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U–Pb geochronology of basement rocks in central Tibet and paleogeographic implications

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The ages and paleogeographic affinities of basement rocks of Tibetan terranes are poorly known. New U– Pb zircon geochronologic data from orthogneisses of the Amdo basement better resolve Neoproterozoic and Cambro-Ordovician magmatism in central Tibet. The Amdo basement is exposed within the Bangong suture zone between the Lhasa and Qiangtang terranes and is composed of granitic orthogneisses with subordinate paragneisses and metasedimentary rocks. The intermediate-felsic orthogneisses show a bimodal distribution of Neoproterozoic (920–820 Ma) and Cambro-Ordovician (540–460 Ma) crystallization ages. These and other sparse basement ages from Tibetan terranes suggest the plateau is underlain by juvenile crust that is Neoproterozoic or younger; its young age and weaker rheology relative to cratonic blocks bounding the plateau margins likely facilitated the propagation of Indo-Asian deformation far into Asia. The Neoproterozoic ages post-date Rodinia assembly and magmatism of similar ages is documented in the Qaidaim–Kunlun terrane, South China block, the Aravalli–Delhi craton in NW India, the Eastern Ghats of India, and the Prince Charles mountains in Antarctica. The Amdo Neoproterozoic plutons cannot be unambiguously related to one of these regions, but we propose that the Yangtze block of the South China block is the most likely association, with the Amdo basement representing a terrane that possibly rifted from the active Yangtze margin in the middle Neoproterozoic. Cambro-Ordovician granitoids are ubiquitous throughout Gondwana as a product of active margin tectonics following Gondwana assembly and indicate that the Lhasa–Qiangtang terranes were involved in these tectono-magmatic events. U–Pb detrital zircon analysis of two quartzites from the Amdo basement suggest that the protoliths were Carboniferous–Permian continental margin strata widely deposited across the Lhasa and Qiangtang terranes. The detrital zircon age spectra of the upper Paleozoic Tibetan sandstones and other rocks deposited in East Gondwana during the late Neoproterozoic and Paleozoic are all quite similar, making it difficult to use the age spectra for paleogeographic determinations. There is a suggestion in the data that the Qiangtang terrane may have been located further west along Gondwana’s northern boundary than the Lhasa terrane, but more refined spatial and temporal data are needed to verify this configuration.

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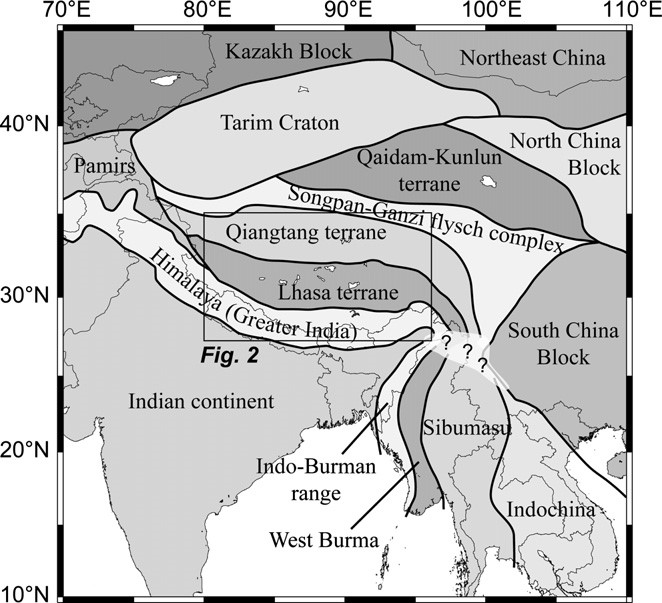
# Introduction

The Tibetan plateau is the largest plateau and orogenic feature on earth and has been the focus of many recent geological and geophysical investigations. However, due to its large size, high elevation, and remoteness, there still remains a poor understanding of the geology of the plateau, particularly within its interior. Like most of central and southeast Asia, Tibet formed from an amalgamation of terranes during the Phanerozoic (Chang and Zheng, 1973; Allégre et al., 1984; Chang et al., 1986; Sengör and

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Natal’in, 1996; Yin and Nie, 1996; Fig. 1) and the geology and position of these terranes prior to their accretion to Asia are not well known. The pre-Mesozoic geological history of the terranes that make up Tibet is obscured by the paucity of basement exposures and the predominance of supracrustal assemblages that are late Paleozoic and younger (e.g. Liu, 1988; Pan et al., 2004).

The limited dating of basement rocks to date suggests that the Tibetan crust is relatively young. U–Pb dating of zircons in gneissic rocks revealed Neoproterozoic crystalline crust in the Amdo basement (850 Ma; Guynn et al., 2006; Fig. 2) and in the central Lhasa terrane just west of Nam Lake (750 Ma; Hu et al., 2004; Fig. 2). The orthogneiss of the Amdo basement also contains Cambrian protoliths (530 Ma; Xu et al., 1985). Gneissic basement exposures in the Qiangtang terrane yielded Ordovician (476–474 Ma) U–Pb zircon crystallization ages (Pullen et al., 2011), while an



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Fig. 1. Terranes and continental blocks that make up southeast Asia. The question marks highlight uncertainties in the continuation or correlation of Tibetan terranes into the Indochina peninsula.

orthogneiss in accretionary mélange from central Qiangtang yielded Cambro-Ordivician ages (Kapp et al., 2000). In the Qaidam–Kunlun terrane of northern Tibet, 930–920 Ma and 825 Ma arc-related rocks have been documented (Gehrels et al., 2003b). These few ages represent the only known pre-Mesozoic crystalline basement from Tibet. Alternatively, isotopic work has been used to suggest that the crust of the Lhasa and possibly Qiangtang terranes is older, perhaps even Archean. Nd isotope data from the Cambrian orthogneiss of Amdo yielded Mesoproterozoic model ages (Harris et al., 1988b), while Sr, Nd and zircon Hf isotopic studies on Cretaceous granitoids of the Lhasa terrane yield Proterozoic and Archean model ages (Chiu et al., 2009; Zhu et al., 2009a). It is possible, though, that the enriched radiogenic isotopic compositions could result from the assimilation of melted sedimentary rocks that were themselves sourced from older continents far from Tibet, rather than from pre-Neoproterozoic crystalline crust (Ding et al., 2003). If the latter is the case, and the juvenile ages of the basement exposures are representative of the entire Tibetan crust, then the spatial extent of the modern Tibetan plateau may have been pre-determined by the distribution of more juvenile (e.g. Neoproterozoic and Phanerozoic), and presumably rheologically weaker crust compared to the more ancient (e.g. Archean and Paleoproterozoic) Tarim North China and South China blocks bounding the plateau (Molnar and Tapponnier, 1981; Fig. 1).

The Lhasa and Qiangtang terranes are widely interpreted to have been located along East Gondwana’s margin during the Paleozoic on the basis of widespread Carboniferous–Permian diamictites and Gondwana flora and fauna (Leeder et al., 1988; Metcalfe, 1996). Traditionally, they have been considered to have formed a composite terrane located on the northern margin of India (e.g. Metcalfe, 1996, 2006; Scotese, 2001), with the Qiangtang terrane rifting during the Late Permian (Leeder et al., 1988; Pearce and Mei, 1988; Yin, 1997; Yin and Harrison, 2000) followed by the Lhasa terrane during the Late Triassic (Pearce and Mei, 1988; Gaetani and Garzanti, 1991; Yin and Harrison, 2000). Recently, though, a paleogeophraphic connection between the Lhasa terrane and northwestern Australia during the Permian has been proposed (Ferrari et al., 2008; Yang et al., 2009; Zhu et al., 2009b, 2010) and Zhu et al. (2010) present geological evidence that Lhasa was an isolated terrane located in the Paleo-Tethys during the Early Permian.

We present new U–Pb igneous and detrital zircon data from metamorphic rocks of the Amdo basement that help elucidate the age of the central Tibetan basement. The data confirm a significant episode of early Neoproterozoic magmatism, first reported by Guynn et al. (2006), and show that the widespread Cambro-Ordovician tectonism along the margins of Gondwana also affected the Amdo basement. The age of the early Neoproterozoic

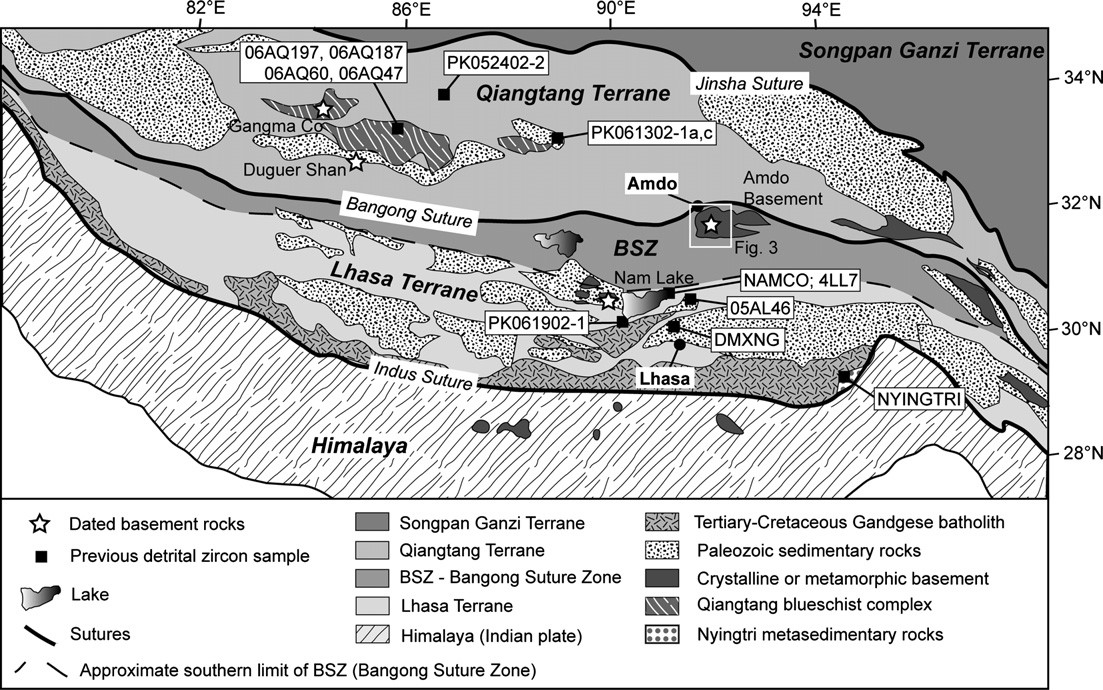


Fig. 2. General geological map of central and southern Tibet based on Pan et al. (2004). Squares are sample locations of previous Paleozoic and older detrital zircon samples. Stars represent previously reported basement ages from Tibet. Dashed line represents the approximate southern boundary of the Bangong suture zone based on ophiolites and mapped Mesozoic mélange. BSZ = Bangong suture zone.

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magmatism, combined with U–Pb detrital zircon age spectra of a paragneiss in the Amdo basement, suggest a possible South China block (specifically, Yangtze block) affinity. Detrital zircon U–Pb age spectra of quartzites from the basement are similar to age spectra from Carboniferous–Permian strata of the Lhasa and Qiangtang terranes, suggesting the latter are the protoliths of the former. The age spectra of upper Paleozoic strata from central and southern Tibet are similar to those from other strata deposited in northern East Gondwana during the late Neoproterozoic and Paleozoic. The similarities between these detrital zircon age signatures makes it difficult to discriminate between proposed paleogeographic positions of the Tibetan terranes, though a slight difference suggests the Qiangtang terrane and Amdo basement may have been located further west than the Lhasa terrane.

# Regional geology during the Neoproterozoic and Phanerozoic

In this paper, the ancient Tethys oceanic realm in Asia is subdivided into three regions after Sengör (1984) and Metcalfe (1996): the Paleo-Tethys, which separated the Cimmerian terranes (including the Qiangtang and Sibumasu terranes; Fig. 1) from Eurasia; the Meso-Tethys, which separated the Lhasa and Qiangtang terranes; and the Neo-Tethys, which was consumed between India and the southern margin of Eurasia (i.e. Lhasa terrane). These three designations do not necessarily indicate separate, unconnected oceans, but rather oceanic lithosphere that was created and consumed between distinct continental terranes. Within the supercontinent Gondwana, West Gondwana refers to South America and Africa while East Gondwana refers to India, Antarctica and Australia. The timescale used is from Gradstein et al. (2004).

During the late Mesoproterozoic, multiple orogenic belts developed that possibly marked the amalgamation of most of the continents into a supercontinent termed ‘‘Rodinia’’ (e.g. Meert and Torsvik, 2003; Li et al., 2008). The approximately 1300–1000 Ma time interval of this amalgamation is commonly referred to as the ‘‘Grenville’’, based on the North American tectonic province of this time and we use that convention here for convenience. The Neoproterozoic saw the break-up of Rodinia and the reassembly of many of the continents into Gondwana by the Cambrian. The tectonic and paleogeographic histories of even major continents during Rodinia assembly and consequent break-up are not well constrained, particularly India (e.g. Meert and Torsvik, 2003) and the South China block (e.g. Yu et al., 2008), and the situation for smaller continental terranes is even more tenuous. While Gondwana assembly appears to have been complete by the end of the Neoproterozoic, magmatism and tectonism continued until 450 Ma, probably as a result of newly established subduction zones along the margins (Ramezani and Tucker, 2003; Boger and Miller, 2004; Cawood et al., 2007; Horton et al., 2008). During the late Permian, Gondwana began rifting apart, first as terranes along the edges and then as entire continents. The terranes which rifted from East Gondwana accreted to the southern margin of Asia during the Mesozoic (Sengör and Natal’in, 1996; Yin and Harrison, 2000) and culminated in the closure of the Neo-Tethys Ocean by the collision of India with Asia in the Eocene (e.g. Allégre et al., 1984).

The boundary between the Qiangtang and Lhasa terranes is marked by the Bangong suture zone (Allégre et al., 1984; Dewey et al., 1988; Fig. 2). It is defined by a broad and discontinuous belt of ophiolite fragments and mélange and is a result of Meso-Tethys Ocean closure and subsequent collision between the Lhasa and Qiangtang terranes during the Early Cretaceous (Girardeau et al., 1984; Dewey et al., 1988; Kapp et al., 2003a, 2007a; Guynn et al., 2006). The Indus-Yarlung suture, the southern boundary of the Lhasa terrane (Fig. 2), was the site of the collision of India with Asia during the Eocene and rocks to the south of the suture have an Indian affinity (Burg and Chen, 1984; Dewey et al., 1988). The term ‘‘Greater India’’ refers to the northern Indian crust that was subducted beneath Asia during the collision (e.g. Ali and Aitchison, 2005); the rocks of the Himalaya constitute the upper part of this crust (Fig. 2).

Most Gondwana reconstructions place the Lhasa and Qiangtang terranes at the northern edge of India, at approximately the same longitudinal position as today (e.g. Metcalfe, 1996, 1999; Torsvik and Smethurst, 1999; Scotese, 2001), although some authors place the Lhasa terrane adjacent to the northern margin of Australia (Ferrari et al., 2008; Zhu et al., 2009b). The two terranes have similar Carboniferous–Permian diamictite-bearing stratigraphy (Leeder et al., 1988) and shared Gondwanan flora and fauna (Metcalfe, 1996). The Qiangtang terrane is thought to have been part of the long and continuous Cimmerian continent that rifted from northern Gondwana during the Permian and drifted rapidly northward, closing the Paleo-Tethys Ocean and opening the Meso-Tethys Ocean (Sengör, 1979, 1984; Metcalfe, 1996, 2006). The Cimmerian continent was composed, from west to east, of Turkey, Iran, Afghanistan, Qiangtang and Sibumasu (Simao–Burma–Malaya– Sumatra) and its existence is based on similarities in paleolatitudes, flora, fauna and ages of accretionary deformation between the different terranes (Metcalfe (2006) and references therein). Upper Carboniferous and Lower Permian extrusive rocks and volcanoclastic sedimentary rocks in the northern Lhasa terrane have been attributed to rifting of a terrane (Leeder et al., 1988; Pearce and Mei, 1988), possibly the Qiangtang (Yin, 1997; Yin and Harrison, 2000). Separation of the Lhasa terrane from northern India (Gaetani and Garzanti, 1991) is based on Late Triassic rifting in the southern Lhasa terrane (Pearce and Mei, 1988) that was coeval with rifting recorded in the Himalaya (Gaetani and Garzanti, 1991). A summary of the limited paleomagnetic data by Li et al. (2004) suggests that the Lhasa and Qiangtang terranes were at approximately the same latitude until the Qiangtang terrane started drifting northward during the late Permian and their subsequent paleolatitudes are consistent with the timing of rifting and collisional events mentioned above.

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The conventional interpretation of placing the Lhasa terrane north of India and south of the Qiangtang terrane in Gondwana reconstructions has recently been questioned. Ferrari et al. (2008) proposed that the Lhasa terrane was located next to northwest Australia during the Late Carboniferous based on their suggestion of southward subduction of the eastern Paleo-Tethys and a reinterpretation of northern Lhasa terrane Permian volcanic rocks as arc-related rather than rift-related. This alternative Australian connection was further advanced by Zhu et al. (2009b, 2010), although they suggest that during the Late Carboniferous to Early Permian the northern Lhasa terrane was located north of Gondwana within the Paleo-Tethys ocean. In this model, the southern Paleo-Tethys ocean subducted northward beneath the Lhasa terrane’s southern margin leading to collision of the Lhasa terrane with northwest Australia during the Late Permian. The Qiangtang terrane is located adjacent to India in this case and rifted from India during the Middle-Late Permian. This reconstruction is based on: (1) the geochemistry of the Permian basalts which suggests those in the Himalaya and the southern Qiangtang terrane formed in an extensional setting while the southern Lhasa terrane basalts were generated in an arc setting (Zhu et al., 2010); (2) the presence of Middle Permian granites with arc-related geochemical signatures in the central Lhasa terrane (Zhu et al., 2009b); and (3) the presence of a Permian (262 ± 5 Ma) eclogite in the central Lhasa terrane which is interpreted to mark a Middle–Late Permian suture zone (Yang et al., 2009; Zhu et al., 2010). While this arrangement explains the relationships of Permian igneous rocks, it is at odds with floral and faunal data which suggest the West Burma and Sibumasu terranes were located along northwest Australia (Metcalfe (2006) and references therein) and with paleomagnetic data which indicates the Qiangtang terrane was north of the Lhasa terrane (Li et al., 2004). Furthermore, the Lhasa terrane contains the Carboniferous diamictites common to Gondwana (Leeder et al., 1988) which indicates it was not isolated within the Paleo-Tethys during that time.

# Tibetan and Amdo basement geology

Exposures within the Tibetan terranes generally consist of lowgrade supracrustal rocks of late Paleozoic–Cenozoic age (Leeder et al., 1988; Yin and Harrison, 2000; Pan et al., 2004). The only dated basement rocks in the Qiangtang terrane are orthogneisses from the Duguer Shan (476–474 Ma; Pullen et al., 2011) and a block of mafic gneiss in melange near Gangma Co that yielded Cambrian and Ordovician zircon ages (Kapp et al., 2000; Fig. 2) (Fig. 2). Within the Lhasa terrane, just west of Nam Lake (Fig. 2), Hu et al. (2004) used U–Pb in zircon to date a metagabbro (782 ± 11 Ma), a deformed trondhjemite (787 ± 9 Ma) and a deformed granite (748 ± 8 Ma). Cross-cutting relationships with associated metasedimentary rocks suggest the sedimentary protoliths were deposited between 785 and 750 Ma. The only other known Precambrian basement exposure in central Tibet is the Amdo basement which occurs southeast of the town of Amdo (Xu et al., 1985; Dewey et al., 1988; Harris et al., 1988c; Guynn et al., 2006; Fig. 2). It is possible there are additional Precambrian or Cambro-Ordovician rocks in the suture zone to the east (Pan et al., 2004; Zhang et al., 2008; Fig. 2) but no dates have yet been published.

The Amdo basement is composed of upper amphibolite facies orthogneisses with a few, isolated exposures of metasedimentary rocks, mafic amphibolites and migmatites that have been intruded by Jurassic granitoids (Xu et al., 1985; Coward et al., 1988; Harris et al., 1988a; Guynn et al., 2006; Fig. 3 ). The igneous compositions of the orthogneisses are mostly granite and granodiorite with subordinate monzonite, tonalite and quartz-diorite. Xu et al. (1985) analyzed zircon grain fractions from an Amdo orthogneiss along the southern edge of the basement using U–Pb and obtained discordant analyses with 238U/206Pb ages of 465–420 Ma and 206 207 Pb/ Pb ages of 500 Ma. They report a crystallization age of 530 Ma, but this is based on a discordia regression using the zircon with discordant titanite U–Pb analyses from the same orthogneiss, which is an incorrect analysis given the different U–Pb diffusion characteristics of the two minerals. Guynn et al. (2006) reported a U–Pb zircon age of 852 ± 18 Ma for an orthogneiss from the central part of the exposure. Many of the zircons in this orthogneiss were also discordant due to Jurassic metamorphism that resulted in young zircon growth on the rims (Guynn et al., 2006).

The Amdo basement is located within the Bangong suture zone and there are ophiolite exposures north and south of it (Coward et al., 1988). Coward et al. (1988) and Harris et al. (1988b) interpreted the Amdo basement as representing the Lhasa terrane since they regarded the northernmost exposures of ophiolites to mark the actual suture between the Lhasa and Qiangtang terranes. On the other hand, Guynn et al. (2006) suggested the basement may have been associated with the Qiangtang terrane because if subduction of the Meso-Tethys ocean was northward beneath Qiangtang (Dewey et al., 1988), then Middle Jurassic metamorphism of the Amdo basement would be associated with this margin. If the two terranes were contiguous until Triassic rifting (Dewey et al., 1988; Leeder et al., 1988), then the differentiation between them is not critical for Paleozoic paleogeography. However, it has been suggested that the Lhasa terrane was not adjacent to the Qiangtang terrane until their amalgamation during the Early Cretaceous (Ferrari et al., 2008; Zhu et al., 2010).

