Rhyolite	418	4
WJ2004	Xiemisitai Mts	86°02'06.51"	46°42'17.51"	Diorite Porphyry	438	4
WJ2005	Xiemisitai Mts	86°22'57.28"	46°38'23.69"	Alkali granite	304	3
WJ1118	Tarbgatay Mts	84°35'38.05"	46°45'27.26"	Alkali granite	277	1
WJ1121	Tarbgatay Mts	84°21'17.0"	46°41'18.4"	Alkali granite	277	5
WJ1142	Xiazijie	86°10'45.2"	46°34'32.4"	Granodiorite	315	2
09BGT-18	Baogutu			Quartz diorite	313	3
09MYL-19	Mayile Mts	83°13'22"	45°34'09"	Diorite	501	3
09MYL-145	Mayile Mts	83°11'46"	45°34'26"	Gabbro	493	5
09MYL-147	Mayile Mts	83°12'16"	45°34'31"	Granite	493	5
08MYL-10	Mayile Mts	83°16'32"	45°40'55"	Diorite	488	5
08MYL-19	Mayile Mts	83°16'24"	45°40'48"	Diorite	485	2
09AEST-8	Mayile Mts	83°23'15"	45°47'47"	Granodiorite	444	2
09AEST-9	Mayile Mts	83°23'15"	45°47'47"	Granodiorite	439	3

09MYL-56	Mayile Mts	83°15'51"	45°40'22"	Diorite	318	4
08MYL-53	Mayile Mts	83°19'16"	45°40'57"	Granodiorite	308	2
08MYL-54	Mayile Mts	83°20'36"	45°41'43"	Granodiorite	313	3
09MYL-37	Mayile Mts	83°16'49"	45°36'45"	Granodiorite	307	2
09JBL-4	Mayile Mts	83°30'01"	45°38'56"	Granodiorite	311	1
09JBL-3	Mayile Mts	83°27'33"	45°40'43"	K-feldspar granite	309	2
08TLG-1	Taergen			K-feldspar granite	309	4
09TK-18	Barleik Mts	83°12'19"	45°52'24"	Trondhjemite	503	3
10TK-84	Barleik Mts	83°13'14"	45°51'36"	diorite	509	3
10TK-88	Barleik Mts	83°13'26"	45°51'56"	diorite	503	3
10TK-3	Barleik Mts	83°11'59"	45°53'13"	Granodiorite	372	2
10TST-2	Barleik Mts	82°44'22"	45°55'15"	K-feldspar granite	277	2
10QE-3	Barleik Mts	82°27'05"	45°43'52"	Granodiorite	311	2
WJ1107	Tarbgatay Mts	84°21'21"	46°53'52"	Gabbro	343	2
WJ1109	Tarbgatay Mts	84°40'54"	46°56'38"	Biotite Granite	329	2
WJ1133	Hongguleleng	86°15'20.7"	46°40'41.3"	Quartz Monzonite	297	3
WJ1135	Hongguleleng	86°31'22.9"	46°41'48.8"	Quartz Monzonite	282	2
WJ1143	Xiazijie	86°14'0.7"	46°34'22.3"	Alkali granite	302	2
WJ1122	Xiemisitai Mts	85°32'20.2"	46°41'36"	Gabbro	420	3
WJ1125	Xiemisitai Mts	85°30'20.0"	46°42'38.3"	K-feldspar granite	420	1
WJ1126	Xiemisitai Mts	85°27'34.9"	46°42'28.7"	Syenitic granite	418	2
WJ1128	Xiemisitai Mts	85°28'30.0"	46°34'44.3"	Rhyolite	419	2
WJ1132	Xiemisitai Mts	85°36'60"	46°39'32.4"	Granodiorite	420	2
WJ1311	Xiemisitai Mts	85°06'54.7"	46°42'23.9"	Granodiorite	419	2
WJ1312	Xiemisitai Mts	85°19'36.6"	46°42'56.1"	K-feldspar granite	420	2
WJ1136	Saier Mts	85°53'18.5"	46°45'43"	Syenitic granite	407	3
WJ1314	Xiemisitai Mts	85°47'36.1"	46°38'41.2"	monzogranite	414	3
18AK01	Akebasitao	84°21'37.80"	45°43'09.21"	A-type granite	305	1
18HATU	Hatu	84°14'24.52"	46°01'06.60"	A-type granite	302	1
18TCG01	Tiechanggou	84°31'16.54"	46°08'19.97"	A-type granite	307	2
18NKM01	Northern Keramay	84°50'42.84"	45°43'56.67"	A-type granite	305	1
WJ1144	Miaoergou	83°54'44.5"	45°31'51.8"	A-type granite	302	2
WJ1117	Wuerkashier	84°03'57.26"	46°17'44.75"	A-type granite	298	2
18MY01	Mayile Mts	83°13'22.36"	45°34'09.57"	Alkali granite	502	2
18MY02	Mayile Mts	83°16'13"	45°40'47"	Diorite	488	2
18MY03	Mayile Mts	82°50'02.08"	45°21'37.99"	Diorite	507	2
19BLK01	Mayile Mts	83°13'05.88"	45°51'33.46"	Diorite	502	3
19BLK02	Mayile Mts	83°13'14.04"	45°51'53.66"	Granodiorite	503	3
19SLH07	Mayile Mts	82°56'39.13"	45°22'41.84"	Trondhjemite	511	3
19MYL01	Mayile Mts	83°14'34.04"	45°34'28.12"	Gabbro	490	4
19SLH02	Mayile Mts	82°58'21.48"	45°19'12.85"	Gabbro	503	2
OK-4	Sawur Mts	86° 17'51"	47° 01'01"	Adamellite	324	6
STS-1	Sawur Mts	86° 01'41"	47° 04'23"	Adamellite	328	6
KE-18	Sawur Mts	86° 21'20"	47° 12'33"	K-feldspar granite	303	8
KY-5	Sawur Mts	86°17'32"	47°13'28"	Alkali granite	298	5
QQH-14	Sawur Mts	86° 15'22"	47°26'38"	Alkali granite	291	9

