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Lhasa Terrane in southern Tibet came from Australia

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Includes the following materials:

1. Table DR1 Sample descriptions and zircon details in this study
2. Analytical techniques
3. Table DR2 Zircon LA-ICPMS U-Pb data of detrital zircons from the Ordovician to Permo-Carboniferous metasedimentary rocks in southern Tibet
4. Table DR3 Zircon Hf isotopic data of detrital zircons from the Ordovician to Permo-Carboniferous metasedimentary rocks in southern Tibet
5. Figure DR1. Photos of thin section and cathodoluminescence (CL) images of representative detrital zircons of Paleozoic metasandstone samples in southern Tibet

   Solid circles indicate the locations of LA-ICPMS U-Pb-Hf analyses. The U-Pb ages and $\varepsilon_{Hf}(t)$ values are given for each spot. The scale bar length in photos and CL image is 100 μm. Q = quartz, Pl = plagioclase, Kfs = K-feldspar.
6. Figure DR2 Concordia plot of detrital zircons recovered from the Ordovician to Permo-Carboniferous metasedimentary rocks in southern Tibet
7. Figure DR3 Detrital zircon age distributions of metasedimentary rocks of this study and previous work. Important age peaks are shown in grey bands. The $^{207}Pb/^{206}Pb$ ages were used for >1000 Ma, and the $^{206}Pb/^{238}U$ ages for younger zircons. Results described in this study exclude analyses with >10% discordance. Data details are given in Table DR2.

Table DR1 Sample descriptions and zircon details in this study

Sample	SL5-1	GB-12	08YR10	NX1-5	XM01	MB07-2	GBJD
Terrane	Tethyan Himalaya	Qiangtang	Lhasa	Lhasa	Lhasa	Lhasa	Lhasa
Location	Selong	NW Rongma	SW Xungba	SW Coqen	NE Xainza	NW Songdo	Gongbo gyamda
GPS position	N28°38.537′ E85°49.867′	N33°29.683′ E85°45.851′	N31°46.819′ E82°09.169′	N30°45.721′ E85°35.234′	N31°00.002′ E88°45.842′	N30°05.015′ E92°16.067′	N29°53.347′ E93°26.893′
Stratigraphical age	Lower Permian Jilong Fm.	Ordovician	Permo-Carboniferous Laga Fm.			Permo-Carboniferous Laigu Fm.	
Lithology	Quartz sandstone	Quartzite	Lithic graywacke	Plagioclase-bearing siltstone	Feldspathic sandstone	Quartzite	Quartzite
Key petrographic features	Poor roundness and good sorting	Indented quartz	Bad roundness and bad sorting, angular quartz	Poor roundness and bad sorting, acid plagioclase with polysynthetic twin	Bad roundness and bad sorting, angular K-feldspar	Indented quartz	Orientated mica, quartz with metamorphosed overgrowth
Grains analyzed for U-Pb ages	100	100	100	100	100	100	105
Th/U > 0.1 (analyses)	93	79	85	77	92	86	94
Concordant zircon ages (Ma)	498–2754 (98 analyses)	492–3564 (81 analyses)	496–2941 (86 analyses)	413–3088 (79 analyses)	414–3602 (93 analyses)	433–2797 (91 analyses)	363–3303 (97 analyses)
Peak clusters	535, 949 (21%)	524, 942 (25%)	532, 1169 (37%)	537, 1151 (29%)	534, 1175 (17%)	552, 1161 (13%)	541, 1171 (24%)

Analytical techniques

LA–ICPMS zircon U-Pb dating

Zircons were separated from ~3 kg samples by heavy-liquid and magnetic methods in the Laboratory of the Geological Team of Hebei Province, China. Cathodoluminescence (CL) images were taken at the Institute of Geology and Geophysics, Chinese Academy of Sciences (Beijing) for inspecting internal structures of individual zircons and for selecting positions for U-Pb and Lu-Hf isotope analyses. It has been shown that analysis of 60 grains provides a 95% probability of finding a population comprising 5% of the total (Dodson et al., 1988; Veevers et al., 2005). In this study, we aimed to analyse at least 100 grains of zircon from each sample (Table DR1) to include all recognizable minor populations. Detrital zircons of varying size and shape were selected randomly, leaving out grains with obvious cracks or inclusions. Thus the number of zircons in each population is statistically representative.