# U–Pb geochronology

We conducted U–Pb zircon geochronology on eight samples of Amdo orthogneiss to determine their crystallization ages. U–Pb ages were also obtained for detrital zircons (DZs) from two quartzites and a paragneiss that occur in the basement exposure. Sample locations are shown in Fig. 3 and their coordinates and resulting ages are listed in Table 1. The zircons were analyzed using the Laser-Ablation Multicollector Inductively Coupled Plasma Mass Spec-

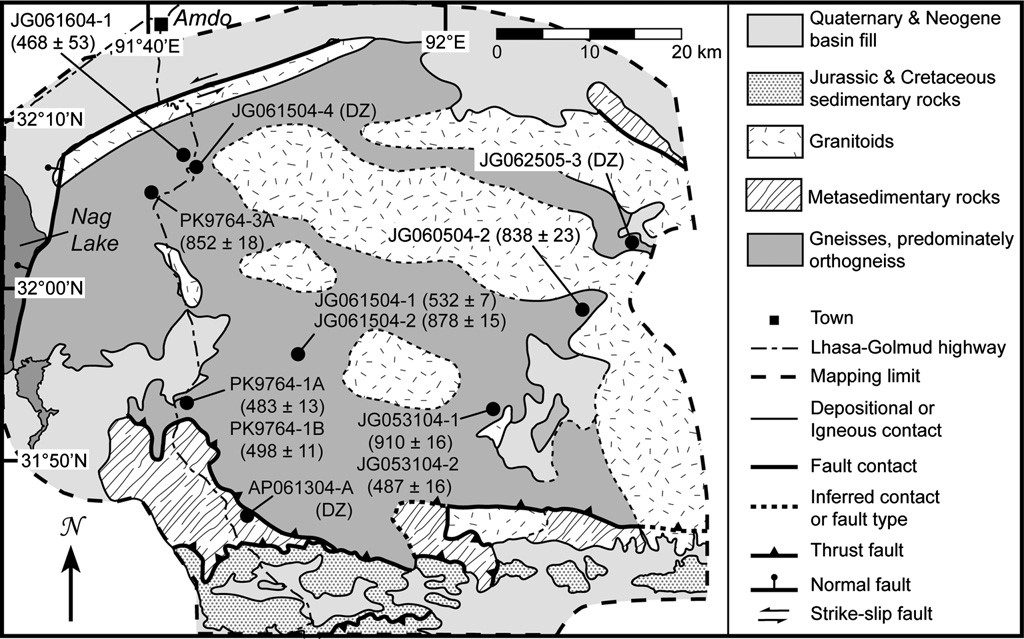


Fig. 3. Simplified geologic map of the Amdo basement, surrounding sedimentary rocks and sample locations analyzed in this study and Guynn et al. (2006), based on our mapping and Pan et al. (2004). Crystallization ages determined by U–Pb on zircon are shown for orthogneiss samples; detrital zircon samples are indicated by ‘‘DZ’’. The Amdo basement continues about 30–40 km to the east of this map.

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Table 1

Location and zircon U–Pb ages of Amdo basement samples.

Sample

N Lat.

E Lon.

Description

Crystallization

Other Zircon ages

Age (Ma)

Type

Age (Ma)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| JG053104-1 | 31.884 | 92.048 | Granitie gneiss | 910 ± 16 |  |  |
| JG061504-2 | 31.932 | 91.838 | Granodiorite gneiss | 878 ± 15 |  |  |
| JG060504-2 | 31.946 | 92.136 | Granodiorite gneiss | 838 ± 23 | Metamorphism | 177 ± 6 |
| JG061604-1 | 32.130 | 91.716 | Granite gneiss | 468 ± 53 | Metamorphism | 181 ± 4 |
| JG061504-1 | 31.932 | 91.838 | Granite gneiss | 532 ± 7 |  |  |
| PK970604-1A | 31.881 | 91.699 | Granodiorite gneiss | 483 ± 13 |  |  |
| PK970604-1B | 31.881 | 91.699 | Granite gneiss | 498 ± 11 |  |  |
| JG053104-2 | 31.885 | 92.060 | Granite gneiss | 487 ± 16 | Inherited | 880 |
| JG061504-4 | 32.123 | 91.711 | Paragneiss |  | Max. depositional | 800–700 |
| JG061504-4 | ‘‘ ’’ | ‘‘ ’’ | ‘‘ ’’ |  | metamorphism | 180 |
| JG062505-3 | 32.048 | 92.209 | Quartzite |  | Max. depositional | 493 ± 64 |
| AP061304-A | 31.794 | 91.773 | Quartzite |  | Max. depositional | 447 ± 30 |

trometer (LA-MC-ICPMS) facility at the University of Arizona Laserchron Center following the methods described in Gehrels et al. (2008). Additional details on the method are provided below.

For magmatic samples, approximately 50 zircon crystals were hand-picked and mounted in epoxy. All sizes and morphologies were selected for analysis, although an attempt was made to choose crystals that were free of inclusions and cracks. For detrital samples, zircons were poured in a layer onto tape and then mounted in epoxy, generally resulting in several hundred grains per sample. Orthogneiss zircons were imaged using cathodeluminescence on the scanning electron microscope (SEM) prior to analysis. The number of grains analyzed ranged from 25 to 50 for orthogneiss samples, depending on age heterogeneity (resulting from lead loss, young zircon growth or inheritance) to approximately 100 for detrital samples. The laser diameter was 25, 35 or 50 lm and had a depth of 12 lm for the first spot size and 20 lm for the second two. Larger spot sizes yield more precise measurements due to the larger volume of material ablated, but in some cases small grain sizes or metamorphic overgrowths required using a smaller spot size. Isotopes with a ‘‘’’, e.g. 206Pb⁄, include a common lead correction (see Gehrels et al., 2008).

The low concentration of 235U relative to 238U produces low concentrations of 207Pb in younger zircons which results in substantially larger measurement uncertainty for 206Pb/207Pb. Consequently, the 206Pb⁄/207Pb⁄ ages for younger grains are less precise than the 206Pb⁄/238U ages. For detrital zircon ages, we use a cutoff of 1000 Ma: if the average of the 206Pb⁄/238U and 206Pb⁄/207Pb⁄ age is less than 1000 Ma, we prefer to use the 206Pb⁄/238U age; if it is greater then the 206Pb⁄/207Pb⁄ age is preferred. One exception is the paragneiss DZ spectrum, where lead loss and metamorphic zircon growth are significant and we have a greater confidence in the accuracy of the 206Pb⁄/207Pb⁄ ages for all the grains despite the loss in precision. Finally, DZ analyses are rejected if they have more than 10% age uncertainty, 30% discordance (defined as the 206 ⁄ 238 206 ⁄ 207 ⁄

Pb / U age divided by the Pb / Pb age) or 5% reverse discordance.

Reported crystallization ages for younger (500 Ma) magmatism is generally based on a weighted average of 206Pb⁄/238U ages for a cluster of concordant analyses. In the case of the older Neoproterozoic magmatism, we typically use 206Pb⁄/207Pb⁄ ages to compensate for lead loss or metamorphic zircon growth. For many of the orthogneiss rocks though, there is not a clear cluster of concordant ages. In these cases, the reported crystallization ages are based on a discordia regression through the zircon analyses and are accordingly less precise. In order to best define the discordia, analyses with large uncertainty or discordance were not used in the regression. Analyses not used in the age determinations due to discordance, high uncertainty, lead loss or metamorphic zircon growth are shown with gray error ellipses in the concordia plots and in italics in the data tables.

Zircons in Amdo basement rocks underwent lead loss and metamorphic zircon growth during Early Jurassic high-grade metamorphism (180 Ma; Guynn et al., 2006). Crystallization of zircon from metamorphic fluids can generally be distinguished from magmatic zircon growth or lead loss by a high U/Th ratio (e.g. Gehrels et al. (2008) and references therein). U/Th ratios of magmatic zircon are typically less than three, while metamorphic zircon U/Th ratios are generally greater than five.

All U–Pb plots, weighted average calculations and discordia regressions were made using Isoplot 3.00 (Ludwig, 2003). All analyses are plotted with 2r or 95% confidence limits, while apparent ages of individual zircon analyses in Table 2 are reported at the 1r level. The stated uncertainties (2r) on the assigned crystallization ages include contributions from all known random and systematic errors. Random and systematic errors are included in the data tables.

4.1. Orthogneiss zircon results

Although complicated by lead loss and metamorphic zircon growth, dating of individual zircons allowed us to define a bimodal distribution of orthogneiss crystallization ages for the Amdo basement (Table 1). The older age group is early Neoproterozoic (920– 820 Ma) and the younger is Cambo-Ordovician (540–460 Ma). Most of the orthogneisses do not have inherited zircons.

4.1.1. JG053104-1

This sample is a felsic gneiss composed of quartz, plagioclase and microcline with minor biotite and is located in the south-central part of the gneiss exposure about 10 km from the southern boundary (Fig. 3). The zircons in this sample exhibit significant lead loss and most analyses are discordant, so we use a discordia regression to define the crystallization age (Fig. 4a). Since there are no Jurassic metamorphic ages in this sample, we anchor the lower intercept of the discordia at 180 ± 10, the age of high-grade metamorphism reported by Guynn et al. (2006). The resulting upper intercept age is 910 ± 16 Ma.

4.1.2. JG061504-2

This granodiorite orthogneiss has a well developed foliation defined by biotite and stretched quartz grains. It was collected 10 km west of the Lhasa–Golmud highway (Fig. 3). This gneiss and JG061504-1 were interlayered within the same exposure, though the latter is more felsic and less deformed. Some zircons in this sample appear to have undergone lead loss (Fig. 4b). One zircon tip yielded an age of 185.6 ± 1.5 Ma and a U/Th ratio of 5.6, significantly higher than the rest of the analyses (U/Th 0.8) indicating it is metamorphic in origin. As there is only one zircon with a Jurassic age in this sample, we use the age of metamorphism reported by Guynn et al. (2006) to anchor the discordia line at

Amdo basement U–Pb Zircon geochronologic analyses by Laser-Ablation Multicollector ICP mass spectrometry.

Spot ID

U (ppm)

206

Pb

204

Pb

U/Th

Isotopic ratios

Apparent ages (Ma)

Preferred

age (Ma)

207

Pb

235

U

a

±(

)

%

206

Pb

238

U

a

)

±(

%

Error corr.

206

Pb

238

U

a

±(

Ma

)

207

Pb

235

U

a

Ma

)

±(

Pb

206

207

Pb

a

±(

)

±(

Ma

)

Ma

Orthogneiss JG053104-1 206Pb/238U Systematic error (2r): 1.18%

04 2018 6305 1.7 1.2509 4.2 0.1292 3.5 0.84 783.3 25.9 823.8 23.6 934.8 46.5 783.3 25.9 07 1402 15,363 1.2 1.3258 1.0 0.1382 0.7 0.71 834.8 5.8 857.1 6.1 915.2 15.2 834.8 5.8 11 1045 134,293 0.9 1.3549 1.4 0.1404 1.2 0.86 847.0 9.4 869.7 8.1 927.9 14.5 847.0 9.4 12 1430 84,931 1.4 1.3251 1.8 0.1376 1.7 0.92 831.0 12.9 856.8 10.4 923.9 14.4 831.0 12.9 13 1300 105,755 1.2 1.3898 1.6 0.1443 1.5 0.90 868.8 12.0 884.6 9.7 924.2 14.4 868.8 12.0 14 679 53,443 0.9 1.3759 1.0 0.1438 0.7 0.70 865.8 5.7 878.7 5.9 911.3 14.7 865.8 5.7 17 1473 112,261 1.1 1.2362 1.9 0.1298 1.8 0.93 787.0 13.0 817.2 10.6 900.2 14.5 787.0 13.0 18 2054 2530 1.6 1.1601 4.4 0.1198 3.2 0.73 729.4 22.2 782.0 24.1 935.1 62.0 729.4 22.2 21 1272 82,698 1.1 1.2940 4.0 0.1355 4.0 0.98 819.4 30.4 843.1 23.0 905.9 14.5 819.4 30.4 22 1951 91,430 1.5 1.3031 1.0 0.1365 0.7 0.71 825.1 5.4 847.1 5.7 905.2 14.4 825.1 5.4 24 760 97,904 1.1 1.3787 2.2 0.1432 2.1 0.95 862.5 16.9 879.9 13.0 923.9 14.4 862.5 16.9

25 2579 1628 1.3 1.1216 2.4 0.1143 2.1 0.89 697.7 13.9 763.8 12.7 962.3 22.4 697.7 13.9 28 1939 47,177 1.2 1.0971 5.1 0.1177 5.0 0.99 717.5 34.1 751.9 26.9 855.8 14.9 717.5 34.1 32 1755 72,528 1.8 1.2526 1.5 0.1341 1.3 0.88 811.1 10.1 824.6 8.5 861.0 14.7 811.1 10.1 34 1374 12,596 1.0 1.3773 1.0 0.1442 0.7 0.68 868.6 5.7 879.3 6.0 906.3 15.4 868.6 5.7

36 1385 60,243 1.1 1.3190 1.1 0.1409 0.7 0.65 850.0 5.6 854.1 6.2 864.5 17.1 850.0 5.6

38 1218 31,672 1.7 1.3249 1.0 0.1411 0.7 0.71 851.0 5.6 856.6 5.7 871.2 14.6 851.0 5.6 40 1289 93,209 1.5 1.1657 1.7 0.1253 1.5 0.88 760.9 11.1 784.6 9.5 852.9 16.9 760.9 11.1 44 1929 1808 0.9 0.6358 2.4 0.0703 1.9 0.77 438.2 7.8 499.7 9.5 792.0 32.5 438.2 7.8 48 1531 14,646 1.3 1.2683 1.1 0.1344 0.8 0.72 813.0 5.8 831.6 6.0 881.6 15.1 813.0 5.8

1. 1314 44,169 1.2 1.2819 1.4 0.1361 1.1 0.82 822.4 8.8 837.7 7.9 878.3 16.3 822.4 8.8
2. 2023 66,468 1.1 1.3138 1.2 0.1393 1.0 0.82 840.8 7.8 851.8 7.0 880.6 14.5 840.8 7.8
3. 1396 48,616 1.6 1.2576 1.1 0.1340 0.9 0.78 810.4 6.7 826.8 6.4 871.1 14.6 810.4 6.7

57 1904 18,262 1.2 1.3170 1.0 0.1390 0.7 0.70 838.9 5.6 853.2 5.8 890.6 14.8 838.9 5.6 58 2406 9441 1.2 1.3008 1.0 0.1375 0.7 0.69 830.7 5.5 846.1 5.9 886.6 15.3 830.7 5.5 59 1034 24,812 3.1 0.9468 6.5 0.1057 6.4 0.98 647.8 39.6 676.4 32.3 773.1 26.9 647.8 39.6 60 1054 4206 1.6 0.9490 4.7 0.1022 4.5 0.96 627.5 27.0 677.6 23.1 847.9 25.9 627.5 27.0 63 1230 91,586 1.0 1.3456 1.0 0.1417 0.8 0.73 854.4 6.1 865.6 6.0 894.5 14.5 854.4 6.1

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Orthogneiss JG061504-2 206Pb/238U Systematic error (2r): 1.24%

01c 272 18,248 0.7 1.3950 1.3 0.1494 0.7 0.56 897.8 5.9 886.8 7.4 859.4 21.7 897.8 5.9

01t 271 27,949 0.8 1.3464 1.5 0.1422 0.8 0.56 857.2 6.6 866.0 8.6 888.4 25.3 857.2 6.6

02 197 4769 0.7 1.2174 3.7 0.1276 0.7 0.19 774.4 5.1 808.6 20.8 904.0 75.4 774.4 5.1 03 341 14,268 0.7 1.3409 1.7 0.1428 0.7 0.41 860.3 5.6 863.6 9.8 872.1 31.9 860.3 5.6

04 252 15,451 0.5 1.3498 1.7 0.1447 0.7 0.40 871.2 5.7 867.5 10.2 858.0 33.3 871.2 5.7 06 298 26,227 0.7 1.3763 1.9 0.1464 1.4 0.71 880.9 11.3 878.9 11.3 873.6 28.0 880.9 11.3 07 388 11,405 0.8 1.3567 1.5 0.1437 0.7 0.48 865.6 5.7 870.4 8.6 882.8 26.7 865.6 5.7

1. 400 16,652 0.7 1.2614 1.4 0.1338 1.0 0.72 809.6 7.7 828.6 7.9 879.8 19.9 809.6 7.7
2. 679 27,528 0.6 1.3642 1.0 0.1445 0.7 0.69 870.3 5.7 873.7 6.0 882.3 15.3 870.3 5.7 10 325 19,822 0.8 1.2008 1.8 0.1292 1.1 0.61 783.3 8.0 800.9 9.9 850.2 29.6 783.3 8.0 11 490 7216 0.6 1.1667 1.7 0.1236 0.7 0.42 751.2 5.1 785.1 9.2 882.6 31.6 751.2 5.1

13 425 46,859 0.9 1.2535 1.6 0.1343 0.7 0.45 812.3 5.3 825.0 8.9 859.3 29.1 812.3 5.3 14 596 23,906 1.6 1.3064 1.8 0.1389 1.5 0.84 838.5 12.1 848.5 10.5 874.8 20.3 838.5 12.1 15 610 57,193 0.7 1.2821 1.0 0.1361 0.7 0.71 822.3 5.4 837.8 5.7 878.9 14.5 822.3 5.4 16 297 34,382 0.8 1.3451 3.3 0.1448 3.1 0.93 871.8 24.9 865.5 19.1 849.3 25.1 871.8 24.9 17 522 30,514 0.7 1.2862 1.5 0.1368 1.2 0.81 826.3 9.5 839.6 8.6 874.9 18.2 826.3 9.5 18 204 7534 1.5 0.9324 5.8 0.1025 4.1 0.71 629.2 24.8 668.9 28.6 805.1 86.3 629.2 24.8

19 388 20,690 0.8 1.3380 2.4 0.1426 2.2 0.91 859.6 17.5 862.4 13.9 869.4 20.5 859.6 17.5 20 266 29,916 0.9 1.5867 9.1 0.1602 6.9 0.75 957.9 61.2 965.0 56.8 981.3 121.9 957.9 61.2 21 440 6778 0.5 1.3323 2.0 0.1404 1.6 0.77 847.0 12.4 859.9 11.8 893.3 27.0 847.0 12.4 22 288 34,587 0.7 1.2937 1.4 0.1400 0.7 0.51 844.6 5.5 842.9 7.9 838.6 24.7 844.6 5.5 23 2313 13,363 1.0 1.3327 1.1 0.1413 0.9 0.76 852.1 6.9 860.1 6.5 880.7 15.0 852.1 6.9 24 303 19,830 0.7 1.2449 2.4 0.1330 2.0 0.83 804.8 15.1 821.1 13.6 865.5 28.1 804.8 15.1 25 353 31,912 1.0 1.3014 2.6 0.1397 2.4 0.92 843.1 18.9 846.3 14.9 854.8 21.3 843.1 18.9 25c 454 43,190 0.8 1.4154 3.9 0.1492 3.8 0.98 896.6 32.0 895.5 23.2 892.7 15.8 896.6 32.0 26 408 29,624 0.6 1.3304 1.2 0.1412 0.8 0.63 851.2 6.2 859.1 7.2 879.4 20.0 851.2 6.2

27 395 33,655 0.7 1.2958 1.0 0.1388 0.7 0.70 838.0 5.5 843.9 5.7 859.4 14.8 838.0 5.5

29t 1266 5249 5.6 0.2130 3.3 0.0292 0.8 0.26 185.6 1.5 196.1 5.8 324.2 71.3 185.6 1.5 30 455 43,389 0.9 1.4374 1.9 0.1530 1.7 0.91 917.8 14.6 904.6 11.3 872.8 16.3 917.8 14.6

Orthogneiss JG060,504-2 206Pb/238U Systematic error (2r): 1.31 %

02C 774 35,290 0.8 1.0754 5.6 0.1207 5.0 0.88 734.4 34.4 741.4 29.7 762.4 56.3 734.4 34.4

04C 531 14,026 1.3 1.0489 5.2 0.1110 3.3 0.64 678.4 21.4 728.4 26.8 885.2 81.7 678.4 21.4 05C 2673 11,665 0.4 0.4471 8.8 0.0533 8.4 0.95 335.0 27.4 375.2 27.7 632.0 59.5 335.0 27.4 05T 1537 30,736 8.7 0.1888 2.1 0.0275 1.2 0.57 175.2 2.1 175.6 3.4 181.6 40.9 175.2 2.1 06C 1121 3587 0.4 1.0742 7.7 0.1075 6.1 0.79 658.5 38.1 740.8 40.5 998.4 95.7 658.5 38.1 06T 1315 34,851 1.1 1.1881 4.0 0.1273 3.8 0.95 772.6 27.4 795.1 22.0 858.5 26.8 772.6 27.4 07C 618 4268 0.9 0.7104 7.9 0.0751 6.6 0.83 466.8 29.5 545.0 33.4 887.0 91.8 466.8 29.5 07T 1705 7691 2.6 0.4954 4.5 0.0614 4.2 0.94 383.9 15.7 408.6 15.1 550.3 34.4 383.9 15.7 08C 390 36,365 2.8 1.0137 2.6 0.1127 1.8 0.70 688.5 12.0 710.7 13.3 781.4 38.9 688.5 12.0 09 1424 48,798 2.2 0.7874 4.1 0.0913 3.7 0.90 563.3 19.9 589.7 18.4 692.8 38.2 563.3 19.9 10 727 5710 0.6 0.7037 11.3 0.0724 7.8 0.69 450.8 34.0 541.0 47.4 941.5 167.4 450.8 34.0 11 1331 31,741 1.5 0.9258 6.7 0.1042 6.0 0.89 638.8 36.2 665.4 32.5 756.7 62.7 638.8 36.2 12T 1189 20,107 5.6 0.2342 6.9 0.0331 6.8 0.98 210.2 14.0 213.7 13.3 251.7 28.5 210.2 14.0

13C 1138 6590 1.0 0.9036 6.1 0.0943 5.3 0.88 580.8 29.6 653.7 29.2 913.9 59.7 580.8 29.6 14C 1827 23,787 1.4 0.7387 8.4 0.0837 8.3 0.99 518.0 41.5 561.6 36.2 742.7 19.3 518.0 41.5 15C 391 2572 1.4 0.9310 6.8 0.0936 5.3 0.78 576.8 29.2 668.1 33.4 989.7 87.7 576.8 29.2 16 866 22,114 0.7 1.2963 2.1 0.1365 1.5 0.72 824.7 11.5 844.1 11.8 895.4 29.3 824.7 11.5

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17T 1126 26,909 7.7 0.1928 3.7 0.0281 3.2 0.86 178.8 5.6 179.0 6.0 181.8 43.3 178.8 5.6 18 925 19,172 1.0 0.8553 3.4 0.0935 2.9 0.84 576.0 15.8 627.5 15.9 818.0 38.5 576.0 15.8 19C 178 14,251 1.3 0.9455 3.6 0.1066 3.5 0.96 652.9 21.6 675.7 17.9 752.5 22.6 652.9 21.6 20C 1211 3035 1.0 0.9967 11.6 0.0960 8.0 0.70 590.7 45.4 702.1 58.6 1077.2 166.9 590.7 45.4 21C 555 22,277 1.2 1.0692 2.9 0.1176 2.7 0.91 716.8 18.1 738.4 15.4 804.4 25.3 716.8 18.1