Method	Data sources
LA-ICPMS	Cao et al., 2016
LA-ICPMS	Cao et al., 2016
SHRIMP II	Chen et al., 2010
SHRIMP II	Chen et al., 2010
SHRIMP II	Chen et al., 2010
SHRIMP II	Chen et al., 2010
SHRIMP II	Chen et al., 2010
SHRIMP II	Chen et al., 2010
SHRIMP	Chen et al., 2010
LA-ICP-MS	Chen et al., 2010
LA-ICP-MS	Chen et al., 2010
SHRIMP II	Chen et al., 2010
SHRIMP II	Chen et al., 2010
SHRIMP	Chen et al., 2010
SHRIMP	Chen et al., 2010
SHRIMP	Chen et al., 2010
LA-ICP-MS	Chen et al., 2010
SHRIMP	Chen et al., 2010
SHRIMP	Chen et al., 2010
SHRIMP	Chen et al., 2010
SHRIMP	Chen et al., 2010
LA-ICP-MS	Chen et al., 2015
LA-ICP-MS	Chen et al., 2015
LA-ICP-MS	Chen et al., 2015
LA-ICP-MS	Chen et al., 2015
LA-ICP-MS	Chen et al., 2015
LA-ICP-MS	Chen et al., 2019
LA-ICP-MS	Chen et al., 2019
LA-ICP-MS	Chen et al., 2019
LA-ICP-MS	Geng et al., 2009
LA-ICP-MS	Geng et al., 2009
LA-ICP-MS	Geng et al., 2009
LA-ICP-MS	Geng et al., 2009
SHRIMP	Geng et al., 2009
SHRIMP	Geng et al., 2009
LA-ICP-MS	Geng et al., 2009
SHRIMP	Han et al., 2006
SHRIMP	Han et al., 2006
SHRIMP	Han et al., 2006
SHRIMP	Han et al., 2006
SHRIMP	Han et al., 2006
SHRIMP	Han et al., 2006
SHRIMP	Han et al., 2006
SHRIMP	He and Chen, 2011
LA-ICP-MS	Liu et al., 2017
LA-ICP-MS	Liu et al., 2017
LA-ICP-MS	Liu et al., 2017
LA-ICP-MS	Liu et al., 2017
LA-ICP-MS	Liu et al., 2017
LA-ICP-MS	Liu et al., 2017
LA-ICP-MS	Liu et al., 2017
LA-ICP-MS	Liu et al., 2017
LA-ICP-MS	Liu et al., 2017
LA-ICP-MS	Ren et al., 2014
LA-ICP-MS	Ren et al., 2014
LA-ICP-MS	Ren et al., 2014