Zircon U-Pb dating were conducted by LA-ICP-MS at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan. Detailed operating conditions for the laser ablation system and the ICP-MS instrument and data reduction are the same as description by Liu et al. (2008, 2010). Laser sampling was performed using a GeoLas 2005. An Agilent 7500a ICP-MS instrument was used to acquire ion-signal intensities. Helium was applied as a carrier gas. Argon was used as the make-up gas and mixed with the carrier gas via a T-connector before entering the ICP. Nitrogen was added into the central gas flow (Ar+He) of the Ar plasma to decrease the detection limit and improve precision (Hu et al., 2008). Each analysis incorporated a background acquisition of approximately 20-30 s (gas blank) followed by 50 s data acquisition from the sample. The Agilent Chemstation was utilized for the acquisition of each individual analysis. Off-line selection and integration of background and analyse signals, and time-drift correction and U-Pb dating were performed by *ICPMSDataCal* (Liu et al., 2008, 2010).

Zircon 91500 was used as external standard for U-Pb dating, and was analyzed twice every 5 analyses. Time-dependent drifts of U-Th-Pb isotopic ratios were corrected using a linear interpolation (with time) for every five analyses according to the variations of 91500 (i.e., 2 zircon 91500 + 5 samples + 2 zircon 91500) (Liu et al., 2010). Preferred U-Th-Pb isotopic ratios used for 91500 are from Wiedenbeck et al. (1995). Uncertainty of preferred values for the external standard 91500 was propagated to the ultimate results of the samples. Common lead was corrected for using the correction

function (Anderson, 2002). ISOPLOT (version 3.0) (Ludwig, 2003) was used for plotting concordia diagrams and age spectra, and for age calculations. Uncertainties on individual analyses are reported as 1-sigma; mean ages for pooled $^{206}Pb/^{238}U$ results are reported as 2σ. The zircon U-Pb isotopic data are given in Table DR2.

Zircon Hf isotopic analytical method

In situ Hf isotope measurements were subsequently done on the same spots or the same age domains for age determinations of the concordant grains, as guided by CL images. Zircons from sample GB-12, NX1-5, and SL5-1 were done using LA-ICPMS with a beam size of 60 μm and laser pulse frequency of 8 Hz at the Institute of Geology and Geophysics in the Chinese Academy of Sciences (Beijing) (IGGCAS). Zircons from sample 08YR10, XM01, MB07-2, and GBJD were done using a Nu Plasma HR MC-ICP-MS (Nu Instruments Ltd., UK), coupled to a GeoLas 2005 excimer ArF laser-ablation system with a beam size of 44 μm and the laser pulse frequency of 8 Hz at the State Key Laboratory of Continental Dynamics, Northwest University (Xi'an). Details of instrumental conditions and data acquisition were given in Wu et al. (2006) and Yuan et al. (2008). During the analysis at the IGGCAS, $^{176}Hf/^{177}Hf$ ratios of the zircon standard (91500) were 0.282286 ± 12 ($2\sigma_n$, n = 21). During the analysis in Xi'an, the measured values of well-characterized zircon standards (91500, GJ-1, and Monastery) agree with the recommended values (cf. Yuan et al., 2008) to within 2σ. During the analysis at the IGGCAS, $^{176}Hf/^{177}Hf$ ratios of the zircon standard (91500) were 0.282286 ± 12 ($2\sigma_n$, n = 21). During the analysis in Xi'an, the obtained Hf isotopic compositions are 0.282016 ± 20 ($2\sigma_n$, n = 84) for GJ-1 standard and 0.282735 ± 24 ($2\sigma_n$, n = 84) for Monastery standard, respectively, agreeing with the recommended values (cf. Yuan et al., 2008) to within 2σ.

Initial $^{176}Hf/^{177}Hf$ ratios and $\varepsilon_{Hf}(t)$ values were calculated with the reference to the chondritic reservoir (CHUR) at the time of zircon growth from magmas. The decay constant for ^{176}Lu of 1.867×10^{-11} $year^{-1}$ (Soderlund et al., 2004), the chondritic $^{176}Hf/^{177}Hf$ ratio of 0.282772 and $^{176}Lu/^{177}Hf$ ratio of 0.0332 (Blichert-Toft and Albarède, 1997) were adopted. Depleted mantle model ages (T_{DM}) used for basic to intermediate rocks were calculated with reference to the depleted mantle at a present-day $^{176}Hf/^{177}Hf$ ratio of 0.28325, similar to that of the average MORB (Nowell et al., 1998) and $^{176}Lu/^{177}Hf$ = 0.0384 (Griffin et al., 2000). For each zircon, we also calculated the Hf isotope crustal model age (T_{DM}^{C}), by assuming its parental magma to have been derived from an average continental crust, with

$^{176}Lu/^{177}Hf$ = 0.015, that originated from the depleted mantle source (Griffin et al., 2002). Our conclusions would not be affected if other decay constants were used. The zircon Lu-Hf isotopic data are given in Table DR3.