22C 148 11,050 1.5 0.9237 7.7 0.1004 6.7 0.87 616.5 39.7 664.3 37.7 830.3 78.3 616.5 39.7

23B 490 19,643 0.6 0.8070 4.1 0.0901 4.0 0.97 556.0 21.1 600.8 18.6 773.6 22.2 556.0 21.1 23C 436 41,116 1.9 1.1853 1.8 0.1298 1.2 0.70 786.6 9.1 793.8 9.7 814.1 26.2 786.6 9.1 24C 521 29,236 1.2 0.8077 2.2 0.0910 2.0 0.87 561.6 10.5 601.2 10.1 753.2 23.0 561.6 10.5 25B 874 3326 2.4 0.4281 5.6 0.0478 5.4 0.96 300.9 15.9 361.8 17.1 773.9 31.8 300.9 15.9 25C 1322 13,605 0.8 1.1515 4.6 0.1242 4.4 0.95 754.4 31.3 777.9 25.0 845.9 28.7 754.4 31.3

26 893 65,606 1.2 1.0673 2.5 0.1176 2.2 0.85 716.8 14.7 737.4 13.4 800.7 27.9 716.8 14.7 27C 245 22,289 4.2 0.7129 9.9 0.0816 9.3 0.94 505.9 45.2 546.5 41.9 719.6 72.7 505.9 45.2 27T 879 77,814 1.5 1.1613 2.0 0.1265 1.7 0.89 768.0 12.6 782.6 10.7 824.2 19.0 768.0 12.6

28 1361 25,624 1.7 0.4851 3.8 0.0575 3.5 0.90 360.4 12.1 401.6 12.7 645.8 35.3 360.4 12.1 29 475 40,628 1.4 1.2419 2.0 0.1338 1.0 0.51 809.7 7.6 819.7 11.1 846.9 35.4 809.7 7.6 30 778 21,358 0.9 1.0714 6.4 0.1155 5.8 0.91 704.9 38.7 739.4 33.5 845.5 55.3 704.9 38.7 32T 986 61,327 1.4 1.1775 2.5 0.1272 2.2 0.87 771.7 16.0 790.1 13.9 842.4 25.8 771.7 16.0 33T 1438 75,909 1.1 1.1260 1.6 0.1225 1.5 0.91 745.1 10.2 765.8 8.6 826.7 14.2 754.1 10.2 34 1276 3425 1.2 0.7988 6.7 0.0815 5.2 0.78 505.3 25.1 596.2 30.0 958.8 85.6 505.3 25.1

36 1375 55,224 1.7 0.7249 6.0 0.0817 6.0 0.99 506.5 29.1 553.5 25.8 752.1 20.3 506.5 29.1

Orthogneiss JG061504-1 206Pb/238U Systematic error (2r): 0.81%

01 251 23,740 1.4 1.1567 3.1 0.1278 2.0 0.64 775.1 14.5 780.4 16.9 795.7 49.9 775.1 14.5 03 1063 10,816 2.3 0.7089 1.2 0.0862 0.7 0.61 533.1 3.6 544.1 4.9 590.4 20.0 533.1 3.6 04 300 2755 0.3 0.6680 6.1 0.0812 1.1 0.19 503.3 5.5 519.5 24.8 591.2 130.3 503.3 5.5 06 1362 13,880 114.2 0.2053 2.4 0.0295 1.2 0.49 187.4 2.1 189.6 4.1 216.5 47.8 187.4 2.1 07t 768 18,708 1.7 0.7104 2.6 0.0874 2.3 0.87 540.2 11.8 545.0 11.1 565.0 28.6 540.2 11.8 07t2 738 8804 2.4 0.6924 1.8 0.0855 0.9 0.49 529.1 4.5 534.2 7.5 556.2 34.3 529.1 4.5 09c 502 12,778 1.5 1.2813 1.7 0.1370 0.7 0.43 827.8 5.6 837.4 9.6 863.2 31.4 827.8 5.6 10 466 10,641 2.0 0.8258 9.7 0.0931 9.2 0.96 574.0 50.7 611.3 44.4 751.9 60.0 574.0 50.7 11 544 46,871 3.5 0.6992 2.2 0.0866 1.8 0.79 535.1 9.0 538.3 9.2 551.7 29.4 535.1 9.0 12 356 24,705 0.4 0.6834 1.7 0.0859 0.9 0.50 531.2 4.5 528.8 7.2 518.5 33.2 531.2 4.5 14 416 21,498 0.6 0.6180 5.3 0.0788 4.8 0.92 489.1 22.8 488.6 20.4 486.2 45.5 489.7 22.8 16 507 21,896 0.5 0.6566 1.5 0.0844 0.8 0.56 522.5 4.1 512.5 5.9 468.3 26.8 522.5 4.1

207Pba

235U

17 711 18,372 0.6 0.6708 4.7 0.0809 1.5 0.31 501.4 7.0 521.2 19.2 608.9 96.9 501.4 7.0 21 698 27,793 3.3 0.4658 5.5 0.0609 5.1 0.93 381.4 18.9 388.3 17.7 429.4 45.5 381.4 18.9 22 289 9378 0.4 0.6893 3.5 0.0870 0.7 0.20 537.8 3.6 532.4 14.6 509.1 76.1 537.8 3.6

28 564 2073 21.2 0.4551 16.7 0.0527 3.1 0.18 331.4 9.9 380.9 52.9 694.1 351.0 331.4 9.9

Orthogneiss PK97-6-4-1B 206Pb/238U Systematic error (2r): 1.30%

01 770 46,403 1.8 0.6304 6.3 0.0796 5.8 0.92 494.0 27.7 496.4 24.8 507.2 53.8 494.0 27.7

03 349 8546 2.2 0.4152 6.2 0.0530 5.1 0.83 332.9 16.6 352.6 18.5 484.3 77.3 332.9 16.6 04 696 36,334 1.6 0.5140 2.3 0.0659 2.0 0.86 411.4 8.0 421.1 8.0 475.0 26.5 411.4 8.0 05 826 37,512 1.9 0.6106 2.5 0.0774 2.4 0.95 480.6 11.1 484.0 9.7 500.0 16.8 480.6 11.1 06 1211 3629 1.6 0.6230 6.6 0.0710 5.8 0.88 441.9 24.8 491.7 25.8 730.9 67.0 441.9 24.8 07 348 19,334 1.5 0.6285 3.3 0.0798 2.5 0.74 494.8 11.7 495.2 13.0 496.6 49.2 494.8 11.7 08 725 767 2.0 0.8050 10.5 0.0726 4.1 0.39 451.5 18.1 599.6 47.7 1208.5 191.0 451.5 18.1 09 190 14,772 1.8 0.6317 3.7 0.0836 3.2 0.86 517.4 15.9 497.2 14.7 405.1 43.4 517.4 15.9 10C 473 27,629 1.8 0.6159 8.0 0.0763 2.9 0.37 473.9 13.5 487.3 30.9 550.5 162.1 473.9 13.5 10T 639 41,913 2.0 0.6129 2.6 0.0776 2.4 0.92 481.9 10.9 485.4 9.9 501.8 21.8 481.9 10.9 11 549 21,325 1.8 0.5961 6.5 0.0764 6.3 0.96 474.8 28.7 474.7 24.6 474.4 37.9 474.8 28.7 12 227 19,250 1.8 0.6266 2.3 0.0806 1.6 0.71 499.9 7.7 494.0 8.8 466.6 35.2 499.9 7.7 13 383 18,759 1.4 0.6504 3.9 0.0808 1.2 0.31 500.6 5.9 508.7 15.8 545.3 81.9 500.6 5.9 14 528 12,746 1.7 0.6987 5.5 0.0899 4.7 0.84 554.7 24.8 538.0 23.2 467.7 66.2 554.7 24.8 15 170 14,553 1.6 0.6581 3.4 0.0830 1.8 0.52 513.8 8.7 513.4 13.6 511.9 63.2 513.8 8.7 16C 2912 3110 0.6 0.4940 8.7 0.0560 5.0 0.57 351.2 17.1 407.6 29.3 741.1 151.5 351.2 17.1 16T 667 3995 1.5 0.7314 6.3 0.0823 2.7 0.43 509.8 13.1 557.4 26.9 756.9 119.6 509.8 13.7

17 544 10,925 1.5 0.5997 5.7 0.0746 4.9 0.86 463.8 22.1 477.0 21.8 541.1 63.2 463.8 22.7 18 1427 1027 2.6 0.5324 14.0 0.0493 4.9 0.35 310.1 14.9 433.4 49.3 1156.3 260.2 310.1 74.9 19 298 14,191 1.7 0.6804 3.7 0.0856 2.5 0.67 529.4 12.7 527.0 15.3 516.5 60.6 529.4 12.7 20 208 18,732 1.6 0.6274 2.8 0.0812 1.8 0.65 503.5 8.8 494.5 10.9 452.7 47.1 503.5 8.8

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Orthogneiss JG061604-1 206Pb/238U Systematic error (2r): 1.15%

01 161 4536 0.7 0.5780 3.6 0.0788 2.3 0.65 488.8 11.0 463.2 13.3 338.0 61.1 488.8 11.0 02 162 3107 0.6 0.5878 4.0 0.0760 1.3 0.32 472.3 5.9 469.4 15.1 455.3 84.4 472.3 5.9 03 399 2277 1.0 0.4075 6.6 0.0526 4.1 0.61 330.7 13.1 347.0 19.5 457.8 116.5 330.7 13.1 04c 327 4212 54.3 0.1819 7.8 0.0287 1.4 0.18 182.1 2.6 169.7 12.1 1.0 184.2 182.1 2.6 04t 553 5646 49.9 0.1884 2.8 0.0275 0.9 0.31 175.1 1.5 175.2 4.6 177.5 63.3 175.1 1.5 05e 443 5803 1.1 0.5494 9.6 0.0672 4.0 0.42 419.5 16.4 444.6 34.5 576.6 189.4 419.5 16.4 06 311 2984 35.3 0.1837 8.3 0.0275 2.6 0.31 174.7 4.4 171.3 13.0 124.4 185.1 174.7 4.4 07 429 5706 14.8 0.1857 7.9 0.0283 2.7 0.34 180.0 4.8 173.0 12.6 78.6 177.9 180.0 4.8

1. 830 10,912 53.2 0.1872 4.4 0.0286 1.2 0.27 181.5 2.1 174.3 7.0 77.2 99.7 181.5 2.1
2. 511 7751 39.2 0.1819 4.9 0.0275 0.9 0.19 175.0 1.6 169.7 7.7 96.3 115.0 175.0 1.6 10c 224 1297 0.9 0.4168 9.3 0.0521 2.3 0.25 327.3 7.4 353.8 27.9 531.3 198.6 327.3 7.4

10t 290 11,561 0.7 0.6520 2.7 0.0845 0.9 0.35 522.8 4.7 509.7 10.6 451.4 55.1 522.8 4.7 11c 405 22,387 1.0 0.5514 7.3 0.0719 6.5 0.88 447.6 28.1 445.9 26.5 437.2 76.1 447.6 28.1 11t 427 10,364 35.8 0.1919 5.9 0.0292 0.7 0.12 185.7 1.3 178.3 9.6 81.2 139.0 185.7 1.3 12 326 3348 0.6 0.4397 8.3 0.0571 6.9 0.83 358.1 24.0 370.0 25.7 445.4 102.0 358.1 24.0 13c 629 8708 1.0 0.5050 12.3 0.0638 12.0 0.97 398.6 46.3 415.1 41.9 507.7 60.6 398.6 46.3 13t 325 15,444 1.5 0.5082 3.1 0.0642 1.0 0.31 401.3 3.7 417.2 10.6 506.0 64.6 401.3 3.7

14 175 7634 0.8 0.5950 5.0 0.0779 1.4 0.28 483.3 6.6 474.1 18.9 429.8 106.7 483.3 6.6 15c 341 7384 1.0 0.3449 14.4 0.0468 12.6 0.87 294.7 36.2 300.9 37.5 349.4 159.3 294.7 36.2 15t 581 11,864 14.4 0.1866 4.2 0.0272 1.1 0.27 172.9 1.9 173.7 6.7 184.2 93.7 172.9 1.9

16 251 5906 49.9 0.1893 10.2 0.0282 1.7 0.16 179.2 2.9 176.0 16.5 133.8 236.7 179.2 2.9 17 775 14,382 61.2 0.1936 5.0 0.0285 3.7 0.74 181.1 6.6 179.7 8.2 161.5 78.5 181.1 6.6 18 365 26,666 0.8 0.6389 3.4 0.0810 2.6 0.76 502.0 12.4 501.6 13.4 500.1 48.2 502.0 12.4 19 468 11,114 15.0 0.1900 4.7 0.0291 0.8 0.17 184.8 1.4 176.6 7.6 68.1 110.2 184.8 1.4

20 210 4845 49.8 0.2018 7.9 0.0301 0.7 0.09 191.1 1.4 186.6 13.4 130.2 185.0 191.1 1.4

21c 645 26,177 0.9 0.5893 1.8 0.0748 0.7 0.40 465.2 3.3 470.4 6.9 496.3 37.2 465.2 3.3 21t 461 12,015 0.8 0.5272 3.0 0.0684 1.1 0.37 426.2 4.6 430.0 10.6 450.0 62.5 426.2 4.6 22 269 10,435 0.9 0.4603 4.4 0.0613 1.9 0.43 383.8 7.0 384.5 14.0 388.6 88.4 383.8 7.0 23 337 11,045 2.5 0.3167 10.7 0.0435 9.9 0.93 274.2 26.6 279.3 26.0 322.0 89.7 274.2 26.6 24 184 12,167 0.9 0.7629 4.8 0.0958 0.8 0.17 589.9 4.7 575.7 21.2 520.1 104.2 589.9 4.7

25 571 14,545 56.5 0.1937 4.1 0.0286 2.0 0.50 182.0 3.7 179.8 6.8 150.8 83.5 182.0 3.7 26c 282 10,382 59.9 0.1978 5.3 0.0287 0.7 0.13 182.2 1.3 183.3 8.9 198.0 122.8 182.2 1.3 27 132 2240 0.8 0.7447 28.5 0.0811 5.2 0.18 502.4 25.1 565.1 124.3 826.4 596.7 502.4 25.1 28 319 5598 0.7 0.6383 6.9 0.0792 1.0 0.14 491.5 4.6 501.2 27.3 546.0 149.5 491.5 4.6

29 344 10,588 52.7 0.1935 6.1 0.0288 0.8 0.13 182.8 1.4 179.6 10.0 137.8 141.4 182.8 1.4

Orthogneiss PK97-6-4-1A 206Pb/238U Systematic error (2r): 1.30%

01 471 14,669 0.9 0.5985 3.4 0.0735 2.9 0.86 457.1 12.9 476.3 13.0 570.0 37.9 457.1 12.9 02 133 5153 1.0 0.6749 9.4 0.0837 3.6 0.38 518.1 17.7 523.7 38.3 547.8 189.5 518.1 17.7 04 175 7256 2.2 0.5978 2.7 0.0753 2.0 0.73 468.1 9.0 475.8 10.4 513.3 40.6 468.1 9.0 05 415 24,215 1.2 0.6591 7.5 0.0821 7.2 0.97 508.5 35.3 514.0 30.1 538.7 41.4 508.5 35.3 06 1339 970 19.0 0.3130 5.4 0.0315 4.1 0.75 200.2 8.1 276.5 13.2 985.3 73.1 200.2 8.1 07 726 26,669 1.1 0.6453 1.7 0.0804 1.2 0.68 498.7 5.6 505.6 6.8 536.7 27.1 498.7 5.6 08 399 9460 1.8 0.5783 8.3 0.0714 4.4 0.52 444.8 18.8 463.3 31.0 556.2 154.8 444.8 18.8 09 230 10,450 2.2 0.5007 9.4 0.0665 9.2 0.98 414.9 36.9 412.1 31.9 396.5 46.9 414.9 36.9

10 132 6112 1.1 0.6333 5.0 0.0796 1.5 0.30 493.6 7.2 498.1 19.8 518.9 105.3 493.6 7.2 11 219 5375 1.3 0.5958 2.9 0.0717 1.5 0.51 446.2 6.4 474.6 11.0 614.2 53.6 446.2 6.4 12 216 6397 1.3 0.5795 7.9 0.0774 7.6 0.97 480.3 35.3 464.1 29.4 384.8 45.4 480.3 35.3 13 484 7556 6.1 0.2349 6.4 0.0334 5.7 0.89 211.8 11.8 214.2 12.4 240.5 68.0 211.8 11.8 14 227 4007 1.2 0.6883 11.0 0.0779 2.4 0.22 483.8 11.4 531.8 45.4 743.5 226.5 483.8 11.4 15 302 9874 1.2 0.6069 4.0 0.0754 2.4 0.61 468.5 11.0 481.6 15.2 544.6 68.7 468.5 11.0 16 393 6590 0.7 0.6719 8.7 0.0788 4.4 0.50 489.3 20.6 521.9 35.6 667.2 161.4 489.3 20.6 17 139 3940 1.1 0.6790 7.7 0.0837 6.2 0.80 518.2 30.6 526.2 31.4 561.0 99.2 518.2 30.6 18 528 26,875 1.2 0.6261 2.8 0.0786 1.6 0.56 488.0 7.5 493.7 11.1 520.2 51.7 488.0 7.5 19 474 25,490 1.3 0.6332 1.7 0.0798 1.4 0.83 494.8 6.7 498.1 6.7 512.9 20.6 494.8 6.7 21 433 13,518 1.3 0.6731 3.0 0.0850 2.3 0.77 525.9 11.6 522.6 12.1 508.2 41.7 525.9 11.6

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22 386 9674 1.8 0.8299 3.7 0.0781 3.0 0.80 484.6 13.8 613.6 17.0 1123.7 44.0 484.6 13.8 23 411 10,480 1.7 0.5872 8.6 0.0719 8.2 0.95 447.9 35.3 469.1 32.4 574.2 59.6 447.9 35.3 24 458 10,239 1.3 0.6311 2.7 0.0767 1.6 0.59 476.2 7.4 496.8 10.7 593.1 47.4 476.2 7.4

25 688 1408 1.5 0.5776 7.2 0.0614 6.0 0.83 384.3 22.2 462.9 26.8 874.7 84.2 384.3 22.2 26 666 24,597 1.0 0.5335 4.8 0.0659 4.3 0.90 411.4 17.1 434.1 16.9 556.8 45.8 411.4 17.1

27 949 13,843 17.1 0.1967 3.5 0.0295 3.2 0.91 187.6 5.9 182.3 5.8 113.4 34.8 187.6 5.9

Orthogneiss JG053104-2 206Pb/238U Systematic error (2r): 0.94%

010R 329 6789 1.2 1.1988 3.8 0.1284 1.6 0.41 778.9 11.5 800.0 21.2 859.3 72.6 778.9 11.5

01C 828 24,428 1.2 0.6365 2.9 0.0792 1.0 0.34 491.3 4.7 500.1 11.4 540.9 59.6 491.3 4.7

01R 527 19,951 1.2 0.6555 3.3 0.0819 1.2 0.35 507.2 5.7 511.9 13.3 532.7 67.8 507.2 5.7 02C 633 11,402 0.8 1.1768 4.0 0.1244 2.7 0.68 755.8 19.3 789.8 21.7 887.0 59.9 755.8 19.3 02T 451 14,854 5.4 0.5900 5.1 0.0682 1.4 0.27 425.5 5.8 470.9 19.3 698.2 104.8 425.5 5.8 03C 404 17,986 0.9 1.2330 2.9 0.1312 1.6 0.54 794.5 11.8 815.7 16.5 874.2 51.4 794.5 11.8

03R 436 16,151 1.1 1.3333 3.0 0.1419 2.3 0.75 855.5 18.3 860.3 17.6 872.7 41.2 855.5 18.3

04T 121 2858 3.2 0.7213 13.8 0.0766 5.4 0.39 475.5 24.6 551.4 58.8 878.8 263.9 475.5 24.6

05C 562 18,117 1.5 1.2477 6.9 0.1314 6.5 0.95 795.7 48.9 822.3 38.9 895.0 45.9 795.7 48.9 05R 637 3019 1.0 1.2302 8.4 0.1247 1.0 0.12 757.3 7.5 814.4 46.9 973.8 169.7 757.3 7.5 06C 364 11,360 1.5 1.1389 2.9 0.1251 2.1 0.73 759.7 15.0 772.0 15.5 807.8 41.2 759.7 15.0

06R 644 14,390 1.9 1.1592 2.9 0.1261 1.5 0.52 765.7 11.0 781.6 16.0 827.0 52.5 765.7 11.0 07C 177 7018 1.2 1.3462 6.7 0.1351 2.3 0.34 817.2 17.6 865.9 39.2 992.8 128.8 817.2 17.6

07R 150 4029 1.3 1.2527 8.4 0.1286 1.6 0.19 779.9 11.7 824.6 47.5 947.1 169.4 779.9 11.7

08R 626 2023 2.0 0.6985 8.0 0.0861 2.2 0.28 532.5 11.4 537.9 33.3 560.7 167.2 532.5 11.4 09C 539 7293 1.5 0.6066 4.6 0.0756 2.7 0.59 470.1 12.3 481.4 17.6 535.9 80.9 470.1 12.3 09R 548 3456 1.7 0.6369 9.8 0.0771 1.2 0.12 478.6 5.5 500.4 38.9 601.2 212.0 478.6 5.5

10C 360 10,394 1.0 1.1995 2.6 0.1289 1.2 0.45 781.6 8.8 800.4 14.6 852.9 48.9 781.6 8.8

11C 394 26,682 1.3 1.2579 2.2 0.1368 1.0 0.46 826.8 7.9 826.9 12.5 827.4 40.8 826.8 7.9 11 R 436 16,915 1.5 1.2579 3.2 0.1346 1.4 0.44 814.0 10.7 827.0 17.9 862.1 58.8 814.0 10.7 12C 337 25,423 1.8 1.3316 3.5 0.1420 2.4 0.69 856.0 19.5 859.6 20.5 868.6 53.0 856.0 19.5 12R 315 37,777 1.6 1.3056 3.1 0.1414 1.1 0.36 852.4 9.0 848.2 17.9 837.0 60.6 852.4 9.0

13R 443 15,826 1.5 1.2899 2.6 0.1360 1.5 0.57 822.0 11.4 841.2 14.9 892.3 44.3 822.0 11.4 14C 807 12,463 1.9 0.6220 3.4 0.0754 1.6 0.45 468.5 7.0 491.1 13.4 597.8 66.3 468.5 7.0

14R 322 5574 2.6 0.5022 11.3 0.0636 3.5 0.31 397.3 13.5 413.2 38.5 503.2 238.2 397.3 13.5 15C 395 1883 1.2 1.4383 12.2 0.1361 2.3 0.19 822.6 17.7 905.0 73.4 1111.8 240.6 822.6 17.7 15R 377 13,146 1.5 1.3036 1.8 0.1397 0.7 0.39 843.0 5.5 847.3 10.4 858.5 34.5 843.0 5.5 16C 451 7751 1.5 1.4053 5.1 0.1434 1.8 0.35 863.7 14.5 891.2 30.3 960.0 97.7 863.7 14.5