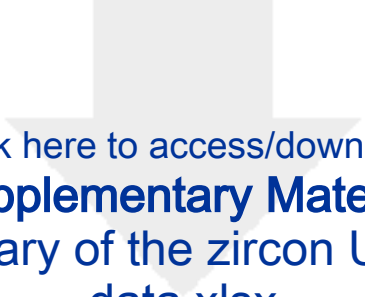
SIMS	Ren et al., 2014
LA-ICP-MS	Ren et al., 2014
LA-ICP-MS	Ren et al., 2014
SIMS	Ren et al., 2014
LA-ICP-MS	Ren et al., 2014
LA-ICP-MS	Ren et al., 2014
SHRIMP	Song et al., 2011
LA-ICP-MS	Su et al., 2006
LA-ICP-MS	Su et al., 2006
LA-ICP-MS	Tang et al., 2010
LA-ICP-MS	Tang et al., 2010
LA-ICP-MS	Tang et al., 2010
LA-ICP-MS	Tang et al., 2012
SIMS	Tang et al., 2019
SIMS	Tang et al., 2019
SIMS	Tang et al., 2019
SIMS	Tang et al., 2019
SIMS	Tang et al., 2019
SIMS	Tang et al., 2019
LA-ICPMS	Tang et al., 2019
LA-ICPMS	Tang et al., 2019
SIMS	Tang et al., 2019
SIMS	Tang et al., 2019
SIMS	Tang et al., 2019
SIMS	Tang et al., 2019
SIMS	Tang et al., 2019
SIMS	Tang et al., 2019
SIMS	Tang et al., 2019
SIMS	Tang et al., 2019
SIMS	Tang et al., 2019
LA-ICPMS	this study
LA-ICPMS	this study
LA-ICPMS	this study
LA-ICPMS	this study
LA-ICPMS	this study
LA-ICPMS	this study
LA-ICPMS	this study
LA-ICPMS	this study
LA-ICPMS	this study
LA-ICPMS	this study
LA-ICPMS	this study
LA-ICPMS	this study
LA-ICPMS	this study
LA-ICPMS	this study
LA-ICPMS	this study
LA-ICPMS	this study
SHRIMP	Wei et al., 2011
LA-ICP-MS	Xu et al., 2012
SIMS	Xu et al., 2012
SIMS	Xu et al., 2012
SHRIMP	Xu et al., 2012
LA-ICP-MS	Xu et al., 2012
LA-ICP-MS	Xu et al., 2012
LA-ICP-MS	Xu et al., 2012

SIMS	Xu et al., 2012
LA-ICP-MS	Xu et al., 2012
SHRIMP	Xu et al., 2012
LA-ICP-MS	Xu et al., 2012
LA-ICP-MS	Xu et al., 2012
LA-ICP-MS	Xu et al., 2012
LA-ICP-MS	Xu et al., 2012
LA-ICP-MS	Xu et al., 2013
LA-ICP-MS	Xu et al., 2013
LA-ICP-MS	Xu et al., 2013
LA-ICP-MS	Xu et al., 2013
LA-ICP-MS	Xu et al., 2013
LA-ICP-MS	Xu et al., 2013
LA-ICPMS	Yin et al., 2013b
LA-ICPMS	Yin et al., 2013b
LA-ICPMS	Yin et al., 2013b
LA-ICPMS	Yin et al., 2013b
LA-ICPMS	Yin et al., 2013b
LA-ICP-MS	Yin et al., 2017
LA-ICP-MS	Yin et al., 2017
LA-ICP-MS	Yin et al., 2017
LA-ICP-MS	Yin et al., 2017
LA-ICP-MS	Yin et al., 2017
LA-ICP-MS	Yin et al., 2017
LA-ICP-MS	Yin et al., 2017
LA-ICP-MS	Yin et al., 2018
LA-ICPMS	Yin et al., 2021
LA-ICPMS	Yin et al., 2021
LA-ICPMS	Yin et al., 2021
LA-ICPMS	Yin et al., 2021
LA-ICPMS	Yin et al., 2021
LA-ICPMS	Yin et al., 2021
LA-ICPMS	Zhang et al., 2022
LA-ICPMS	Zhang et al., 2022
LA-ICPMS	Zhang et al., 2022
LA-ICPMS	Zhang et al., 2022
LA-ICPMS	Zhang et al., 2022
LA-ICPMS	Zhang et al., 2022
LA-ICPMS	Zhang et al., 2022
SHRIMP	Zhou et al., 2008
SHRIMP	Zhou et al., 2008
SHRIMP	Zhou et al., 2008
SHRIMP	Zhou et al., 2008
SHRIMP	Zhou et al., 2008

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

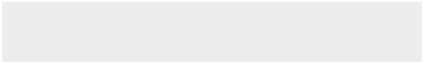
☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:



[Click here to access/download](#)

Supplementary Material

Table S1 A summary of the zircon U-Pb, Hf-O isotope
data.xlsx





[Click here to access/download](#)

Supplementary Material

Table S2 In situ zircon Hf-O isotopes.xlsx