References

Blichert-Toft, J., and Albarède, F., 1997, The Lu-Hf geochemistry of chondrites and the evolution of the mantle-crust system: Earth and Planetary Science Letters, v. 148, p. 243–258.

Dodson, M.H., Compston, W., Williams, I.S., and Wilson, J.F., 1988, A search for ancient detrital zircons in Zimbabwean sediments: Journal of the Geological Society of London, v.145, p.977–983, doi:10.1144/gsjgs.145.6.0977.

Griffin, W.L., Pearson, N.J., Belousova, E., Jackson, S.E., van Achterbergh, E., O'Reilly, S.Y., and Shee, S.R., 2000, The Hf isotope composition of cratonic mantle: LAM-MC-ICPMS analysis of zircon megacrysts in kimberlites: Geochimica et Cosmochimica Acta, v. 64, p. 133–147.

Griffin, W.L., Wang, X., Jackson, S.E., Pearson, N.J., O'Reilly, S.Y., Xu, X., and Zhou, X., 2002, Zircon chemistry and magma mixing, SE China: In-situ analysis of Hf isotopes, Tonglu and Pingtan igneous complexes: Lithos, v. 61, p. 237–269.

Hu, Z.C., Gao, S., Liu, Y.S., Hu, S.H., Chen, H.H., and Yuan, H.L., 2008, Signal enhancement in laser ablation ICP-MS by addition of nitrogen in the central channel gas: Journal of Analytical Atomic Spectrometry, v. 23, p. 1093–1101.

Liu, Y.S., Hu, Z.C., Gao, S., Günther, D., Xu, J., Gao, C.G., and Chen, H.H., 2008, In situ analysis of major and trace elements of anhydrous minerals by LA-ICP-MS without applying an internal standard: Chemical Geology, v. 257, p. 34–43.

Liu, Y., Gao, S., Hu, Z., Gao, C., Zong, K., and Wang, D., 2010, Continental and oceanic crust recycling-induced melt-peridotite interactions in the Trans-North China Orogen: U-Pb dating, Hf isotopes and trace elements in zircons of mantle xenoliths: Journal of Petrology, v. 51, p. 537–571.

Ludwig, K.R., 2003, ISOPLOT 3.00: A Geochronological Toolkit for Microsoft Excel. Berkeley: Berkeley Geochronology Center, California.

Nowell, G.M., Kempton, P.D., Noble, S.R., Fitton, J.G., Saunders, A.D., Mahoney, J.J., and Taylor,

R.N., 1998, High precision Hf isotope measurements of MORB and OIB by thermal ionization mass spectrometry: insights into the depleted mantle: Chemical Geology, v. 149, p. 211–233.