16R 461 3495 2.4 0.7242 15.0 0.0791 13.8 0.92 490.5 65.4 553.2 64.1 820.2 121.9 490.5 65.4

17 R 213 5131 4.7 0.4358 17.9 0.0473 15.1 0.84 297.7 44.0 367.3 55.3 833.9 200.5 297.7 44.0 18C 291 9018 1.5 1.5501 3.7 0.1546 1.9 0.51 926.5 16.2 950.5 22.8 1006.5 64.6 926.5 16.2 18R 1123 34,467 1.0 0.7856 28.0 0.0854 27.5 0.98 528.1 139.6 588.7 125.8 829.7 109.8 528.1 139.6 19C 694 29,586 1.6 1.2932 1.3 0.1341 0.8 0.64 811.0 6.3 842.7 7.5 927.3 20.7 811.0 6.3 19R 431 23,055 1.7 1.3269 5.0 0.1392 4.0 0.80 840.2 31.3 857.5 28.9 902.7 62.0 840.2 31.3 20C 294 16,364 2.0 1.2065 6.4 0.1279 1.8 0.28 775.6 13.2 803.6 35.3 881.8 126.1 775.6 13.2 21C 886 31,479 0.9 1.2089 4.0 0.1270 3.8 0.95 771.0 27.6 804.7 22.3 899.1 26.9 771.0 27.6 21R 439 34,094 1.6 1.2416 3.7 0.1318 2.5 0.68 798.3 19.0 819.6 20.8 877.9 56.0 798.3 19.0

Orthogneiss JG063004-1 206Pb/238U Systematic error (2r): 1.34%

01C 1043 14,734 12.8 0.1934 6.1 0.0283 1.9 0.30 180.0 3.3 179.5 10.0 172.7 135.8 180.0 3.3 01R 893 11,938 19.4 0.1958 8.7 0.0290 0.9 0.10 184.5 1.7 181.6 14.4 143.1 202.9 184.5 1.7 03 365 5190 35.8 0.1789 13.4 0.0281 1.9 0.14 178.9 3.3 167.1 20.6 2.0 320.1 178.9 3.3

05 3714 9099 77.9 0.1920 3.7 0.0282 2.2 0.60 179.1 3.9 178.3 6.0 168.3 68.7 179.1 3.9 06T 387 4393 24.9 0.1891 19.7 0.0266 2.0 0.10 169.5 3.3 175.9 31.9 262.3 454.6 169.5 3.3 07 53 267 57.6 0.0824 87.3 0.0270 7.9 0.09 172.0 13.4 80.4 67.6 2220.0 1277.7 172.0 13.4 08 822 6752 17.2 0.1852 4.8 0.0275 1.6 0.32 175.0 2.7 172.5 7.6 138.4 106.3 175.0 2.7 09 254 1075 16.8 0.2865 15.1 0.0421 4.4 0.29 265.6 11.5 255.8 34.1 167.4 337.8 265.6 11.5

11 49 469 75.7 0.2486 69.8 0.0267 9.5 0.14 169.7 15.9 225.5 142.0 856.5 1662.5 169.7 15.9 12 138 1631 32.2 0.2229 24.9 0.0320 2.7 0.11 203.3 5.5 204.3 46.1 216.5 580.0 203.3 5.5

13 925 6520 15.7 0.1817 8.9 0.0277 1.5 0.17 175.9 2.5 169.5 13.9 81.4 208.3 175.9 2.5 14 799 5430 19.3 0.1889 7.8 0.0280 1.0 0.13 177.9 1.8 175.7 12.5 145.2 180.8 177.9 1.8

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1. 1345 23,033 28.8 0.1907 4.1 0.0287 2.3 0.57 182.2 4.2 177.3 6.7 111.7 80.6 182.2 4.2
2. 1029 10,544 22.5 0.1837 5.7 0.0284 1.9 0.32 180.7 3.3 171.2 9.0 42.1 129.1 180.7 3.3 17R 815 11,477 19.9 0.2067 5.0 0.0296 1.6 0.32 188.2 3.0 190.8 8.7 222.2 109.2 188.2 3.0 18 61 1267 20.3 0.2927 43.1 0.0290 7.0 0.16 184.0 12.7 260.6 99.4 1022.0 902.2 184.0 12.7 19 1391 39,990 39.6 0.1887 4.8 0.0278 2.6 0.53 176.8 4.5 175.5 7.8 158.6 96.0 176.8 4.5

22 1188 8972 30.0 0.1942 9.6 0.0277 1.8 0.19 176.4 3.2 180.2 15.9 231.1 219.1 176.4 3.2 2C 47 388 67.3 0.3270 88.7 0.0271 7.5 0.08 172.7 12.7 287.3 225.6 1368.5 8.4 172.7 12.7 B1 1227 19,568 45.6 0.2018 2.6 0.0295 2.1 0.81 187.5 3.9 186.7 4.5 175.8 36.3 187.5 3.9

B2 1386 34,576 29.2 0.1922 2.7 0.0283 2.3 0.83 179.6 4.1 178.5 4.5 164.2 35.5 179.6 4.1 B3 946 13,632 25.1 0.2047 1.9 0.0295 1.5 0.76 187.2 2.7 189.1 3.3 212.6 29.0 187.2 2.7 B4 1281 30,474 27.8 0.1967 1.9 0.0287 1.3 0.71 182.2 2.4 182.3 3.1 183.7 30.5 182.2 2.4 B5 763 34,610 3.5 1.4639 4.5 0.1341 4.1 0.92 811.3 31.6 915.6 27.3 1176.2 35.8 811.3 31.6

B6 38 1470 61.6 0.1923 18.5 0.0276 9.0 0.48 175.3 15.5 178.6 30.4 221.9 377.8 175.3 15.5 B6T 185 1185 37.4 0.2151 13.5 0.0275 3.2 0.24 175.2 5.5 197.8 24.3 477.1 290.8 175.2 5.5 B7 564 25,235 15.5 0.1916 2.7 0.0276 1.7 0.65 175.3 3.0 178.0 4.4 213.4 47.8 175.3 3.0

B9 28 3387 56.5 0.2482 27.3 0.0297 8.4 0.31 188.7 15.6 225.1 55.2 625.2 569.2 188.7 15.6

Paragneiss JG061504-4 206Pb/238U Systematic error (2r): 1.51%

a01 597 82,630 1.5 4.0917 1.6 0.2817 1.0 0.64 1599.8 14.5 1652.6 13.1 1720.5 22.8 1720.5 22.8 a02 299 7215 1.8 3.7755 4.6 0.2710 4.1 0.89 1546.0 55.9 1587.5 36.6 1643.2 38.3 1643.2 38.3 a93 151 25,090 1.6 2.0461 1.7 0.1884 1.2 0.73 1112.7 12.5 1131.0 11.4 1166.3 22.6 1166.3 22.6 a04 197 15,895 0.7 1.1624 4.1 0.1256 3.8 0.93 762.8 27.2 783.1 22.1 841.2 30.1 762.8 27.2 a05 154 5024 0.8 1.4887 5.0 0.1522 1.5 0.31 913.4 13.1 925.8 30.5 955.4 97.6 913.4 13.1 a05t1 492 21,967 12.3 0.1980 7.3 0.0273 2.8 0.38 173.6 4.8 183.5 12.3 312.6 154.1 173.6 4.8 a06 98 15,309 1.3 4.1344 2.2 0.2863 2.0 0.93 1623.1 28.8 1661.1 17.7 1709.5 15.0 1709.5 15.0 a07 513 17,530 1.9 1.1179 1.6 0.1233 0.93 749.5 10.3 762.0 8.4 798.8 12.3 749.5 10.3

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| a08 | 217 | 61,871 | 0.6 | 9.4811 | 1.9 | 0.4172 | 1.1 | 0.60 | 2247.9 | 21.5 | 2385.7 | 17.5 | 2505.6 | 25.7 | 2505.6 | 25.7 |
| a09 | 243 | 25,649 | 0.7 | 1.2827 | 1.4 | 0.1372 | 1.0 | 0.73 | 828.7 | 7.8 | 838.1 | 7.8 | 862.9 | 19.2 | 828.7 | 7.8 |
| a10 | 376 | 20,935 | 3.0 | 0.6608 | 3.3 | 0.0752 | 3.1 | 0.94 | 467.3 | 13.9 | 515.1 | 13.2 | 733.2 | 23.4 | 467.3 | 13.9 |
| a10t1 | 808 | 86,708 | 13.8 | 0.2054 | 3.8 | 0.0284 | 2.0 | 0.52 | 180.8 | 3.5 | 189.7 | 6.6 | 301.9 | 73.8 | 180.8 | 3.5 |
| a11 | 160 | 20,559 | 1.2 | 1.2216 | 3.2 | 0.1320 | 2.2 | 0.68 | 799.3 | 16.6 | 810.5 | 18.1 | 841.5 | 49.5 | 799.3 | 16.6 |
| a11t1 | 235 | 23,693 | 1.7 | 1.2747 | 4.7 | 0.1413 | 2.9 | 0.62 | 851.9 | 23.2 | 834.5 | 26.6 | 788.4 | 77.0 | 851.9 | 23.2 |
| a12 | 531 | 58,166 | 0.7 | 3.6742 | 1.4 | 0.2684 | 1.1 | 0.78 | 1532.9 | 15.1 | 1565.8 | 11.3 | 1610.4 | 16.6 | 1610.4 | 16.6 |
| a13 | 147 | 22,655 | 1.1 | 1.2606 | 2.0 | 0.1353 | 1.2 | 0.60 | 818.0 | 9.1 | 828.2 | 11.1 | 855.7 | 32.4 | 818.0 | 9.1 |
| a14 | 26 | 13,410 | 1.2 | 13.1298 | 1.8 | 0.5028 | 1.0 | 0.55 | 2625.7 | 21.6 | 2689.0 | 17.1 | 2737.0 | 24.8 | 2737.0 | 24.8 |
| a15 | 263 | 25,031 | 0.4 | 1.5111 | 2.1 | 0.1550 | 1.4 | 0.66 | 929.1 | 12.1 | 934.9 | 12.8 | 948.5 | 32.1 | 929.1 | 12.1 |
| a16 | 90 | 19,734 | 1.7 | 6.8180 | 2.0 | 0.3378 | 1.7 | 0.84 | 1876.1 | 27.8 | 2088.1 | 18.1 | 2304.0 | 19.3 | 2304.0 | 19.3 |
| a16t1 | 615 | 7843 | 10.3 | 0.1813 | 4.0 | 0.0281 | 2.5 | 0.62 | 178.8 | 4.3 | 169.2 | 6.2 | 36.4 | 74.6 | 178.8 | 4.3 |
| a17 | 656 | 48,492 | 0.9 | 1.5137 | 1.6 | 0.1547 | 1.5 | 0.93 | 927.2 | 13.1 | 935.9 | 9.9 | 956.5 | 11.9 | 927.2 | 13.1 |
| a18X | 144 | 17,829 | 1.4 | 5.0264 | 4.6 | 0.3112 | 4.4 | 0.96 | 1746.5 | 66.7 | 1823.8 | 38.7 | 1913.2 | 24.3 | 1913.2 | 24.3 |
| a19 | 420 | 40,564 | 1.6 | 1.4400 | 1.4 | 0.1504 | 1.2 | 0.83 | 903.4 | 9.9 | 905.7 | 8.5 | 911.3 | 16.5 | 903.4 | 9.9 |
| a20 | 699 | 84,673 | 1.7 | 3.4106 | 1.3 | 0.2483 | 1.0 | 0.80 | 1429.8 | 12.8 | 1506.8 | 9.9 | 1616.8 | 14.2 | 1616.8 | 14.2 |
| a22 | 625 | 156,689 | 1.2 | 9.4482 | 1.7 | 0.4148 | 1.2 | 0.70 | 2236.9 | 22.9 | 2382.5 | 16.0 | 2509.6 | 21.0 | 2509.6 | 21.0 |
| a23 | 343 | 21,386 | 0.8 | 1.0897 | 9.2 | 0.1194 | 8.7 | 0.95 | 727.4 | 59.9 | 748.4 | 48.6 | 811.6 | 60.3 | 727.4 | 59.9 |
| a24 | 194 | 15,064 | 0.6 | 1.4612 | 2.2 | 0.1496 | 1.7 | 0.77 | 898.6 | 14.5 | 914.5 | 13.5 | 953.1 | 29.3 | 898.6 | 14.5 |
| a25 | 175 | 20,470 | 1.2 | 1.3317 | 2.5 | 0.1440 | 2.2 | 0.88 | 867.3 | 17.5 | 859.6 | 14.2 | 839.8 | 24.3 | 867.3 | 17.5 |
| a26 | 677 | 49,738 | 0.9 | 1.2181 | 2.4 | 0.1326 | 1.9 | 0.79 | 802.6 | 14.6 | 808.9 | 13.6 | 826.3 | 31.1 | 802.6 | 14.6 |
| a27 | 247 | 29,007 | 1.1 | 1.6252 | 1.6 | 0.1642 | 1.4 | 0.87 | 980.1 | 12.9 | 980.0 | 10.2 | 979.8 | 16.3 | 980.1 | 12.9 |
| a28 | 200 | 23,338 | 1.8 | 2.8027 | 1.3 | 0.2321 | 1.0 | 0.74 | 1345.6 | 12.1 | 1356.3 | 10.1 | 1373.1 | 17.4 | 1373.1 | 17.4 |
| a29 | 129 | 40,905 | 1.3 | 9.6724 | 2.2 | 0.4277 | 2.0 | 0.93 | 2295.3 | 39.0 | 2404.1 | 20.0 | 2497.5 | 13.5 | 2497.5 | 13.5 |
| a30 | 239 | 51,917 | 1.0 | 4.0783 | 1.6 | 0.2790 | 1.0 | 0.64 | 1586.5 | 14.1 | 1650.0 | 12.7 | 1731.8 | 21.8 | 1731.8 | 21.8 |
| a31c | 197 | 28,746 | 2.2 | 3.2887 | 9.5 | 0.2347 | 8.9 | 0.95 | 1359.0 | 109.6 | 1478.4 | 73.7 | 1654.1 | 56.8 | 1654.1 | 56.8 |
| a31t1 | 1051 | 7405 | 9.9 | 0.1888 | 5.7 | 0.0283 | 1.5 | 0.26 | 779.7 | 2.6 | 175.6 | 9.2 | 121.2 | 130.2 | 179.7 | 2.6 |
| a31t2 | 750 | 7826 | 10.2 | 0.1927 | 3.4 | 0.0274 | 1.5 | 0.43 | 774.3 | 2.5 | 178.9 | 5.6 | 239.7 | 71.4 | 174.3 | 2.5 |
| a32t1 | 330 | 31,997 | 1.8 | 1.2327 | 2.9 | 0.1315 | 1.2 | 0.43 | 796.6 | 9.1 | 815.6 | 16.1 | 867.6 | 53.8 | 796.6 | 9.1 |
| a33c | 106 | 165,386 | 1.5 | 1.3006 | 4.8 | 0.1335 | 2.3 | 0.47 | 807.8 | 17.1 | 846.0 | 27.8 | 947.4 | 87.9 | 807.8 | 17.1 |
| a34c | 301 | 1,162,314 | 1.7 | 9.6153 | 2.6 | 0.4283 | 1.7 | 0.64 | 2298.3 | 32.3 | 2398.6 | 24.0 | 2485.0 | 33.7 | 2485.0 | 33.7 |
| a34c2 | 440 | 303,994 | 2.1 | 9.1957 | 2.3 | 0.4043 | 2.0 | 0.87 | 2188.7 | 37.2 | 2357.7 | 21.1 | 2507.3 | 19.0 | 2507.3 | 19.0 |
| a34c3 | 477 | 286,250 | 2.9 | 8.5739 | 3.6 | 0.3834 | 3.4 | 0.96 | 2092.3 | 61.6 | 2293.8 | 32.7 | 2478.5 | 16.9 | 2478.5 | 16.9 |
| a34t1 | 525 | 11,365 | 16.0 | 0.2084 | 7.5 | 0.0273 | 3.3 | 0.44 | 173.9 | 5.6 | 192.3 | 13.1 | 424.0 | 149.9 | 173.9 | 5.6 |
| a34t2 | 241 | 38,975 | 2.2 | 8.5649 | 5.8 | 0.3927 | 5.1 | 0.87 | 2135.2 | 92.3 | 2292.8 | 53.1 | 2436.5 | 48.5 | 2436.5 | 48.5 |
| a35c | 512 | 226,956 | 1.5 | 4.3677 | 3.0 | 0.2977 | 2.6 | 0.88 | 1679.7 | 39.2 | 1706.2 | 24.8 | 1739.0 | 25.9 | 1739.0 | 25.9 |
| a35t1 | 800 | 30,468 | 11.6 | 0.1952 | 4.7 | 0.0275 | 2.0 | 0.42 | 174.7 | 3.4 | 181.0 | 7.8 | 264.2 | 97.9 | 174.7 | 3.4 |
| a35t2 | 812 | 53,797 | 10.9 | 0.2018 | 2.9 | 0.0283 | 1.6 | 0.54 | 179.8 | 2.8 | 186.7 | 4.9 | 273.9 | 55.8 | 179.8 | 2.8 |
| a36c | 259 | 107,604 | 0.8 | 3.0608 | 2.6 | 0.2444 | 2.2 | 0.82 | 1409.8 | 27.3 | 1422.9 | 20.1 | 1442.7 | 28.6 | 1442.7 | 28.6 |
| a36t1 | 354 | 131,109 | 5.3 | 2.2304 | 3.1 | 0.1811 | 2.5 | 0.82 | 1073.1 | 25.1 | 1190.6 | 21.7 | 1410.8 | 33.9 | 1410.8 | 33.9 |
| a37c | 266 | 183,644 | 1.1 | 1.2847 | 3.4 | 0.1364 | 1.3 | 0.37 | 824.4 | 9.8 | 839.0 | 19.4 | 877.7 | 65.4 | 824.4 | 9.8 |
| a37t1 | 91 | 11,713 | 1.7 | 1.1306 | 7.0 | 0.1196 | 3.8 | 123.3 | 728.0 | 25.9 | 768.7 | 38.0 | 886.2 | 723.3 | 728.0 | 25.9 |
| a38c | 238 | 223,276 | 1.0 | 10.3756 | 3.1 | 0.4513 | 1.7 | 0.57 | 2401.0 | 34.9 | 2468.9 | 28.3 | 2525.2 | 42.2 | 2525.2 | 42.2 |
| a38t1 | 811 | 34,025 | 11.9 | 0.1952 | 3.3 | 0.0280 | 2.0 | 0.63 | 178.3 | 3.6 | 181.0 | 5.4 | 217.2 | 58.5 | 178.3 | 3.6 |
| a39c | 299 | 67,215 | 1.5 | 1.1253 | 8.1 | 0.1210 | 7.6 | 0.94 | 736.5 | 52.8 | 765.5 | 43.5 | 851.2 | 57.6 | 736.5 | 52.8 |
| a39t1 | 651 | 26,161 | 11.7 | 0.1986 | 7.0 | 0.0271 | 3.2 | 0.46 | 172.2 | 5.4 | 183.9 | 11.7 | 337.2 | 140.3 | 172.2 | 5.4 |
| a40t1 | 514 | 1529 | 9.9 | 0.5245 | 36.6 | 0.0289 | 5.6 | 0.15 | 183.8 | 10.1 | 428.2 | 128.4 | 2118.2 | 657.2 | 2118.2 | 657.2 |
| a41c | 191 | 76,329 | 1.4 | 1.5459 | 3.1 | 0.1542 | 2.5 | 0.81 | 924.2 | 21.6 | 948.8 | 19.2 | 1006.4 | 37.2 | 924.2 | 21.6 |
| a42c | 186 | 36,742 | 1.7 | 3.9855 | 3.3 | 0.2810 | 2.2 | 0.68 | 1596.2 | 31.6 | 1631.2 | 26.9 | 1676.7 | 45.1 | 1676.7 | 45.1 |
| a42t1 | 854 | 22,889 | 14.8 | 0.2000 | 4.2 | 0.0269 | 3.0 | 0.70 | 171.0 | 5.0 | 185.1 | 7.2 | 369.6 | 68.8 | 171.0 | 5.0 |
| a43c | 197 | 59,035 | 0.5 | 1.6810 | 1.6 | 0.1658 | 1.2 | 0.77 | 988.7 | 11.3 | 1001.3 | 10.2 | 1029.2 | 20.6 | 1029.2 | 20.6 |
| a43t1 | 565 | 35,817 | 14.5 | 0.1899 | 3.9 | 0.0276 | 1.8 | 0.48 | 175.6 | 3.2 | 176.5 | 6.2 | 189.1 | 78.9 | 175.6 | 3.2 |
| b01 | 96 | 14,363 | 1.3 | 3.5045 | 2.7 | 0.2635 | 2.4 | 0.91 | 1507.9 | 32.3 | 1528.2 | 21.0 | 1556.4 | 21.0 | 1556.4 | 21.0 |
| b02 | 369 | 29,478 | 1.7 | 1.4162 | 5.1 | 0.1449 | 4.8 | 0.94 | 872.4 | 38.9 | 895.8 | 30.3 | 953.9 | 36.7 | 872.4 | 38.9 |
| b03 | 283 | 29,272 | 2.4 | 2.0562 | 1.9 | 0.1901 | 1.5 | 0.83 | 1121.8 | 15.7 | 1134.4 | 12.6 | 1158.5 | 20.7 | 1158.5 | 20.7 |
| b04 | 417 | 59,966 | 2.1 | 3.9700 | 1.3 | 0.2662 | 1.0 | 0.77 | 1521.6 | 13.6 | 1628.1 | 10.5 | 1768.6 | 15.0 | 1768.6 | 15.0 |
| b06 | 180 | 15,292 | 0.8 | 1.4891 | 2.1 | 0.1544 | 1.5 | 0.72 | 925.4 | 12.9 | 925.9 | 12.5 | 927.1 | 29.3 | 925.4 | 12.9 |
| b07 | 357 | 104,480 | 1.7 | 9.8341 | 2.0 | 0.4350 | 1.4 | 0.72 | 2328.0 | 27.9 | 2419.4 | 18.3 | 2497.1 | 23.2 | 2497.1 | 23.2 |
| b08 | 93 | 10,297 | 1.5 | 1.2120 | 3.9 | 0.1339 | 3.5 | 0.90 | 810.0 | 26.6 | 806.1 | 21.6 | 795.3 | 35.2 | 810.0 | 26.6 |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| b09 | 193 | 3368 | 1.1 | 1.2800 | 5.4 | 0.1361 | 4.9 | 0.92 | 822.6 | 38.2 | 836.8 | 30.5 | 874.9 | 42.4 | 822.6 | 38.2 |
| b100 | 315 | 31,769 | 1.6 | 3.1463 | 4.3 | 0.2331 | 4.0 | 0.93 | 1350.7 | 48.5 | 1444.1 | 32.9 | 1584.4 | 28.7 | 1584.4 | 28.7 |
| b101 | 373 | 106,070 | 1.9 | 4.2804 | 3.7 | 0.2940 | 3.2 | 0.88 | 1661.6 | 47.2 | 1689.6 | 30.1 | 1724.5 | 31.8 | 1724.5 | 31.8 |
| b102 | 102 | 74,870 | 3.2 | 8.2692 | 5.8 | 0.3664 | 5.2 | 0.90 | 2012.6 | 90.8 | 2261.0 | 52.8 | 2493.9 | 42.3 | 2493.9 | 42.3 |
| b103 | 559 | 151,880 | 2.4 | 3.3941 | 5.5 | 0.2549 | 3.4 | 0.61 | 1463.8 | 44.4 | 1503.0 | 43.4 | 1558.8 | 82.0 | 1558.8 | 82.0 |
| b104 | 141 | 74,944 | 1.5 | 7.7041 | 3.5 | 0.3424 | 3.4 | 0.96 | 1898.3 | 55.2 | 2197.1 | 31.3 | 2488.9 | 15.7 | 2488.9 | 15.7 |
| b105 | 265 | 76,113 | 2.1 | 3.3759 | 3.5 | 0.2524 | 2.9 | 0.82 | 1451.0 | 37.7 | 1498.8 | 27.6 | 1567.1 | 37.5 | 1567.1 | 37.5 |
| b107 | 257 | 168,839 | 1.5 | 10.1533 | 2.5 | 0.4434 | 1.9 | 0.75 | 2366.0 | 37.9 | 2448.8 | 23.5 | 2518.3 | 28.2 | 2518.3 | 28.2 |
| b108 | 491 | 26,308 | 2.1 | 0.7853 | 5.5 | 0.0864 | 5.2 | 0.95 | 534.1 | 26.9 | 588.5 | 24.6 | 804.2 | 35.9 | 534.1 | 26.9 |
| b109 | 527 | 11,983 | 1.2 | 1.0746 | 3.0 | 0.1113 | 2.8 | 0.92 | 680.5 | 18.1 | 741.0 | 15.9 | 928.5 | 23.9 | 680.5 | 18.1 |
| b11 | 260 | 31,120 | 2.1 | 3.0375 | 2.6 | 0.2416 | 2.1 | 0.78 | 1395.2 | 25.8 | 1417.1 | 20.1 | 1450.1 | 31.1 | 1450.1 | 31.1 |
| b110 | 160 | 24,315 | 1.6 | 1.1901 | 3.3 | 0.1262 | 2.4 | 0.73 | 766.2 | 17.4 | 796.0 | 18.2 | 880.3 | 46.7 | 766.2 | 17.4 |
| b111 | 271 | 80,342 | 1.4 | 6.1810 | 2.1 | 0.3503 | 1.2 | 0.60 | 1936.0 | 20.9 | 2001.8 | 18.2 | 2070.4 | 29.3 | 2070.4 | 29.3 |
| b12 | 241 | 15,335 | 2.1 | 1.2218 | 2.7 | 0.1340 | 1.7 | 0.62 | 810.7 | 12.9 | 810.6 | 15.2 | 810.4 | 44.7 | 810.7 | 12.9 |
| b13 | 378 | 21,027 | 2.1 | 1.1708 | 2.2 | 0.1289 | 1.6 | 0.75 | 781.5 | 11.9 | 787.0 | 11.9 | 802.8 | 30.2 | 781.5 | 11.9 |
| b14 | 117 | 16,811 | 1.8 | 2.5673 | 2.4 | 0.2154 | 1.8 | 0.73 | 1257.5 | 20.2 | 1291.4 | 17.7 | 1348.1 | 31.8 | 1348.1 | 31.8 |
| b15 | 254 | 21,377 | 0.8 | 1.2322 | 3.8 | 0.1352 | 3.5 | 0.92 | 817.6 | 27.0 | 815.4 | 21.3 | 809.2 | 30.6 | 817.6 | 27.0 |
| b16 | 234 | 91,694 | 1.0 | 9.9122 | 2.3 | 0.4288 | 1.3 | 0.55 | 2300.2 | 24.6 | 2426.6 | 21.4 | 2534.4 | 32.6 | 2534.4 | 32.6 |
| b17 | 676 | 64,940 | 2.1 | 3.7170 | 3.1 | 0.2615 | 2.3 | 0.74 | 1497.3 | 31.1 | 1575.0 | 25.1 | 1680.7 | 39.0 | 1680.7 | 39.0 |
| b18 | 181 | 25,406 | 2.1 | 1.4932 | 2.7 | 0.1519 | 1.9 | 0.70 | 911.9 | 16.3 | 927.6 | 16.7 | 965.3 | 40.2 | 911.9 | 16.3 |
| b19 | 139 | 11,734 | 0.7 | 1.2689 | 4.1 | 0.1381 | 2.8 | 0.68 | 833.6 | 21.6 | 831.9 | 23.0 | 827.3 | 62.0 | 833.6 | 21.6 |
| b20 | 79 | 18,580 | 1.8 | 4.2966 | 4.3 | 0.2953 | 4.0 | 0.93 | 1668.2 | 59.3 | 1692.7 | 35.7 | 1723.2 | 29.1 | 1723.2 | 29.1 |
| b21 | 138 | 18,439 | 1.3 | 8.8128 | 1.8 | 0.3775 | 1.2 | 0.69 | 2064.4 | 21.6 | 2318.8 | 16.1 | 2551.1 | 21.4 | 2551.1 | 21.4 |
| b22 | 466 | 61,141 | 1.7 | 4.1332 | 1.7 | 0.2822 | 1.2 | 0.71 | 1602.4 | 17.2 | 1660.9 | 14.0 | 1735.6 | 22.2 | 1735.6 | 22.2 |
| b23 | 271 | 57,399 | 2.3 | 10.5610 | 1.7 | 0.4515 | 1.2 | 0.72 | 2401.9 | 24.5 | 2485.3 | 15.7 | 2554.1 | 19.6 | 2554.1 | 19.6 |
| b25 | 66 | 13,227 | 0.9 | 4.1914 | 1.8 | 0.2928 | 1.3 | 0.76 | 1655.5 | 19.4 | 1672.3 | 14.4 | 1693.5 | 21.2 | 1693.5 | 21.2 |
| b26 | 806 | 69,686 | 1.5 | 3.6899 | 2.7 | 0.2578 | 2.1 | 0.75 | 1478.8 | 27.3 | 1569.2 | 21.9 | 1693.0 | 33.2 | 1693.0 | 33.2 |
| b28 | 199 | 17,629 | 1.9 | 1.0900 | 3.9 | 0.1201 | 3.0 | 0.76 | 731.0 | 20.5 | 748.5 | 20.8 | 801.2 | 53.7 | 731.0 | 20.5 |
| b29 | 200 | 32,806 | 0.8 | 3.2770 | 3.3 | 0.2348 | 2.1 | 0.65 | 1359.9 | 26.4 | 1475.6 | 25.7 | 1646.3 | 46.6 | 1646.3 | 46.6 |
| b30 | 118 | 3074 | 1.7 | 1.1766 | 7.0 | 0.1385 | 1.8 | 0.25 | 836.1 | 13.8 | 789.7 | 38.5 | 661.1 | 145.8 | 836.1 | 13.8 |
| b32 | 105 | 2696 | 2.6 | 1.0641 | 7.6 | 0.1276 | 1.9 | 0.25 | 774.0 | 13.8 | 735.8 | 40.0 | 621.4 | 160.0 | 774.0 | 13.8 |
| b33 | 232 | 58,867 | 5.6 | 5.5125 | 4.0 | 0.3418 | 3.2 | 0.79 | 1895.3 | 52.4 | 1902.5 | 34.6 | 1910.5 | 44.2 | 1910.5 | 44.2 |
| b34 | 169 | 37,156 | 1.6 | 3.9877 | 4.6 | 0.2754 | 3.2 | 0.71 | 1568.1 | 45.0 | 1631.7 | 37.2 | 1714.6 | 59.6 | 1714.6 | 59.6 |
| b35 | 367 | 50,217 | 5.6 | 3.6853 | 6.8 | 0.2504 | 5.7 | 0.84 | 1440.6 | 74.0 | 1568.2 | 54.4 | 1744.4 | 67.1 | 1744.4 | 67.1 |
| b36 | 214 | 20,304 | 1.5 | 1.2411 | 2.7 | 0.1347 | 2.1 | 0.79 | 814.7 | 16.3 | 819.4 | 15.1 | 832.1 | 34.4 | 814.7 | 16.3 |
| b38 | 194 | 9874 | 2.9 | 1.9227 | 4.2 | 0.1806 | 2.8 | 0.66 | 1070.1 | 27.3 | 1089.0 | 27.9 | 1127.0 | 62.3 | 1127.0 | 62.3 |
| b40 | 212 | 63,180 | 1.6 | 4.4739 | 2.9 | 0.3010 | 1.6 | 0.54 | 1696.3 | 23.7 | 1726.2 | 24.5 | 1762.5 | 45.3 | 1762.5 | 45.3 |
| b41c | 477 | 27,747 | 2.6 | 8.3877 | 3.5 | 0.3725 | 3.2 | 0.91 | 2041.2 | 56.7 | 2273.8 | 32.2 | 2490.2 | 24.4 | 2490.2 | 24.4 |
| b41t1 | 680 | 13,003 | 16.6 | 0.1826 | 2.5 | 0.0270 | 1.7 | 0.70 | 171.7 | 2.9 | 170.3 | 3.9 | 150.0 | 41.8 | 171.7 | 2.9 |
| b42 | 556 | 59,796 | 2.3 | 3.3175 | 2.6 | 0.2386 | 2.2 | 0.84 | 1379.2 | 26.9 | 1485.2 | 20.0 | 1640.0 | 25.5 | 1640.0 | 25.5 |
| b43 | 70 | 13,185 | 0.5 | 2.3747 | 2.6 | 0.2088 | 1.9 | 0.71 | 1222.2 | 20.6 | 1235.0 | 18.6 | 1257.4 | 35.6 | 1257.4 | 35.6 |
| b44 | 223 | 18,470 | 2.5 | 1.2117 | 2.3 | 0.1310 | 1.2 | 0.50 | 793.4 | 8.7 | 806.0 | 13.0 | 840.9 | 42.2 | 793.4 | 8.7 |
| b45 | 332 | 60,806 | 2.2 | 1.3151 | 2.6 | 0.1340 | 1.7 | 0.67 | 810.8 | 13.3 | 852.4 | 14.9 | 962.2 | 38.9 | 810.8 | 13.3 |
| b46 | 429 | 82,371 | 0.7 | 4.6007 | 5.2 | 0.2916 | 5.0 | 0.96 | 1649.6 | 72.9 | 1749.4 | 43.7 | 1870.8 | 28.0 | 1870.8 | 28.0 |
| b47 | 434 | 32,006 | 1.3 | 1.2027 | 3.7 | 0.1327 | 1.6 | 0.44 | 803.1 | 12.3 | 801.8 | 20.6 | 798.5 | 69.9 | 803.1 | 12.3 |
| b48 | 159 | 21,648 | 1.8 | 1.2207 | 3.5 | 0.1323 | 1.9 | 0.54 | 800.8 | 14.4 | 810.1 | 19.7 | 835.6 | 62.1 | 800.8 | 14.4 |
| b49 | 122 | 26,103 | 1.8 | 1.2192 | 4.3 | 0.1327 | 2.8 | 0.65 | 803.2 | 20.8 | 809.4 | 23.8 | 826.3 | 67.8 | 803.2 | 20.8 |
| b50c | 36 | 18,037 | 1.2 | 3.1426 | 2.5 | 0.2482 | 1.6 | 0.63 | 1429.3 | 20.3 | 1443.2 | 19.4 | 1463.7 | 37.2 | 1463.7 | 37.2 |
| b50t1 | 613 | 9499 | 17.9 | 0.1816 | 2.4 | 0.0266 | 1.7 | 0.71 | 169.4 | 2.8 | 169.5 | 3.7 | 170.2 | 39.0 | 169.4 | 2.8 |
| b51 | 342 | 20,938 | 1.2 | 1.2815 | 2.9 | 0.1350 | 2.1 | 0.72 | 816.3 | 16.2 | 837.5 | 16.7 | 894.1 | 41.7 | 816.3 | 16.2 |
| b52 | 198 | 22,372 | 1.9 | 1.2527 | 2.5 | 0.1361 | 1.3 | 0.51 | 822.8 | 9.9 | 824.6 | 14.2 | 829.5 | 45.1 | 822.8 | 9.9 |
| b53 | 131 | 56,381 | 1.3 | 17.8389 | 3.9 | 0.5417 | 3.1 | 0.81 | 2790.5 | 71.2 | 2981.1 | 37.4 | 3112.3 | 36.3 | 3112.3 | 36.3 |
| b54 | 107 | 1339 | 2.6 | 2.9748 | 2.7 | 0.2277 | 1.5 | 0.56 | 1322.7 | 18.4 | 1401.2 | 20.9 | 1522.8 | 42.8 | 1522.8 | 42.8 |
| b55 | 343 | 66,875 | 2.3 | 3.1868 | 2.6 | 0.2452 |  | 0.57 | 1413.8 | 19.2 | 1454.0 | 20.3 | 1513.1 | 40.6 | 1513.1 | 40.6 |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| b57c | 327 | 41,664 | 0.9 | 1.4269 | 1.5 | 0.1442 | 1.0 | 0.68 | 868.5 | 8.1 | 900.2 | 8.8 | 978.9 | 22.0 | 868.5 | 8.1 |
| b57t1 | 382 | 8634 | 16.4 | 0.1741 | 3.0 | 0.0268 | 2.1 | 0.69 | 170.4 | 3.5 | 163.0 | 4.6 | 55.9 | 52.7 | 170.4 | 3.5 |
| b58c | 135 | 37,728 | 1.6 | 3.6503 | 6.8 | 0.2634 | 6.3 | 0.94 | 1507.1 | 85.3 | 1560.6 | 54.1 | 1633.7 | 44.1 | 1633.7 | 44.1 |
| b58t1 | 480 | 11,872 | 15.0 | 0.1774 | 3.0 | 0.0271 | 2.4 | 0.80 | 172.3 | 4.1 | 165.8 | 4.6 | 74.4 | 42.6 | 172.3 | 4.1 |
| b59 | 451 | 74,550 | 2.5 | 4.0215 | 2.2 | 0.2779 | 1.5 | 0.67 | 1580.9 | 21.0 | 1638.6 | 18.2 | 1713.3 | 30.5 | 1713.3 | 30.5 |
| b60 | 860 | 47,087 | 1.9 | 1.6706 | 5.7 | 0.1602 | 5.7 | 0.99 | 958.0 | 50.3 | 997.4 | 36.4 | 1085.2 | 17.7 | 1085.2 | 17.7 |
| b62 | 930 | 103,082 | 1.1 | 2.7676 | 1.7 | 0.2272 | 1.3 | 0.73 | 1320.0 | 15.2 | 1346.8 | 13.0 | 1389.8 | 22.9 | 1389.8 | 22.9 |
| b63 | 213 | 60,115 | 2.2 | 9.4796 | 2.5 | 0.4224 | 2.0 | 0.80 | 2271.2 | 38.1 | 2385.6 | 23.0 | 2484.8 | 25.5 | 2484.8 | 25.5 |
| b64 | 487 | 31,031 | 9.5 | 1.6297 | 2.4 | 0.1622 | 1.2 | 0.50 | 968.7 | 10.7 | 981.7 | 14.9 | 1010.9 | 41.4 | 968.7 | 10.7 |
| b65 | 321 | 86,618 | 3.0 | 4.4636 | 1.7 | 0.2928 | 1.0 | 0.60 | 1655.7 | 15.2 | 1724.2 | 14.5 | 1808.4 | 25.5 | 1808.4 | 25.5 |
| b67 | 95 | 11,880 | 1.5 | 1.2655 | 4.7 | 0.1372 | 2.0 | 0.41 | 828.7 | 15.2 | 830.4 | 26.9 | 834.9 | 90.2 | 828.7 | 15.2 |
| b68 | 61 | 17,600 | 2.3 | 2.6497 | 3.8 | 0.1955 | 2.7 | 0.72 | 1151.0 | 28.8 | 1314.6 | 28.1 | 1592.3 | 49.6 | 1592.3 | 49.6 |
| b69 | 284 | 105,932 | 2.8 | 4.6636 | 3.3 | 0.2981 | 2.7 | 0.82 | 1681.9 | 39.7 | 1760.7 | 27.5 | 1855.7 | 34.3 | 1855.7 | 34.3 |
| b70 | 76 | 20,646 | 1.7 | 1.1393 | 3.6 | 0.1296 | 2.7 | 0.75 | 785.4 | 20.1 | 772.2 | 19.6 | 734.1 | 50.9 | 785.4 | 20.1 |
| b71 | 74 | 11,233 | 1.6 | 1.4609 | 2.2 | 0.1537 | 1.1 | 0.50 | 921.8 | 9.4 | 914.4 | 13.2 | 896.4 | 39.2 | 921.8 | 9.4 |
| b72 | 698 | 27,046 | 2.2 | 1.0552 | 2.6 | 0.1090 | 2.4 | 0.93 | 667.1 | 15.1 | 731.4 | 13.4 | 934.0 | 19.6 | 667.1 | 15.1 |
| b73 | 169 | 55,177 | 2.4 | 1.2200 | 4.3 | 0.1345 | 2.7 | 0.62 | 813.4 | 20.6 | 809.8 | 24.2 | 799.9 | 71.1 | 813.4 | 20.6 |
| b74 | 544 | 130,410 | 1.5 | 10.5468 | 1.6 | 0.4526 | 1.1 | 0.66 | 2406.6 | 21.2 | 2484.0 | 14.9 | 2548.0 | 20.3 | 2548.0 | 20.3 |
| b75 | 739 | 44,195 | 1.1 | 1.2088 | 2.2 | 0.1314 | 1.9 | 0.88 | 795.6 | 14.6 | 804.6 | 12.3 | 829.6 | 22.1 | 795.6 | 14.6 |
| b76 | 310 | 92,519 | 1.3 | 3.0475 | 2.0 | 0.2389 | 1.5 | 0.73 | 1380.9 | 18.4 | 1419.6 | 15.5 | 1478.2 | 26.4 | 1478.2 | 26.4 |
| b77 | 83 | 13,486 | 1.4 | 1.7738 | 4.0 | 0.1686 | 3.7 | 0.93 | 1004.2 | 34.5 | 1035.9 | 26.0 | 1103.5 | 30.3 | 1103.5 | 30.3 |
| b78 | 240 | 86,175 | 2.7 | 3.9709 | 2.0 | 0.2704 | 1.4 | 0.71 | 1542.6 | 19.8 | 1628.3 | 16.5 | 1740.8 | 26.2 | 1740.8 | 26.2 |
| b79 | 425 | 57,768 | 1.4 | 1.1083 | 8.4 | 0.1210 | 8.2 | 0.98 | 736.5 | 57.3 | 757.3 | 44.9 | 819.2 | 36.6 | 736.5 | 57.3 |
| b80 | 95 | 7746 | 1.1 | 1.1476 | 3.5 | 0.1310 | 1.9 | 0.54 | 793.4 | 13.9 | 776.1 | 18.7 | 726.7 | 61.7 | 793.4 | 13.9 |
| b81 | 219 | 36,905 | 1.3 | 1.6057 | 5.4 | 0.1592 | 4.8 | 0.89 | 952.6 | 42.4 | 972.4 | 33.8 | 1017.5 | 50.4 | 952.6 | 42.4 |
| b82 | 105 | 10,047 | 2.3 | 1.2563 | 3.2 | 0.1355 | 2.5 | 0.77 | 819.4 | 19.0 | 826.2 | 18.3 | 844.7 | 43.2 | 819.4 | 19.0 |
| b83 | 450 | 100,934 | 9.0 | 2.4749 | 6.9 | 0.2039 | 6.6 | 0.97 | 1196.3 | 72.3 | 1264.7 | 49.6 | 1383.1 | 34.2 | 1383.1 | 34.2 |
| b84 | 79 | 33,661 | 2.9 | 3.4415 | 5.0 | 0.2513 | 4.5 | 0.91 | 1445.2 | 58.8 | 1513.9 | 39.3 | 1611.3 | 38.5 | 1611.3 | 38.5 |
| b85 | 84 | 2952 | 1.4 | 1.2071 | 7.6 | 0.1360 | 2.3 | 0.30 | 822.0 | 17.5 | 803.9 | 42.1 | 754.0 | 152.8 | 822.0 | 17.5 |
| b86 | 268 | 6959 | 1.6 | 1.3458 | 1.9 | 0.1371 | 1.0 | 0.54 | 828.1 | 7.9 | 865.8 | 11.0 | 963.4 | 32.6 | 828.1 | 7.9 |
| b87 | 116 | 75,513 | 2.8 | 2.3758 | 1.8 | 0.2080 | 1.0 | 0.55 | 1218.3 | 11.1 | 1235.3 | 13.0 | 1265.2 | 29.8 | 1265.2 | 29.8 |
| b88 | 60 | 18,237 | 2.6 | 1.0503 | 2.8 | 0.1198 | 2.1 | 0.76 | 729.6 | 14.6 | 729.0 | 14.4 | 727.2 | 38.0 | 729.6 | 14.6 |
| b90 | 832 | 249,827 | 2.5 | 18.7506 | 3.4 | 0.5553 | 3.1 | 0.90 | 2847.1 | 70.4 | 3029.1 | 32.6 | 3152.1 | 22.9 | 3152.1 | 22.9 |
| b91 | 127 | 130,552 | 1.7 | 10.2788 | 2.6 | 0.4482 | 1.7 | 0.68 | 2387.3 | 34.4 | 2460.2 | 23.6 | 2521.0 | 31.6 | 2521.0 | 31.6 |
| b92 | 202 | 73,402 | 1.9 | 1.6725 | 2.6 | 0.1672 | 1.0 | 0.39 | 996.9 | 9.2 | 998.1 | 16.2 | 1000.9 | 47.8 | 996.9 | 9.2 |
| b93 | 555 | 42,523 | 5.3 | 2.3493 | 4.2 | 0.1880 | 3.2 | 0.77 | 1110.5 | 32.8 | 1227.3 | 29.9 | 1438.9 | 51.3 | 1438.9 | 51.3 |
| b94 | 441 | 64,279 | 1.9 | 3.5772 | 2.5 | 0.2584 | 1.4 | 0.55 | 1481.5 | 18.2 | 1544.5 | 19.8 | 1631.8 | 38.8 | 1631.8 | 38.8 |
| b95 | 151 | 15,742 | 1.1 | 1.2958 | 4.0 | 0.1405 | 2.8 | 0.71 | 847.6 | 22.2 | 843.9 | 22.7 | 834.1 | 58.3 | 847.6 | 22.2 |
| b96 | 151 | 15,411 | 1.8 | 1.3067 | 3.8 | 0.1397 | 2.9 | 0.75 | 842.8 | 22.5 | 848.7 | 21.7 | 864.2 | 51.4 | 842.8 | 22.5 |
| b99 | 179 | 142,432 | 1.9 | 12.2655 | 1.4 | 0.4854 | 1.0 | 0.70 | 2550.8 | 21.1 | 2624.9 | 13.5 | 2682.6 | 17.0 | 2682.6 | 17.0 |
| Quartzite JG062505-3 | |  | 206 238 Pb/ U Systematic error (2r): | | |  |  | 1.33% |  |  |  |  |  |  |  |  |
| 01 315 | | 75,354 | 1.4 5.0405 1.9 | | | 0.3184 | 1.7 | 0.88 | 1781.7 | 26.0 | 1826.1 | 16.0 | 1877.2 | 16.1 | 1877.2 | 16.1 |
| 02 170 | | 9896 | 0.9 0.6038 3.3 | | | 0.0811 | 2.0 | 0.60 | 502.8 | 9.5 | 479.6 | 12.5 | 370.1 | 59.1 | 502.8 | 9.5 |
| 03 304 | | 29,765 | 0.9 1.2093 9.3 | | | 0.1286 | 8.9 | 0.95 | 779.9 | 65.1 | 804.9 | 51.7 | 874.8 | 58.3 | 779.9 | 65.1 |
| 04 97 | | 17,349 | 0.6 2.6868 3.0 | | | 0.2317 | 2.2 | 0.73 | 1343.1 | 26.5 | 1324.8 | 22.2 | 1295.3 | 39.9 | 1295.3 | 39.9 |
| 05 638 | | 33,360 | 0.9 2.1866 2.8 | | | 0.1946 | 2.5 | 0.88 | 1146.3 | 26.2 | 1176.8 | 19.7 | 1233.3 | 26.2 | 1233.3 | 26.2 |
| 06 404 | | 47,094 | 0.7 3.6249 7.0 | | | 0.2360 | 7.0 | 0.99 | 1365.6 | 85.8 | 1555.0 | 56.1 | 1822.7 | 16.9 | 1822.7 | 16.9 |
| 07 395 | | 95,740 | 4.3 5.3718 1.6 | | | 0.3371 | 1.2 | 0.77 | 1872.5 | 20.2 | 1880.4 | 13.8 | 1889.0 | 18.5 | 1889.0 | 18.5 |
| 08 387 | | 39,668 | 1.4 1.6820 4.4 | | | 0.1698 | 3.9 | 0.88 | 1011.0 | 36.3 | 1001.7 | 28.0 | 981.6 | 42.4 | 1011.0 | 36.3 |
| 09 638 | | 91,598 | 1.1 3.0785 2.1 | | | 0.2460 | 1.8 | 0.86 | 1418.0 | 22.5 | 1427.3 | 15.9 | 1441.3 | 20.4 | 1441.3 | 20.4 |
| 10 443 | | 60,537 | 1.5 1.5897 1.9 | | | 0.1599 | 1.5 | 0.79 | 956.3 | 13.0 | 966.2 | 11.6 | 988.6 | 23.4 | 956.3 | 13.0 |
| 11 427 | | 42,242 | 1.3 1.5740 2.3 | | | 0.1564 | 1.7 | 0.75 | 937.0 | 15.3 | 960.0 | 14.5 | 1013.1 | 31.3 | 937.0 | 15.3 |
| 12 1022 | | 79,431 | 2.5 1.1923 1.6 | | | 0.1282 | 1.0 | 0.63 | 777.7 | 7.3 | 797.0 | 8.7 | 851.3 | 25.4 | 777.7 | 7.3 |
| 13 505 | | 52,436 | 3.1 1.5707 3.0 | | | 0.1560 | 2.7 | 0.89 | 934.6 | 23.3 | 958.7 | 18.5 | 1014.5 | 27.0 | 934.6 | 23.3 |
| 14 533 | | 39,939 | 1.2 1.4777 1.5 | | | 0.1517 | 1.1 | 0.76 | 910.8 | 9.4 | 921.3 | 8.9 | 946.5 | 19.6 | 910.8 | 9.4 |
| 15 333 | | 68,933 | 0.6 9.6617 1.4 | | | 0.4248 | 1.2 | 0.85 | 2282.1 | 23.6 | 2403.1 | 13.3 | 2507.2 | 12.8 | 2507.2 | 12.8 |
| 16 190 | | 32,628 | 2.8 5.2795 2.6 | | | 0.3327 | 2.1 | 0.84 | 1851.3 | 34.4 | 1865.6 | 21.8 | 1881.4 | 25.3 | 1881.4 | 25.3 |
| 17 114 | | 19,238 | 0.6 4.3494 2.2 | | | 0.2983 | 1.9 | 0.89 | 1682.7 | 28.5 | 1702.8 | 17.8 | 1727.6 | 17.9 | 1727.6 | 17.9 |