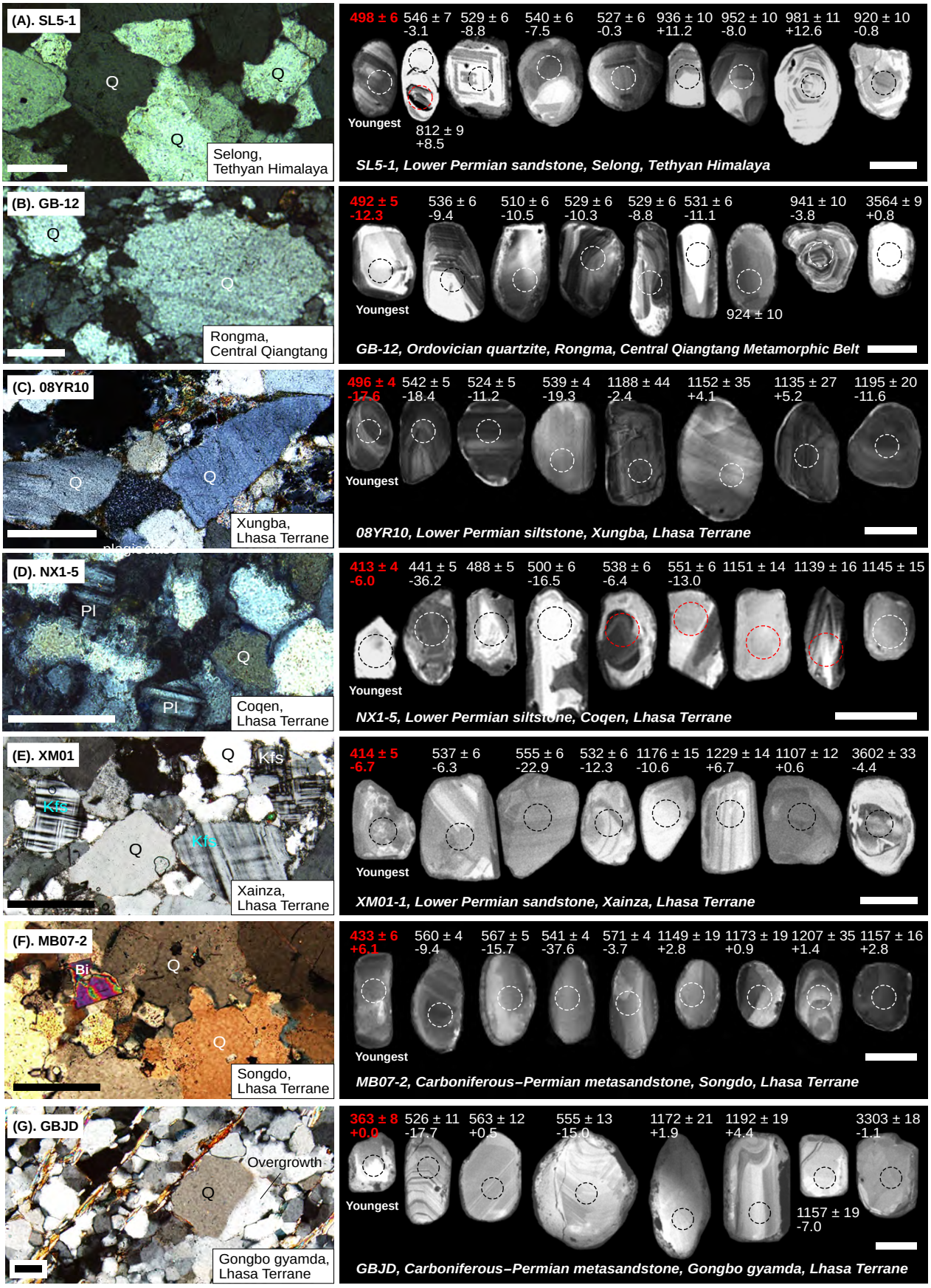
Soderlund, U., Patchett, P.J., Vervoort, J.D., and Isachsen, C.E., 2004, The ^{176}Lu decay constant determined by Lu-Hf and U-Pb isotope systematics of Precambrian mafic intrusions: Earth and Planetary Science Letters, v. 219, p. 311–324.

Veevers, J.J., Saeed, A., Belousova, E.A., and Griffin, W.L., 2005, U-Pb ages and source composition by Hf-isotope and trace-element analysis of detrital zircons in Permian sandstone and modern sand from southwestern Australia and a review of the paleogeographical and denudational history of the Yilgarn Craton: Earth-Science Reviews, v.68, p.245–279, doi:10.1016/j.earscirev.2004.05.005.

Wiedenbeck, M., Alle, P., Corfu, F., Griffin, W.L., Meier, M., Oberli, F., Quadt, A.V., Roddick, J.C., and Spiegel, W. 1995, Three natural zircon standards for U-Th-Pb, Lu-Hf, trace element and REE analyses: Geostandards and Geoanalytical Research, v. 19, p. 1–23.