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18 294 40,637 1.0 3.8571 1.9 0.2796 1.4 0.71 1589.3 19.2 1604.8 15.5 1625.1 25.3 1625.1 25.3 19 763 59,226 1.9 1.5881 2.1 0.1603 1.0 0.49 958.6 8.9 965.5 12.8 981.4 36.5 958.6 8.9 20 319 69,131 1.5 4.7504 2.5 0.3002 1.4 0.58 1692.1 21.3 1776.2 20.6 1876.4 35.9 1876.4 35.9

1. 143 6644 0.6 0.6071 11.0 0.0786 7.6 0.69 487.6 35.7 481.7 42.2 453.9 176.7 487.6 35.7
2. 294 30,957 0.9 2.1836 2.6 0.1972 1.0 0.38 1160.1 10.6 1175.8 18.4 1204.8 48.3 1204.8 48.3 23 94 10,404 0.4 1.4748 3.6 0.1542 2.4 0.67 924.4 21.0 920.1 21.8 909.8 54.9 924.4 21.0 24 115 18,167 1.0 2.4919 1.8 0.2155 1.4 0.75 1257.9 15.5 1269.7 13.1 1289.8 23.4 1289.8 23.4 25 245 39,713 3.5 5.0880 2.5 0.3178 1.8 0.73 1778.7 28.5 1834.1 21.3 1897.5 30.8 1897.5 30.8 26 564 49,204 1.5 1.5388 3.1 0.1557 2.7 0.87 933.0 23.4 946.0 19.0 976.4 31.0 933.0 23.4

27 188 35,425 0.8 5.0049 6.1 0.3079 3.5 0.58 1730.6 53.6 1820.2 51.9 1924.3 89.7 1924.3 89.7 28 554 48,118 0.9 1.6123 1.9 0.1614 1.5 0.81 964.7 13.6 975.0 18141 998.3 22.4 964.7 13.6 29 265 29,280 2.0 2.5413 5.6 0.2049 5.4 0.96 1201.7 58.9 1284.0 40.6 1424.3 28.2 1424.3 28.2

30 203 30,786 1.6 2.0077 1.8 0.1859 1.2 0.70 1099.2 12.4 1118.1 11.9 1155.2 24.9 1155.2 24.9 31 623 36,676 3.1 1.6078 3.7 0.1633 2.7 0.75 975.3 24.8 973.3 22.9 968.6 49.2 975.3 24.8 32 187 17,498 0.9 1.2500 1.7 0.1371 1.0 0.60 828.4 8.0 823.4 9.7 809.8 28.9 828.4 8.0 33 176 37,339 0.8 10.1411 1.4 0.4496 1.0 0.71 2393.4 20.0 2447.7 13.1 2493.2 16.9 2493.2 16.9 34 368 21,512 1.6 0.6508 3.7 0.0825 3.6 0.97 511.1 17.9 509.0 15.0 499.5 20.1 511.1 17.9 35 91 19,814 1.2 10.2244 1.7 0.4517 1.3 0.78 2402.7 26.2 2455.3 15.6 2499.1 17.9 2499.1 17.9 36 417 29,248 4.4 1.5608 1.2 0.1562 1.0 0.82 935.6 8.7 954.8 7.6 999.2 14.3 935.6 8.7 37 195 11,686 2.6 9.5841 4.3 0.4300 3.2 0.74 2305.7 62.5 2395.6 40.0 2473.0 49.3 2473.0 49.3

38 585 53,088 3.4 1.6734 2.2 0.1659 1.9 0.86 989.3 17.6 998.5 14.2 1018.7 22.9 1018.7 22.9 39 66 12,592 1.4 10.7275 3.6 0.4270 3.5 0.96 2292.3 67.0 2499.8 33.7 2673.0 17.2 2673.0 17.2 40 824 57,138 2.9 1.5002 3.2 0.1509 2.3 0.73 906.3 19.6 930.5 19.3 988.3 44.2 906.3 19.6 41 141 27,436 1.0 6.3252 2.1 0.3669 1.8 0.84 2014.6 31.3 2021.9 18.8 2029.5 20.6 2029.5 20.6 42 239 17,654 0.8 2.0089 8.1 0.1860 6.4 0.79 1099.8 64.4 1118.5 54.8 1155.1 98.5 1155.1 98.5 43 548 45,096 6.9 1.6127 1.9 0.1615 1.6 0.82 965.1 14.1 975.1 12.0 997.7 22.2 965.1 14.1 44 91 12,627 0.5 2.3823 1.4 0.2067 1.0 0.70 1211.4 11.0 1237.3 10.2 1282.7 19.8 1282.7 19.8 45 356 40,327 1.2 7.9193 3.7 0.3722 3.4 0.90 2039.8 58.7 2221.9 33.6 2394.2 27.6 2394.2 27.6 46 318 68,633 2.1 10.4152 1.5 0.4538 1.0 0.68 2412.3 20.1 2472.4 13.7 2522.1 18.3 2522.1 18.3 47 452 42,384 0.9 1.6161 1.7 0.1622 1.0 0.59 969.2 9.0 976.5 10.6 992.8 27.9 969.2 9.0 48 96 4533 1.2 0.5713 3.9 0.0776 1.7 0.44 481.6 8.0 458.8 14.5 346.4 80.0 481.6 8.0 49 108 5186 0.6 0.5820 3.5 0.0797 1.8 0.52 494.0 8.7 465.7 13.2 328.3 68.3 494.0 8.7 50 132 15,904 0.9 2.1818 2.0 0.2011 1.8 0.91 1181.3 19.7 1175.3 13.9 1164.1 16.2 1164.1 16.2 51 132 35,576 1.1 9.5829 1.4 0.4387 1.3 0.90 2344.9 25.0 2395.5 13.0 2438.8 10.5 2438.8 10.5 52 507 85,686 1.9 11.1573 2.2 0.4521 2.1 0.95 2404.4 41.6 2536.4 20.3 2643.6 10.8 2643.6 10.8 53 147 8122 0.7 0.6206 3.2 0.0796 1.6 0.49 493.9 7.4 490.2 12.4 473.4 61.4 493.9 7.4 54 314 62,509 2.7 3.1047 1.4 0.2468 1.0 0.71 1422.1 12.8 1433.9 10.9 1451.4 19.1 1451.4 19.1

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55 791 89,036 3.4 2.1448 1.9 0.1939 1.6 0.85 1142.7 16.8 1163.4 13.0 1202.1 19.3 1202.1 19.3 56 112 4922 0.8 0.5613 5.6 0.0755 4.4 0.78 469.3 19.7 452.4 20.5 367.5 79.3 469.3 19.7 57 113 10,127 1.1 1.5774 1.7 0.1597 1.1 0.64 955.2 9.8 961.3 10.7 975.5 26.9 955.2 9.8 58 328 34,518 2.2 1.4885 2.9 0.1474 2.2 0.76 886.6 18.1 925.7 17.4 1019.9 37.5 886.6 18.1 59 541 79,411 3.0 4.6361 1.9 0.3078 1.3 0.68 1729.9 19.4 1755.8 15.7 1786.8 25.2 1786.8 25.2 60 355 27,255 1.5 0.6574 6.9 0.0835 5.4 0.78 516.7 26.8 513.0 28.0 496.4 96.3 516.7 26.8

1. 79 4142 0.7 2.5374 2.8 0.2143 1.5 0.53 1251.8 16.8 1282.8 20.2 1335.1 45.3 1335.1 45.3
2. 204 16,953 0.6 1.8812 3.7 0.1741 2.9 0.79 1034.9 27.9 1074.5 24.5 1155.8 44.8 1155.8 44.8
3. 640 56,612 0.9 3.1831 4.1 0.2257 3.5 0.87 1311.7 42.0 1453.1 31.5 1666.4 37.6 1666.4 37.6
4. 104 5820 0.9 0.6042 5.4 0.0793 3.6 0.67 492.2 17.2 479.9 20.6 421.2 89.1 492.2 17.2 65 474 51,562 4.4 1.6332 1.5 0.1632 1.0 0.68 974.4 9.0 983.1 9.3 1002.4 22.2 974.4 9.0 66 208 18,141 0.7 1.5001 6.1 0.1473 5.3 0.87 885.9 44.2 930.4 37.3 1037.6 60.3 885.9 44.2

67 1222 95,533 9.7 1.5844 2.3 0.1590 2.1 0.90 951.3 18.4 964.1 14.4 993.4 20.5 951.3 18.4 68 331 78,649 0.8 10.6322 2.0 0.4589 1.0 0.51 2434.5 20.3 2491.5 18.2 2538.3 28.3 2538.3 28.3 69 391 30,351 1.5 1.2396 1.9 0.1344 1.0 0.52 812.8 7.6 818.7 10.8 834.6 34.2 812.8 7.6 70 332 60,699 0.6 10.0840 2.3 0.4472 1.9 0.79 2382.8 37.0 2442.5 21.7 2492.6 24.3 2492.6 24.3

71 451 64,448 1.7 4.4427 2.0 0.2971 0.75 1677.1 21.7 1720.3 16.2 1773.4 23.4 1773.4 23.4 72 92 12,629 0.8 1.5955 3.9 0.1610 3.3 0.84 962.1 29.4 968.5 24.4 982.9 43.2 962.1 29.4

73 261 25,804 1.1 1.4771 2.4 0.1499 1.5 0.63 900.4 12.6 921.0 14.4 970.8 37.7 900.4 12.6 74 592 85,892 1.6 3.2981 1.6 0.2526 1.1 0.69 1451.8 14.7 1480.6 12.8 1522.1 22.4 1522.1 22.4

75 275 47,440 1.7 4.9770 3.2 0.3113 3.1 0.95 1747.3 47.1 1815.4 27.3 1894.6 17.6 1894.6 17.6 76 270 19,526 0.6 1.2974 1.8 0.1368 1.0 0.56 826.6 7.9 844.6 10.3 892.2 30.8 826.6 7.9 77 710 99,923 1.4 3.8045 1.4 0.2779 1.0 0.74 1580.9 14.0 1593.7 10.9 1610.7 17.1 1610.7 17.1 78 167 42,061 0.7 10.4948 2.3 0.4613 2.2 0.95 2445.3 44.1 2479.5 21.1 2507.6 12.0 2507.6 12.0 79 261 19,436 1.8 2.0385 3.0 0.1860 2.5 0.85 1099.4 25.5 1128.5 20.1 1184.7 30.4 1184.7 30.4 80 238 24,217 0.8 1.6095 2.8 0.1610 1.8 0.66 962.6 16.4 973.9 17.4 999.5 42.1 962.6 16.4 81 526 85,491 1.4 4.8211 2.5 0.3076 2.1 0.85 1729.0 32.3 1788.6 21.2 1858.8 24.2 1858.8 24.2

82 915 41,226 1.3 0.6376 5.9 0.0803 4.7 0.80 497.9 22.7 500.8 23.5 514.2 78.9 497.9 22.7 83 335 37,891 1.3 3.5948 3.0 0.2627 2.5 0.83 1503.8 33.4 1548.4 23.7 1609.7 30.8 1609.7 30.8 84 810 18,051 2.6 1.5898 3.5 0.1580 2.7 0.75 945.6 23.4 966.2 22.0 1013.4 47.0 945.6 23.4 85 202 25,817 1.2 2.0837 1.8 0.1905 1.5 0.84 1124.0 15.5 1143.5 12.4 1180.5 19.5 1180.5 19.5 86 333 39,092 0.9 1.4016 2.1 0.1455 1.3 0.61 875.5 10.5 889.6 12.6 924.8 34.6 875.5 10.5

1. 221 53,420 0.9 5.3246 1.9 0.3344 1.0 0.54 1859.5 16.2 1872.8 15.9 1887.6 28.3 1887.6 28.3
2. 289 54,411 1.5 3.8360 1.6 0.2825 1.0 0.62 1603.9 14.5 1600.3 13.3 1595.6 24.1 1595.6 24.1 89 489 43,926 3.5 1.5150 1.2 0.1542 1.0 0.83 924.2 8.6 936.5 7.4 965.3 14.0 924.2 8.6 90 181 46,003 1.4 5.3185 1.5 0.3365 1.0 0.65 1869.8 16.2 1871.8 13.2 1874.1 21.3 1874.1 21.3 91 549 108,409 2.8 4.7505 2.0 0.3086 1.6 0.78 1733.8 24.2 1776.2 17.1 1826.4 23.0 1826.4 23.0 92 117 4868 1.2 0.6110 4.7 0.0798 2.8 0.60 494.9 13.3 484.2 17.9 433.9 83.0 494.9 13.3 93 473 113,880 1.1 10.0392 1.5 0.4431 1.2 0.80 2364.3 24.1 2438.4 14.0 2500.8 15.3 2500.8 15.3 94 42 1997 0.6 0.5579 8.2 0.0762 2.7 0.33 473.2 12.5 450.2 30.0 333.9 176.6 473.2 12.5 95 305 24,803 0.6 1.6038 2.1 0.1608 1.4 0.70 961.0 12.8 971.7 12.9 995.8 30.0 961.0 12.8

96 63 7291 0.5 1.9943 2.0 0.1896 1.6 0.81 1119.2 16.6 1113.6 13.5 1102.6 23.6 1102.6 23.6 97 193 26,288 1.1 4.3570 5.8 0.2968 3.8 0.66 1675.3 56.7 1704.2 48.2 1740.0 80.4 1740.0 80.4 98 403 64,509 0.6 4.3755 1.3 0.2981 1.0 0.76 1681.9 14.8 1707.7 10.9 1739.6 15.6 1739.6 15.6

100 844 46,504 1.2 1.6268 3.8 0.1629 3.6 0.95 973.0 32.7 980.6 24.1 997.8 25.4 973.0 32.7

QuartziteAP061304-A 206Pb/238U Systematic error (2r): 1.34%

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1. 101 803 1.7 1.9035 10.0 0.1632 3.4 0.34 974.4 31.0 1082.3 66.4 1306.5 182.1
2. 88 6028 0.7 2.0687 4.5 0.1869 0.9 0.20 1104.8 9.3 1138.5 31.0 1203.4 87.3 1203.4 87.3 03 710 91,258 1.5 1.5334 1.3 0.1529 1.1 0.85 917.3 9.7 943.9 8.2 1006.4 14.3 917.3 9.7 04 257 10,683 1.3 2.0543 1.9 0.1906 1.1 0.59 1124.5 11.7 1133.7 13.0 1151.5 30.5 1151.5 30.5 05 241 19,678 0.8 2.6356 1.8 0.2195 1.5 0.82 1279.1 17.2 1310.6 13.3 1362.5 20.0 1362.5 20.0 06 128 30,502 1.6 2.7953 2.7 0.2294 2.4 0.86 1331.2 28.5 1354.3 20.5 1390.9 26.6 1390.9 26.6

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180 ± 10 Ma and this results in an upper intercept age of 878 ± 15 Ma.

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4.1.3. JG060504-2

This is a mylonitic orthogneiss of granitic composition from the central part of the Amdo basement (Fig. 3). It contains stretched quartz grains, feldspar porphroblasts and fine-grained biotite which define the foliation. The majority of zircon analyses in this sample are discordant although there are some concordant analyses of Precambrian and Jurassic age (Fig. 4c). Two concordant analyses from the tips of zircons with older cores have moderate U/Th ratios (8) and ages of 175.2 ± 2.1 Ma and 178.8 ± 5.6 Ma. Other tip analyses yielded older ages. Using an average age of 177 ± 6 Ma for the lower intercept of an anchored discordia line and only using analyses with low uncertainty (less than 5% for the isotopic ratios), the upper intercept age of the regression is 838 ± 23 Ma.

4.1.4. JG061604-1

Located along the Lhasa–Golmud highway just south of the northern basement contact (Fig. 3), this fine-grained granite orthogneiss has a weak foliation defined by biotite. There is a distinct cluster of 14 Jurassic ages with a mean 206Pb⁄/238U age of 181 ± 4 Ma, the majority of which are from zircon cores (Fig. 4d). While there are many older ages, they are spread out along the concordia from approximately 600 to 300 Ma with no distinct cluster (Fig. 4d). We interpret the older ages to record Cambro-Ordovician crystallization pulled down by lead loss and the Jurassic age to be metamorphic growth based on the high U/Th ratios (15–60) of the Jurassic zircon analyses (Table 2), the lack of an unambiguous Jurassic age for any other gneiss and the undeformed nature of all documented granitoids of Jurassic age that intrude the Amdo basement (Guynn et al., 2006). A discordia regression yields a poorly defined upper intercept of 468 ± 53 Ma. A conservative interpretation is that the sample has a Cambro-Ordovician protolith, consistent with the other early Paleozoic crystallization ages.

4.1.5. JG061504-1

This sample is a weakly foliated, felsic orthogneiss that contains abundant accessory magnetite, with some crystals up to several mm across. Though interlayered with sample JG061504-1, this orthogneiss has a distinctly different lithology. Many of the zircons have a significant common lead component (i.e. very high 204Pb concentration) and therefore did not yield reliable ages, resulting in fewer retained analyses than most samples (Fig. 4e; Table 2). Two concordant Proterozoic zircons (in Table 2 but not shown in Fig. 4e) are interpreted to be inherited. One zircon yielded a 206 ⁄ 238 Pb / U age of 187.4 ± 2.1 Ma, which we interpret as young, metamorphic zircon growth (U/Th = 114.2). A cluster of seven concordant ages around 530 Ma was used to define a 260Pb⁄/238U crystallization age of 532 ± 7 Ma (Fig. 4f).

4.1.6. PK970604-1A

This sample is a weakly foliated hornblende-biotite granodiorite that was collected from the southern boundary of the Amdo basement along the Lhasa–Golmud highway (Fig. 3). Three zircons from this sample yield Mesozoic ages, but the majority cluster around 500 Ma (Fig. 4g). The Mesozoic ages are likely a mix of metamorphic zircon with some older zircon; they have U/Th ratios over 6 compared to 1 for the older ages. An average of 18 clustered 206Pb⁄/238U ages yields an interpreted crystallization age of 483 ± 13 Ma (Fig. 4h).

4.1.7. PK970604-1B

This granite orthogneiss has a weak foliation defined by flattened quartz grains and biotite that has been mostly altered to chlorite. Though collected near PK970604-1A, it is more felsic

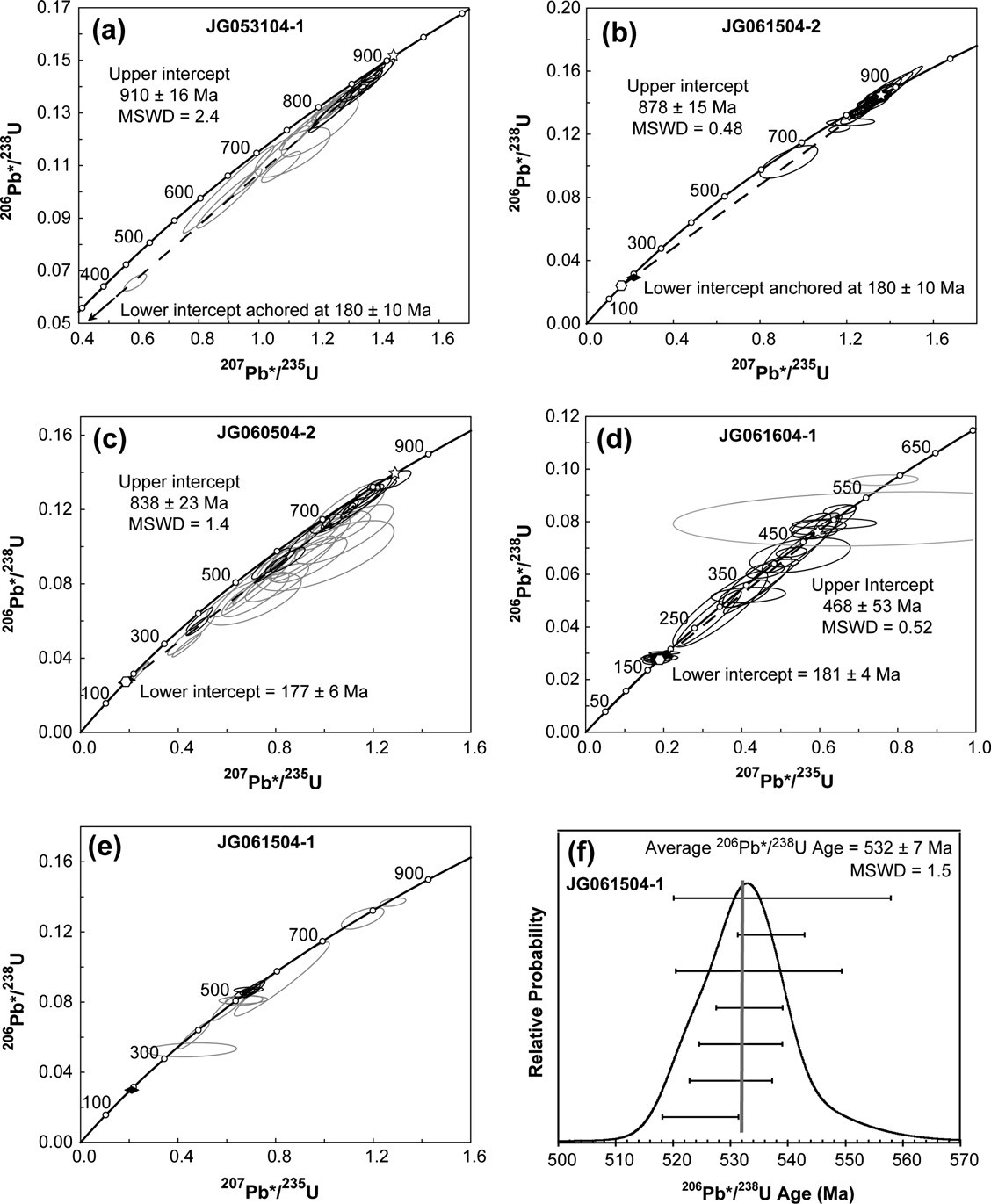


Fig. 4. Concordia plots, combined weighted averages and probability density function (PDF) plots of orthogneiss zircon U–Pb analyses. Error ellipses and error bars are plotted at the 2-r (95% confidence) level. Ellipses in gray were not used in determining discordia regressions or weighted averages, but are included in Table 2. White stars mark the upper intercept value, white hexagons mark the lower intercept and black diamonds represent analyses with an error ellipse too small to be visible at the scale of the figure. Weighted averages and PDFs are made for samples with clusters of ages interpreted to represent crystallization. Vertical line on weighted average plot is the mean age. MSWD = Mean Square Weighted Deviate. Concordia plots for sample: (a) JG053104-1; (b) JG061504-2; (c) JG060504-2; (d) JG061604-1; (e) JG061504-1. (f) Sample JG061504-1 weighted average and PDF of clustered 206Pb⁄/238U ages; (g) sample PK970604-1A concordia; (h) sample PK970604-1A weighted average and PDF of clustered 206 ⁄ 238 206 ⁄ 238

Pb / U ages; (i) sample PK970604-1B concordia; (j) sample PK970604-1B weighted average and PDF of clustered Pb / U ages; (k) sample JG053104-2 concordia and (l) sample JG053104-2 weighted average and PDF of clustered 206Pb⁄/238U ages (for crystallization age) and of clustered 206Pb⁄/207Pb⁄ ages (for older inherited age).

and less deformed. Most analyses were discordant with large uncertainties (Fig. 4i) and there are too few precise ages to define a meaningful discordia regression. A cluster of 13 concordant 206 ⁄ 238 Pb / U ages provides a weighted average age of 498 ± 11 Ma

(Fig. 4j), interpreted to be the crystallization age.

4.1.8. JG053104-2

This is a biotite–granite orthogneiss located near JG053104-1 (Fig. 3). It is composed largely of plagioclase with some quartz and minor biotite and K-feldspar. The orthogneiss has a welldeveloped foliation defined by layers of felsic minerals and aligned biotite. The analyses for this sample yielded two clusters of ages, a large group around 900 Ma and a smaller group around 500 Ma (Fig. 4k). While the population of 500 Ma zircons is much smaller, their concordance and the lack of intermediate ages (500–900 Ma) makes lead loss an unlikely cause of these younger ages. Furthermore, most have U/Th ratios indicative of magmatic zircon (Table 2). As a result, we interpret the younger ages as representing the

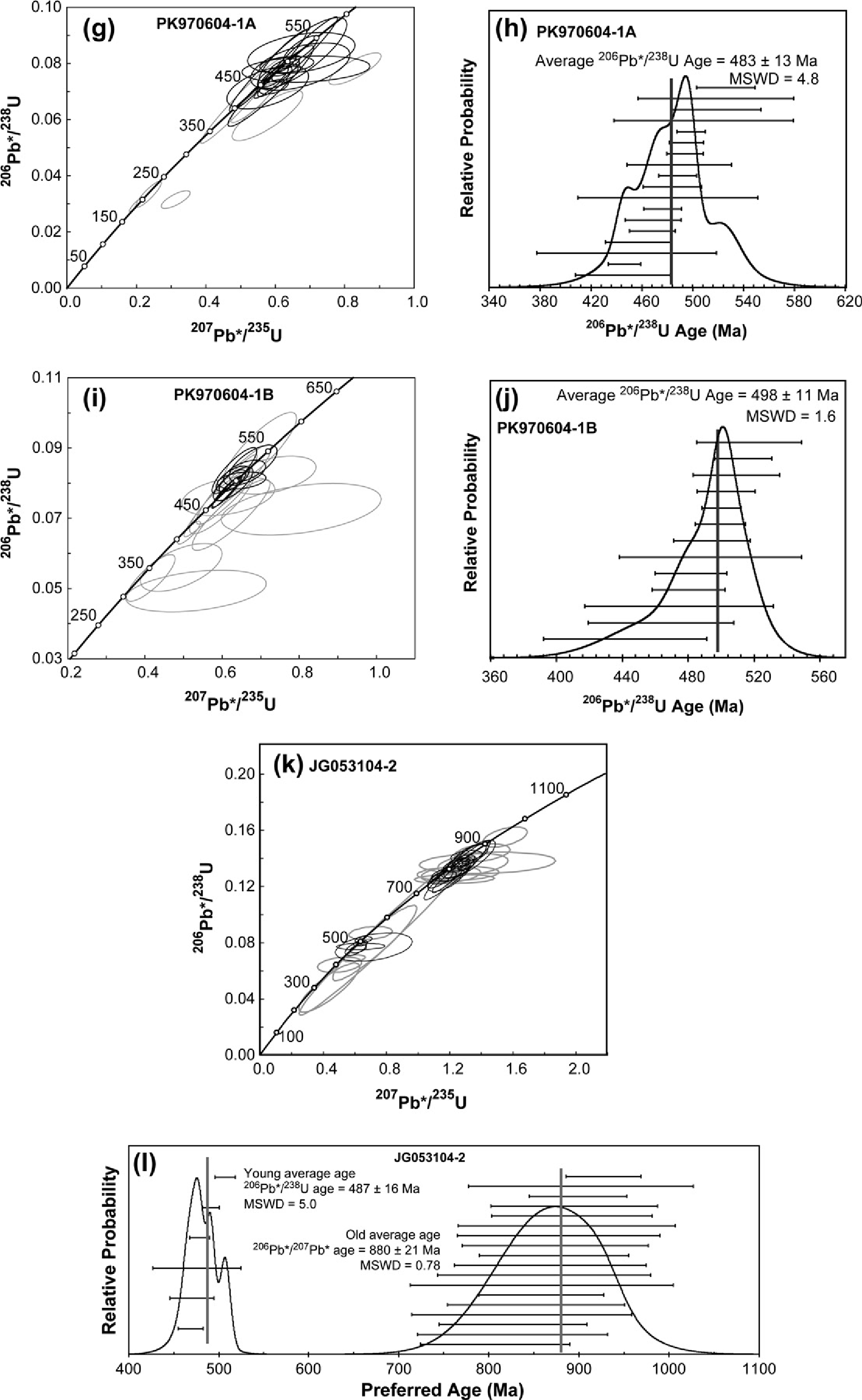


Fig. 4 (continued)

crystallization age and the older zircons to be inherited, although the large number of the latter suggests a significant component of crustal melting of the Precambrian gneiss for the generation of this sample. A weighted average 206Pb⁄/238U age of 487 ± 16 Ma was calculated using six concordant, low uncertainty analyses around 500 Ma (Fig. 4l). A weighted average of 18 low uncertainty, concordant 206Pb⁄/207Pb⁄ ages defines an older, inherited protolith age of 880 ± 21 Ma, consistent with the other Neoproterozoic orthogneiss ages. Considering the uncertainty and discordance, we only confidently report a Cambro-Ordovician crystallization age with significant early Neoproterozoic inheritance.

4.2. Detrital zircon analysis

U–Pb detrital zircon analysis was performed on three samples of metasedimentary rocks from the Amdo basement. The concordia diagrams of all three samples are shown in Fig. 5 and the probability density curves are shown in Fig. 6.

4.2.1. JG061504-4

This dark, banded paragneiss is located along the Lhasa– Golmud highway about halfway across the Amdo basement

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| --- |
| Fig. 5. Pb/U concordia plots for the Amdo metasedimentary detrital zircon samples. Analyses with gray error ellipses are not included in the PDFs due to discordance, large uncertainty or metamorphic overgrowth (see text for criteria). The dashed lines in sample JG061504-4 show inferred lead loss paths as a result of Jurassic metamorphism.    Fig. 6. Probability density functions of Amdo orthogneiss ages and of Amdo metasedimentary detrital zircon ages. The curves have been normalized so that each has the same area. ‘‘s’’ is the number of samples; ‘‘n’’ is the number of individual zircon analyses. |

(Fig. 3). It is largely composed of quartz, plagioclase and biotite.

It has a well-developed banding defined by layers of coarser, more felsic minerals and aligned biotite-rich layers. It also contains minor epidote, muscovite and garnet.

The zircons in this sample have a wide range of morphologies and while some of the grains are well-rounded, others have very well-defined habits with sharp terminations. Cathodeluminescence SEM images reveal that the latter generally have rounded or angular cores separated from the tips by bright zones (Fig. 7). Many of the tips were large enough to analyze with a 25 or 35 lm laser spot size and most of these analyses yielded midJurassic ages and high U/Th ratios, while the cores had much older ages with low U/Th ratios (Fig. 7), revealing that the majority of the euhedral zircon shapes are due to metamorphic growth during Jurassic metamorphism (Guynn et al., 2006). The high-grade metamorphism also appears to have resulted in lead loss for some of the grains so we prefer to rely on the 206Pb⁄/207Pb⁄ ages rather than 206 ⁄ 238 Pb / U ages for construction of the probability density function, despite the larger uncertainty for the former. There were a total of 161 analyses, of which 16 were tips with Jurassic ages and 6 were poor analyses, leaving 139 ages that were used in the age spectrum (Table 2). The resulting age spectrum has broad, overlapping peaks at 850 and 950 Ma, small peaks at 1150 and 1430 Ma and large peaks at 1600, 1700 and 2500 Ma

(Fig. 6). Given the lead loss and metamorphic overgrowth, a maximum depositional age is difficult to assign; we can only estimate it as mid-Neoproterozoic (800–700 Ma) based on the youngest non-Jurassic 206Pb⁄/207Pb⁄ ages. While the middle Neoproterozoic is a maximum depositional age for the paragneiss protolith, the lack of 550–450 Ma zircons, ages which are ubiquitous across Gondwana and in Gondwanan Paleozoic sandstones (Fig. 8), make it unlikely that the paragneiss is younger than Neoproterozoic. Therefore we tentatively assign the paragneiss protolith a mid-late Neoproterozoic depositional age.

4.2.2. JG062505-3

Quartzite sample JG062505-3 comes from a small exposure within the gneisses near the northern edge of the Amdo basement exposure (Fig. 3). All 99 zircon grains analyzed from this quartzite sample are of sufficient quality to include in the age spectrum. This sample yielded a spectrum with many different peaks in the Neoproterozoic and early Paleozoic, including strong peaks at 500 Ma, 550 Ma, 590 Ma, 825 Ma and 910 Ma. There are a few small peaks between 1050 Ma and 1400 Ma, a group of ages at 2500 Ma and a few ages between 2600 Ma and 2800 Ma. The maximum depositional age is 493 ± 64 Ma, a weighted average of the youngest 11 zircons, all of which are concordant and overlap at the 2r level.

4.2.3. AP061304-A

This is a quartzite from a layer located at the southwest edge of the orthogneiss (Fig. 3). A total of 92 zircons from this quartzite were analyzed and 85 of these passed the minimum constraints

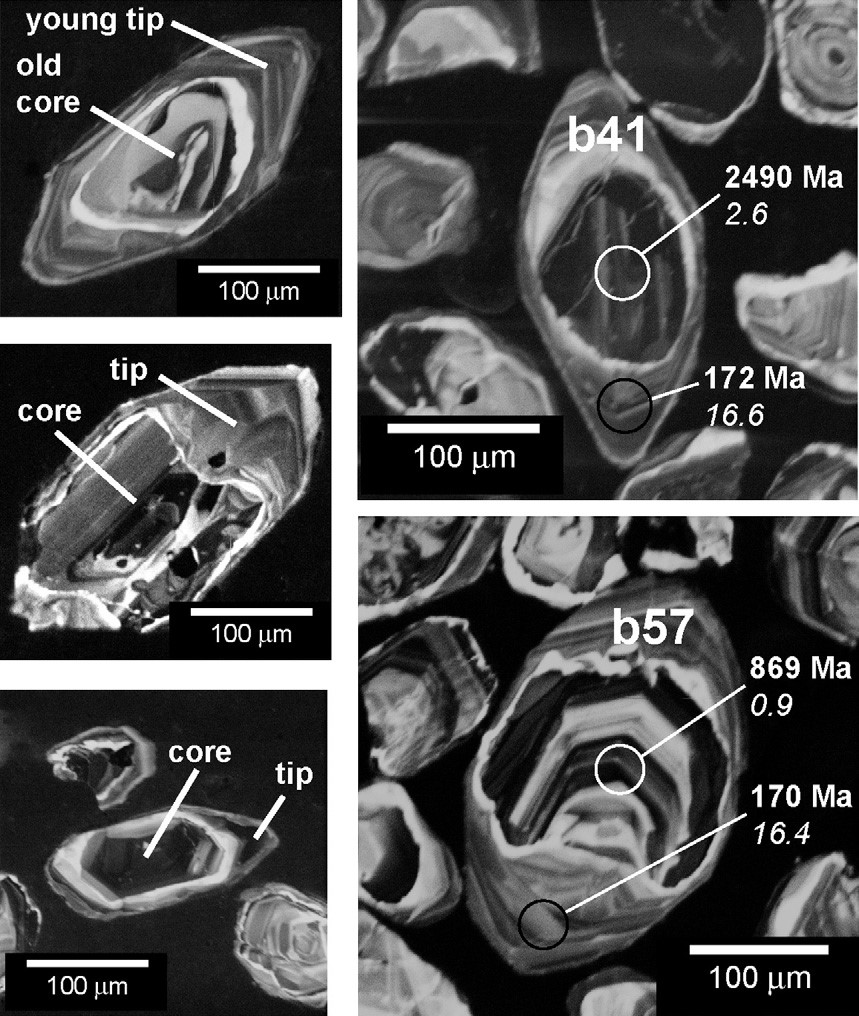


Fig. 7. Cathodeluminescence SEM images of JG061504-4 zircons showing rounded or irregular cores with sharp tips. The cores are older detrital zircon grains and the tips represent Jurassic metamorphic growth, as revealed by U–Pb dating, shown for two of the zircons. The number in italics beneath the age is the U/Th ratio, which is larger for metamorphic zircon.

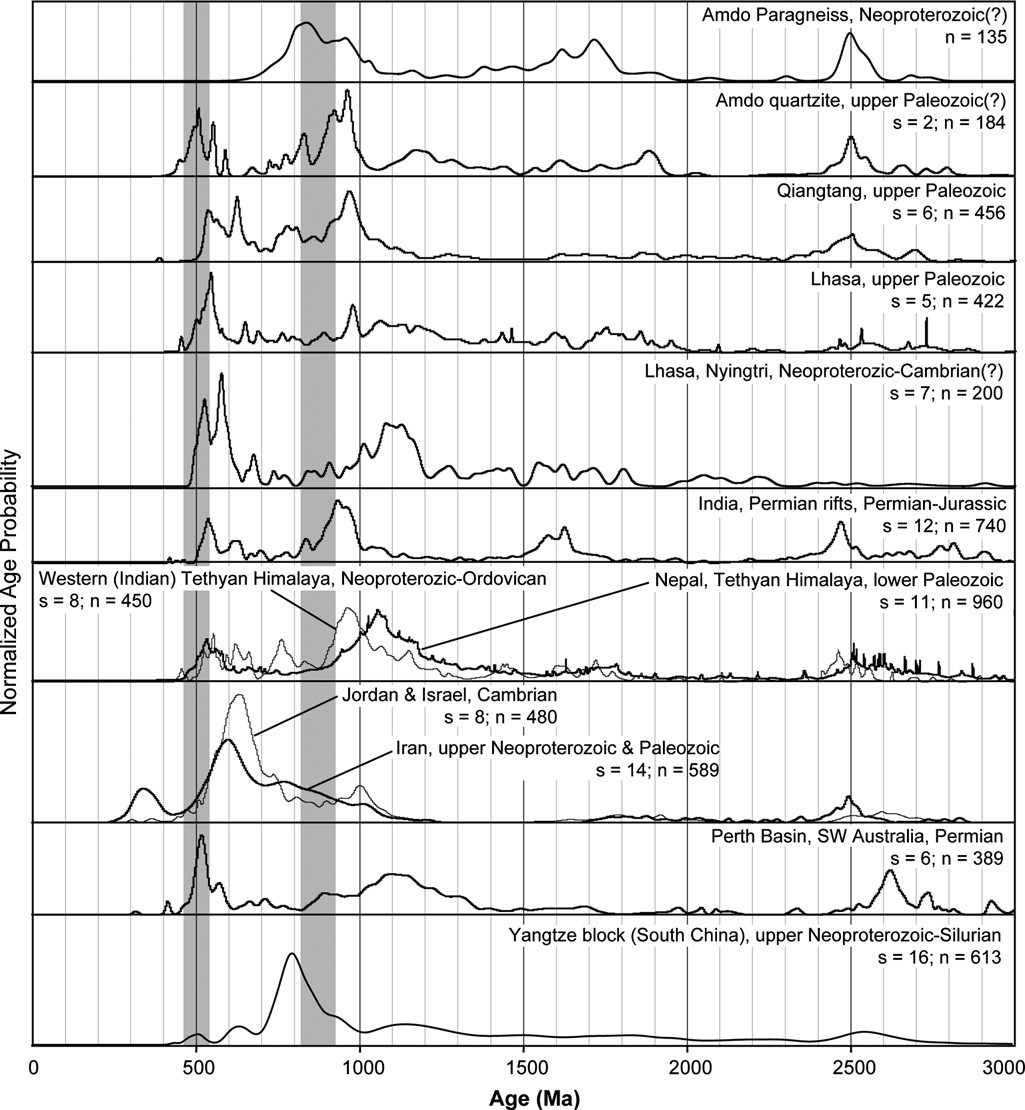


Fig. 8. Probability density plots summarizing regional detrital zircon data sets. The probability density curves have been normalized so that each has the same area. ‘‘s’’ is the number of rock samples; ‘‘n’’ is the total number of zircon age analyses. The two dark gray bands represent the Amdo orthogneiss age groups (Fig. 6). Data sources: Qiangtang upper Paleozoic – Kapp et al., 2000, 2003b; Pullen et al., 2008; Lhasa upper Paleozoic – Kapp et al., 2007b; Leier et al., 2007; Pullen et al., 2008; unpublished (PK061302-1); Lhasa Nyingtri – Dong et al., 2010; Indian Permian rifts – Veevers and Saeed, 2009; western Tethyan Himalaya – Myrow et al., 2010 (samples MS-2, MS-5, Thangpo, PV, Batal, KU-2 and MBQ); Myrow et al., 2003 (sample KL); Nepalese Tethyan Himalaya – Gehrels et al., 2003a; Jordan and Israel – Kolodner et al., 2006; Iran – Horton et al., 2008; Perth Basin – Cawood and Nemchin, 2000; Yangtze Block – Wang et al., 2010a,b; Sun et al., 2009 (samples LGL and ZDS).

to be used in the age spectrum. The age spectrum for this sample has two prominent peaks at 500 Ma and 950 Ma, with two other large peaks at 1875 Ma and 2500 Ma. There is a small peak at 825 Ma and a scattering of ages between 1100 Ma and 1950 Ma. There are only a few Archean ages older than 2600 Ma. The two youngest concordant ages combined give a maximum depositional age of 447 ± 30 Ma; the youngest group of four ages gives a maximum age of 510 Ma.