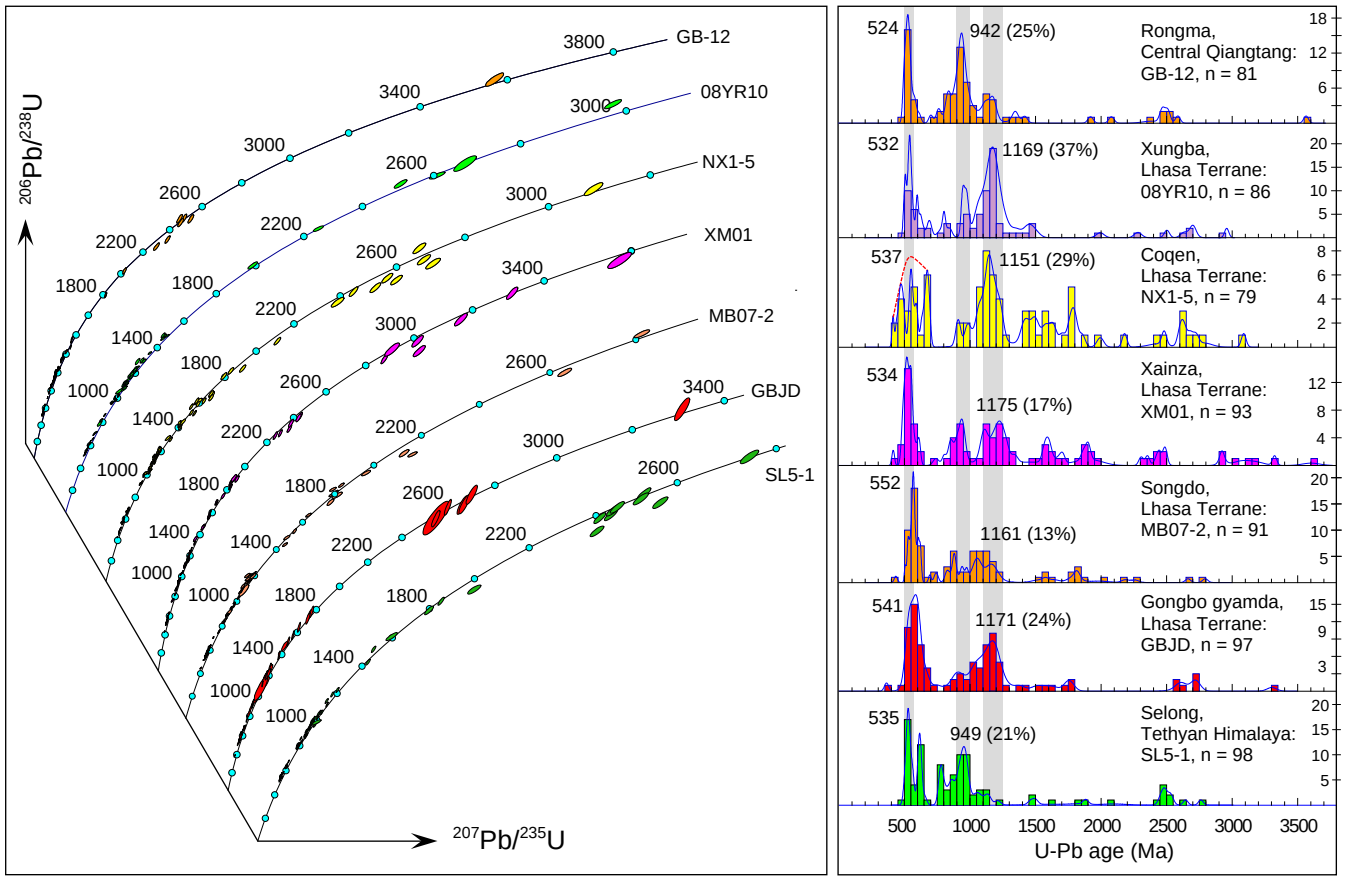
Wu, F.Y., Yang, Y.H., Xie, L.W., Yang, J.H., Xu, P., 2006, Hf isotopic compositions of the standard zircons and baddeleyites used in U-Pb geochronology: Chemical Geology, v. 234, p. 105–126.

Yuan, H.L., Gao, S., Dai, M.N., Zong, C.L., Günther, D., Fontaine, G.H., Liu, X.M., and Diwu, C.R., 2008, Simultaneous determinations of U-Pb age, Hf isotopes and trace element compositions of zircon by excimer laser ablation quadrupole and multiple collector ICP-MS: Chemical Geology, v. 247, p. 100–118.