# Discussion

5.1. Amdo Precambrian Rocks

The Precambrian protoliths of the Amdo orthogneisses were emplaced at 920–820 Ma (Table 1), providing a minimum age for central Tibetan crust. These are the oldest known rocks in central Tibet, and together with the mid-Neoproterozoic ages reported for igneous rocks in the Lhasa terrane (Hu et al., 2004) and early Neoproterozoic granitoids in the Qaidam–Kunlun terrane (Gehrels et al., 2003b), they imply that Tibet is underlain by relatively juvenile crust. The young and therefore rheologically weak crust could explain why deformation related to the Indo-Asian collision has propagated so far into Asia (Molnar and Tapponnier, 1981). While other workers have suggested the crust of Tibet is as old as Early– Middle Proterozoic and even Archean based on isotopic data for the Amdo Cambrian orthogneiss (Harris et al., 1988b) and Phanerozoic granites and detrital zircons from the Lhasa terrane (Chiu et al., 2009; Zhu et al., 2009a), it us uncertain how isotopic compositions have been affected by melting of sedimentary rocks sourced from old cratonic blocks (e.g. India and Australia; Ding et al., 2003). To date, no rocks older than Neoproterozoic have been definitively dated from the Tibetan terranes.

The early Neoproterozoic age of the Amdo gneiss provides some constraint for the origin of these rocks prior to their assembly with Gondwana. This age postdates most of the orogenies responsible for the assembly of Rodinia but is relatively prevalent throughout Asian terranes and also occurs in India and Antarctica.

Early Neoproterozoic magmatism is common throughout the Yangtze craton of the South China block, particularly 825 Ma ages, both as igneous rocks (Li, 1999; Li et al., 2003; Ling et al., 2003; Chen et al., 2006; Wang et al., 2006; Xiao et al., 2007) and as detrital zircon age peaks from Neoproterozoic sedimentary rocks (Sun et al., 2009; Zhou et al., 2009; Wang et al., 2010a). Early Neoproterozoic magmatism of the Jiangnan orogeny is probably related to the collision of the Yangtze and Cathaysia blocks which created the South China block (Fig. 9), with the Cathaysia block attached to Australia at the time (Chen et al., 2006; Wu et al., 2006; Zheng et al., 2007, 2008). The genesis of the later 830–730 Ma magmatism is debated and there are two primary models: (1) subduction along a continental arc located on the western and northern margin of the South China block and related back-arc extension (Zhou et al., 2002, 2006a,b; Ling et al., 2003; Wang et al., 2004; Zhao and Zhou, 2008) or (2) the arrival of a mantle plume leading to the breakup of Rodinia (Li et al., 1999, 2002, 2006, 2011; Wang and Li, 2003; Zhu et al., 2008). Proponents of the former model generally argue for the position of the South China block along the northwestern margin of Australia until rifting in the Late Devonian (Yu et al., 2008; Roger et al., 2010; Wang et al., 2010b; Duan et al., 2011), largely based on detrital zircon provenance data. Proponents of the plume model place the South China block between eastern Australia and Laurentia until rifting and Rodinia break-up in the middle Neoproterozoic (Li et al., 2008, 2011). If the arc-related model is correct, a likely scenario for the origin of the Amdo basement (and the Qiangtang and/or Lhasa terranes) is as part of the continental arc that rifted off either during back-arc extension or in the initial stages of Rodinia break-up. Not only do the Amdo orthogneiss ages match with the South China granite ages, but the primary age group of the Amdo paragneiss detrital zircons is 1000– 750 Ma, similar to the main age peak of Neoproterozoic to early Paleozoic sedimentary rocks from the South China block (Fig. 8).

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| Fig. 9. (a) One possible interpretation of the position of the Lhasa–Qiangtang terrane in East Gondwana during the Permian (290 Ma). Map based on Boger and Miller (2004) and shows major continents, cratons, terranes and orogenic belts of Gondwana. With the exception of South China and Indochina, the configuration of Gondwana is essentially the same from the late Cambrian through the early Permian. The Cambro-Ordovician orogenic belt across northern India is only generally defined due to the overprint by rifting and the Himalayan thrust belt. The Lhasa and Qiangtang terrane outlines are roughly based on the currently defined boundaries with 50% extra width to account for Mesozoic and Cenozoic contraction (Kapp et al., 2005b). Other peri-Gondwana terranes are only generally defined. Extent of Greater India is based on Ali and Aitchison (2005). (b) Inset: The South China block, to scale with East Gondwana but orientation as in present day. AD = Aravalli–Delhi Craton; AF = Africa; AG = Afghanistan blocks; ANS = Arabian–Nubian shield; AN = Antarctica; AU = Australia; BK = Bundelkhand Craton; CB = Cathaysia block; DW = Dharwar Craton; EAO = East African orogeny; EG = Eastern Ghats; GI = Greater India; GC = Gawler Craton; IC = Indo-China; IN = India; IR = Iranian blocks; L = Lhasa terrane; MC – Mawson Craton; MD = Madagascar; NC = Northampton Complex; NPCM; Northern Prince Charles Mountains; PC = Pilbara Craton; Q = Qiangtang terrane; SB = Singhbhum Craton; SCB = South China block; SEY = Seychelles; SPCM = Southern Prince Charles Mountains; SWB = Sibumasu-West Burma; TK = Turkey; YB = Yangtze block; YC = Yilgarn craton. |

The other primary regions of early Neoproterozoic magmatism are on the Indian plate and in Antarctica (Fig. 9). Gneisses dated at 830 Ma occur in the Indo-Pakistan Himalaya (DiPietro and Isachsen, 2001; Singh et al., 2002; Cottle et al., 2009). Igneous rocks of this age also occur in the Aravalli–Delhi craton in NW India (Fig. 9), though most of the dated magmatism is in the 850– 700 Ma range (Deb et al., 2001; Pandit et al., 2003; Buick et al., 2006; Meert et al., 2010), and 1000–800 Ma detrital zircons are abundant in mid-Neoproterozoic sedimentary rocks of the nearby Vindhyanchal Basin (Malone et al., 2008). There is also early Neoproterozoic magmatism and metamorphism in the Eastern Ghats of India (Mezger and Cosca, 1999), as well as the Prince Charles Mountains and Rayner/Napier complex of Antarctica (Boger et al., 2000; Fitzsimons, 2003; Boger and Miller, 2004), though the younger 900–800 Ma ages have not been documented in these regions. Both the Aravalli–Delhi craton and the Eastern Ghats have a smaller volume of early Neoproterozoic granites than the South China block. In addition, taking into account the extent of India consumed by the Indo-Asian collision (Greater India), if the Amdo basement was located along India’s margin in the Neoproterozoic it would have been over 1000 km from the Aravalli–Delhi craton. Furthermore, the detrital age spectra of the paragneiss is quite different from Proterozoic rocks of the Himalaya, suggesting they were not co-located. The Greater Himalayan Sequence is dominated by Grenville ages and contains few Neoproterozoic ages while the Lesser Himalayan Sequence is dominated by 2000– 1800 Ma zircons with a peak at 1900 Ma (Gehrels et al., 2003a).

In general, the scarcity of data for the Neoproterozoic, the many continental fragments that comprised Gondwana and the longitudinal ambiguity of paleomagnetic data all make placing Gondwanan terranes in a pre-Gondwanan paleogeographic framework difficult. Nonetheless, we think the available data suggest that the Amdo basement, and therefore the Qiangtang and/or Lhasa terranes, were located adjacent to the margin of the Yangtze block and rifted off in the middle Neoproterozoic before amalgamating with East Gondwana.

5.2. Cambro-Ordovician magmatism

The younger suite of Amdo orthogneiss intruded the older basement between 540 and 460 Ma (Table 1). Cambro-Ordovician granitoid ages have also been documented in the Qiangtang terrane (Kapp et al., 2000; Pullen et al., 2011). In the Lhasa terrane, Kapp et al. (2005a) reported 550 Ma inherited zircons from Cretaceous-Tertiary granitoids and orthogneisses of the Nyainqentanglha mountains.

Cambro-Ordovician granitoids, emplaced following Pan-African orogenesis and Gondwana assembly, are ubiquitous along the margins of Gondwana and in Gondwanan terranes (Veevers, 2004). They occur in Turkey (Gessner et al., 2004; Ustaömer et al., 2009), Iran (Hassanzadeh et al., 2008), the Arabian–Nubian shield (Stern, 1994), Madagascar (Tucker et al., 1999; Collins et al., 2003), the Himalaya (Schärer and Allègre, 1983; Garzanti et al., 1986; Le Fort, 1986; Lee et al., 2000; Godin et al., 2001; Gehrels et al., 2003a; Cawood et al., 2007; Visonà et al., 2010), and the northwestern Indochina peninsula (Liu et al. (2009) and references therein). The Himalayan granitoids, combined with CambroOrdovician metamorphic monazite ages from rocks of the Greater Himalaya Sequence, have been used to suggest a tectonic event along the Indian margin at this time (e.g. Gehrels et al. (2003a) and references therein). This tectono-magmatism probably extended both to the west (Hassanzadeh et al., 2008; Horton et al., 2008) and to the east (e.g. Cawood et al. (2007) and references therein) and may have been related to a reorganization of plate boundaries following Gondwana amalgamation during the late Neoproterozoic (Boger and Miller, 2004; Cawood et al., 2007).

Cawood et al. (2007) noted that after taking into account Cenozoic shortening, the Himalayan granitoids indicate an extraordinarily wide orogen (over 700 km), similar to the coeval Ross– Delamarian orogeny in Australia. If the Lhasa and Qiangtang terranes were located in the same approximate longitudinal position along the Indian margin as today, the Amdo basement would extend that width to over 1100 km, taking into account 50% shortening of the Lhasa terrane during the Cretaceous and Tertiary (Kapp et al., 2005b). An alternative and more plausible scenario is that these terranes were not spatially associated with northern India. One possibility is that they were displaced to the east or west from their current position relative to the Himalaya. Another possibility, which we prefer, is that they were outboard from India at the end of the Neoproterozoic after rifting off of the South China block, and then collided with the northern margin of East Gondwana causing the Cambro-Ordovician orogenesis observed in the Himalaya (Cawood et al., 2007). Regardless, the Cambro-Ordovician granitoids in terranes of central and southern Tibet indicate that they were involved in the Cambro-Ordovician tectono-magmatic events along the northern margin of Gondwana.

5.3. Amdo quartzite and Lhasa–Qiangtang late Paleozoic detrital zircon signature

The detrital zircon age spectra of the two quartzite samples are quite similar to each other (Fig. 6) and both have a maximum depositional age in the Ordovician, so we regard these as approximately coeval. Sandstones and low-grade quartzites of Carboniferous–Permian age are widely exposed across the Lhasa and Qiangtang terranes (Leeder et al., 1988; Yin et al., 1988; Pan et al., 2004) and comparing a combined Amdo quartzite spectrum to combined age spectra of Carboniferous–Permian samples from the Lhasa and Qiangtang terranes (Fig. 8) reveals that they all have a similar age signature, particularly for the Qiangtang, sharing common 600–500 Ma ages, 1000–900 Ma ages and peaks around 2500 Ma. This suggests that the Amdo quartzite protoliths were late Paleozoic sandstones, with the protoliths of the associated marbles and schists likely being Paleozoic carbonates and mudstones deposited together on a passive margin.

The lack of middle to late Paleozoic zircons in upper Paleozoic Gondwanan sedimentary rocks appears to be a common trait. Of a total of 878 zircons from eleven samples of Lhasa and Qiangtang Carboniferous–Permian sandstone, only two are younger than Ordovician and several samples have maximum ages in the Cambrian, similar to the quartzites. This same pattern is seen in six samples of Permian sandstone from the Perth Basin in western Australia, where only four out of 310 zircons have ages younger than Ordovician (Cawood and Nemchin, 2000), as well as in rocks of the Ordovician–Devonian Tethyan Himalayan Sequence and the Permo-Jurassic rocks of Indian rifts (Fig. 8). The lack of middle to late Paleozoic zircons is probably a result of magmatic quiescence during the development of a passive margin along northern Gondwana following Cambro-Ordovician tectonism and prior to Permo-Triassic rifting.

5.4. Paleozoic detrital zircon signatures and paleogeography

Outside of the major continents, the location of terranes within Gondwana is not well known and has become an increasing source of debate, partly driven by the recent collection of detrital zircon data. The Lhasa and Qiangtang terranes have typically been placed adjacent to Greater India in essentially the same position as they occur today (e.g. Metcalfe, 1996, 2006; Scotese, 2001). Some recent reconstructions have placed the Lhasa terrane next to northwest Australia in the late Permian (Ferrari et al., 2008; Zhu et al., 2010). Ferrari et al. (2008) locate it there in the early Paleozoic, while Zhu et al. (2010) have it isolated outboard of Gondwana prior to Middle Permian accretion and keep the Qiangtang terrane directly adjacent to India. The latter requires that the Qiangtang terrane was south of the Lhasa terrane during the Permian, which is not supported by the available paleomagnetic data (Li et al., 2004).

While Ferrari et al. (2008) and Zhu et al. (2010) place the Lhasa terrane next to northwest Australia, in many traditional reconstructions West Burma, Sibumasu and other Indochina terranes have been placed along this margin in the Paleozoic due to similarities in flora, fauna and stratigraphy (e.g. Metcalfe, 1996, 2006). Other authors have recently suggested that the South China block was located adjacent to northwest Australia prior to rifting in the Late Devonian (Yu et al., 2008; Roger et al., 2010; Wang et al., 2010b; Duan et al., 2011). Alternatively, the South China block has been placed between eastern Australia and Laurentia (Li et al., 2008, 2011), outboard of the Arabian–Nubian shield (Ferrari et al., 2008) or even next to northwest India with the North China block next to northeast India and northwest Australia (Scotese, 2001; McKenzie et al., 2011). Many of the newer reconstructions that place the South China block or Qiangtang terrane adjacent to northwest Australia fail to account for the location of the Indochina terranes such as West Burma or Sibumasu.

In order to use the Amdo, Qiangtang and Lhasa detrital zircon spectra for placing the terranes in a paleogeographic framework, we compare them to the composite detrital zircon age spectra of other rocks deposited during the late Neoproterozoic to late Paleozoic from different Gondwanan continents and terranes (Figs. 8 and 9). Inspection of this figure leads to the following observations:

1. The Middle Eastern rocks of West Gondwana have an age signature that is distinct form those of East Gondwana (Fig. 8). These Cambrian rocks contain one major group of 800–550 Ma ages that is a direct result of being sourced from the Arabian–Nubian shield which contains large volumes of middle-late Neoproterozoic magmatism (Wilde and Youssef, 2002; Avigad et al., 2003; Kolodner et al., 2006; Hassanzadeh et al., 2008). While the East Gondwana Paleozoic rocks have some ages within this range, this major peak is not represented and there are relatively few ages, especially in the 700–600 Ma range, indicating that little detritus from the Arabian–Nubian shield made it to the northern margin of India, possibly as a result of a major orogenic drainage divide created during the Pan-African collision of India with Africa (Fig. 9). While DeCelles et al. (2000) argued for a West Gondwana (Arabian–Nubian shield and east Africa) source for Greater Himalaya and Tethyan Himalaya zircons, these rocks lack a large group of 800–550 Ma ages. The predominance of Grenville ages suggests that East Gondwana is the most likely source for the Himalayan sediments, in particular orogenic provinces in eastern India, western and southern Australia and Antarctica (Yoshida and Upreti, 2006; Cawood et al., 2007), similar to Permian sandstones from the Perth Basin (Cawood and Nemchin, 2000) and Permian–Jurassic rocks from east Indian rift basins (Veevers and Saeed, 2009) (Figs. 8 and 9).
2. 600–500 Ma detrital zircon ages are common to all East Gondwanan sedimentary rocks as a result of the extensive late Neoproterozoic–Ordovician magmatism. Therefore these ages are not very useful for determining sediment sources and terrane paleogeography.
3. Outside of the 600–500 Ma ages, the largest peak is generallyeither between 1000 and 850 Ma or between 1250 and 1000 Ma, with the exception of upper Paleozoic rocks from the Lhasa terrane which have a fairly even distribution of 1250–950 Ma ages. While the spectra have peaks in one or the other of these two groups of ages, most contain ages from both groups, making the difference relatively subtle. The 1250–1000 Ma ages are Grenville and the most likely sources are the late Mesoproterozoic orogenies of western Australia, west Antarctica and possibly eastern India (Boger et al., 2000; Fitzsimons, 2000, 2003; Condie, 2003; Meert and Torsvik, 2003; Cox et al., 2004; Veevers et al., 2005), which have already been proposed as the source region for the Greater Himalayan Sequence (Yoshida and Upreti, 2006; Cawood et al., 2007). The Prince Charles Mountains of Antarctica (Boger et al., 2000; Fitzsimons, 2003) and the Eastern Ghats of India (Mezger and Cosca, 1999) are a possible source for 1000–950 Ma ages, as well as the possibility of undated basement of Greater India, Tibet and western Australia. These as well as younger 850– 750 Ma ages are also common to the South China block, which some reconstructions suggest was located next to India in the early Paleozoic (Metcalfe, 1996, 2006; Scotese, 2001). However, even these models rift South China from Australia by the end of the Devonian and since the same 1000–850 Ma ages occur in upper Paleozoic Gondwanan rocks, this requires either an alternate source or recycled lower Paleozoic rocks.
4. The spectra contain small but statistically significant populations of middle Neoproterozoic (800–600 Ma) and PaleoMesoproterozoic (2400–1300 Ma) age peaks which generally do not correlate across regions. The small size of these peaks suggests either local sources of minor magmatic volumes or recycled zircons from older sedimentary strata. The Lesser Himalaya Sequence, which is thought to be directly sourced from the Indian craton, has a predominant group of 2000– 1800 Ma ages (DeCelles et al., 2000; Gehrels et al., 2003a) and the lack of these ages in Tibetan samples might indicate these terranes were not adjacent to India. Indeed, the lack of these ages in the Greater Himalaya Sequence have been used to argue that these rocks are allochthonous to India (DeCelles et al., 2000). On the other hand, this age signature is also largely missing from Permian–Jurassic sediments deposited in Permian rifts of eastern India (Veevers and Saeed, 2009), implying that other mechanisms may be responsible for the lack of a strong interior India signature from Greater Indian and Tibetan rocks. Similarly, Permian sandstones of the southwest Australian Perth basin lack a strong Yilgarn cratonic signature (Cawood and Nemchin, 2000). It is likely that tectonic events, collisional in the early Paleozoic and extensional in the late Paleozoic, produced topography that prevented significant drainage from the interior of the continents to the shelf.
5. The spectra typically contain only one or two small though significant age peaks in the late Archean-earliest Paleoproterozoic. Again, older Archean ages common to the interior cratons are not common in the age spectra.

In summary, the East Gondwanan sedimentary rocks display a wide range of detrital zircon ages but are dominated by 1250– 850 and 600–500 Ma ages derived from orogenic belts rather than cratonic interiors. These ages imply a wide range of sediment sources for East Gondwana during the Paleozoic including distal mountain ranges and probably recycled Proterozoic sedimentary rocks. This wide ranging provenance makes it difficult to use the detrital zircon age signatures to definitively place terranes within Eastern Gondwana.

The Amdo and Qiangtang spectra have distinct 1000–900 Ma age peaks, while the Nyingtri samples of the Lhasa terrane have a distinct 1200–1000 Ma group of ages and the Lhasa terrane upper Paleozoic spectrum has diffuse ages across the 1250–900 Ma age range (Fig. 8). Similarly, Tethyan rocks from the western (Indian) Himalaya also have a 950 Ma peak age, while the Nepalese Tethyan rocks have a 1050 Ma peak (Fig. 8). Cambrian samples collected further east in the Himalaya (Nepal and Bhutan) by Myrow et al. (2010) appear to have a similar provenance as the northwest Indian rocks, although this signature is dissimilar from the Nepalese Himalayan rocks in Gehrels et al. (2003a). While subtle, these east to west differences in the Himalayan rocks may reflect a slight change in provenance and if that is the case, the Qiangtang rocks have an age signature closer to the western Himalaya than the Nepalese Himalaya, while the Lhasa rocks have an age signature more like the latter. The western Himalayan samples also share a 750 Ma peak with the Qiangtang samples. The lack of 1000–900 Ma ages in the western Himalaya and Qiangtang terrane may reflect a more westerly location of the Qiangtang terrane relative to the Lhasa terrane along Gondwana’s margin, farther from the early Neoproterozoic orogens of East Gondwana.

# Conclusions

Orthogneisses from the Amdo basement reveal two periods of magmatism, one in the early Neoproterozoic (920–820 Ma) and another in the Cambro-Ordovician (540–460 Ma). Neoproterozoic magmatism is also recorded in the Lhasa terrane southwest of Amdo while evidence of Cambro-Ordovician magmatism, common in East Gondwana terranes, has also been found in other places within the Lhasa and Qiangtang terranes. The available geochronologic data indicate that the basement of the Lhasa and Qiangtang terranes is Neoproterozoic to early Paleozoic in age.

Two quartzite samples from the Amdo basement have similar detrital zircon age signatures and maximum depositional ages, indicating they are coeval. Their age spectra are very similar to Carboniferous–Permian sandstones that are widespread across the Qiangtang and Lhasa terranes, suggesting their protoliths were late Paleozoic in age.

We propose that the Amdo basement, and therefore possibly the Qiangtang and Lhasa terranes, originated from the Yangtze block of South China during the Neoproterozoic before amalgamating to Gondwana during the early Paleozoic, based on similarities in magmatic and detrital zircon ages. The Amdo basement and its associated terrane(s), Qiangtang and/or Lhasa, could have rifted off during mid-Neoproterozoic extension of the South China block, as a result of back-arc rifting or continental break-up. However, magmatism of this age also occurs in the Aravalli–Delhi craton of eastern India and in Antarctica and more data are required for a confirmation of our proposed link to South China.

The later period of Cambro-Ordovician magmatism is widespread along the former margins of East Gondwana from Turkey to Australia. This magmatism was the result of oceanic subduction along continental margins of the newly formed supercontinent Gondwana as well as possibly terrane collisions (DeCelles et al., 2000; Gehrels et al., 2003a) in response to plate reorganization following Gondwana assembly (Boger and Miller, 2004; Cawood et al., 2007). The presence of this magmatism in central Tibet indicates these terranes were associated with East Gondwana in the early Paleozoic, either as part of an exceptionally wide active continental margin similar to the North American Cordillera or the Australian Ross–Delamerian Orogeny (Cawood et al., 2007) or as terranes that collided with India at this time, creating the Cambro-Ordovician orogeny of the Himalaya (Gehrels et al., 2003a).

The detrital zircon age signatures of upper Neoproterozoic and Paleozoic rocks of East Gondwanan are not very distinct, which unfortunately limits their usefulness for determining paleogeography. There is a suggestion in the data that Tibetan and Himalayan rocks may have a provenance difference from east to west, with more late Mesoproterozoic ages to the east and more early Neoproterozoic ages to the west, but the difference is subtle and Myrow et al. (2010) argue for a well-mixed signature along the Greater Indian margin in the early Paleozoic. If detrital zircon data are to be used for better constraining East Gondwanan paleogeography, it will require a finer resolution of spatial and temporal trends in magmagenesis and sedimentary provenance.

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