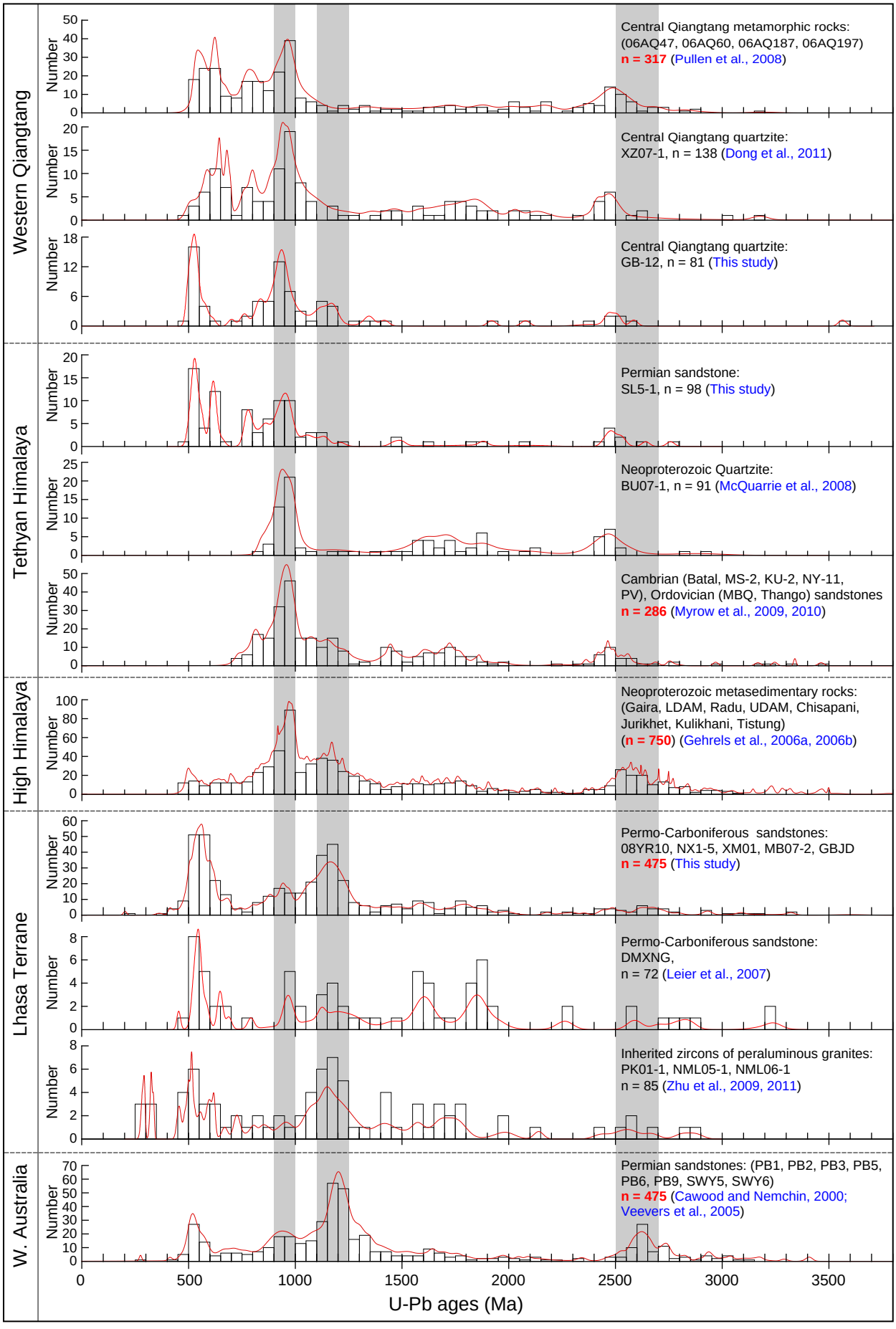
Zhu et al.'s Fig. DR1

Photos of thin section and cathodoluminescence (CL) images of representative detrital zircons of Paleozoic metasandstone samples, southern Tibet. Solid circles indicate the locations of LA-ICPMS U-Pb-Hf analyses. The U-Pb ages and $\varepsilon_{Hf}(t)$ values are given for each spot. The scale bar length in photos and CL image is 100 μm. Q = quartz, Pl = plagioclase, Kfs = K-feldspar.



Zhu et al.'s Fig. DR2

Concordia plot of detrital zircons recovered from the Ordovician to Permo-Carboniferous metasedimentary rocks in southern Tibet



Zhu et al. Fig.DR3.

Detrital zircon age distributions of metasedimentary rocks of this study and previous work. Important age peaks are shown in grey bands. The $^{207}Pb/^{206}Pb$ ages were used for >1000 Ma, and the $^{206}Pb/^{238}U$ ages for younger zircons. Results described in this study exclude analyses with >10% discordance. Data details are given in Table DR2.