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Zircon U-Pb Ages and Lu-Hf Isotopes for Negative to Low $\delta^{18}O$ Magmatic Rocks of Neoproterozoic Age in South China

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A characteristic feature of South China is widespread occurrence of Neoproterozoic magmatic rocks, particularly in the period of 830-740 Ma (Zhang and Zheng, 2013). These rocks occur mainly along the margins and minorly in the interior of the Yangtze Block. The finding of extremely low $\delta^{18}O$ zircons (as low as -9‰ for bulk zircons, Zheng et al., 2004) and low $\delta^{18}O$ magmatism in the northern margin of the Yangtze Block gained more concerns due to their possible link to Neoproterozoic glaciation events. In view of available data for zircon U-Pb ages and O-Hf isotopes in the middle Neoproterozoic magmatic rocks of South China with respect to their spatial distributions, we have placed further constraints on the time of water-rock interactions and the origin of these Neoproterozoic rocks.

A series of studies has been made on the protolith of UHP eclogites and gneisses in the Dabie-Sulu orogenic belt (Rumble et al., 2002; Zheng et al., 2003a,b, 2004, 2006, 2007a, 2008a, 2009; Wu et al., 2007; Tang et al., 2008a, b; Chen et al., 2011; Fu et al., 2013). The results show that mafic and felsic protoliths of theses metamorphic rocks mostly have zircon U-Pb ages of 740-780 Ma and are variably depleted in ^{18}O. Negative $\delta^{18}O$ zircon of magmatic origin only locally occurs in an UHP metagranite in the northeastern edge (Tang et al., 2008b). All zircon $\varepsilon_{Hf}(t)$ values fall into two groups, one from 1.1±0.6 to 10.1±0.6 and the other from −9.1±1.1 to −2.7±0.6. They correspond to two periods of juvenile crustal growth at 1.13±0.14 Ga and 1.98±0.22 Ga, respectively.

Because zircons extracted from the Dabie-Sulu UHP rocks experienced metamorphic recrystallization or contain new overgrowth, their isotope systems are readily reset during the continental subduction-zone metamorphism. This yields mixtures of old residual and newly grown zircon domains in samples. The utilization of microbeam in-situ microanalysis enables discrimination of metamorphic domains from relict domains. The Qinglongshan eclogite and gneiss in the Sulu orogen exhibit the lowest $\delta^{18}O$ values as negative as -10‰ (Chen et al., 2011). Their magmatic cores with U-Pb ages of 769±9 Ma generally have positive $\delta^{18}O$ values of 0.1 to 10.1‰, and high Th/U and $^{176}Lu/^{177}Hf$ ratios. In contrast, newly grown domains with Triassic U-Pb ages have negative $\delta^{18}O$ values of -10.0 to -2.2‰, and low Th/U and $^{176}Lu/^{177}Hf$ ratios. Therefore, the negative $\delta^{18}O$ zircon domains were grown from negative $\delta^{18}O$ metamorphic fluids that were generated by metamorphic dehydration of negative $\delta^{18}O$ hydrothermally altered rocks. More new data for UHP rocks from different localities in the Qinling-Dabie-Sulu orogenic belt show similar results to previous ones (Fu et al., 2013). The average $\delta^{18}O$ values for the Neoproterozoic ‘‘igneous’’ zircon cores vary from -0.9 to 6.9 ‰, significantly higher than that of -9.9 to 6.8 ‰ for the Triassic metamorphic rims. These results indicate that although the igneous cores have higher $\delta^{18}O$ values than the metamorphic rims, the widely existence of low $\delta^{18}O$ magmatism and negative $\delta^{18}O$ magmatism in the northern margin of South China is still evident.

Another way to eliminate the influence of metamorphism is to choose the unmetamorphosed or weakly metamorphosed rocks as the studying objects. Metagranite in the Beihuaiyang low-grade zone is such a candidate because it only suffered metamorphism of greenschist facies. Studies of granites from the Beihuaiyang zone were made by Wu et al. (2007) and Zheng et al. (2007a). The results show that these granites record two groups of U-Pb ages at 780 Ma and 750 Ma, respectively; $\delta^{18}O$ values for bulk zircons are mostly lower than 4‰ and minorly comparable with normal mantle values; most zircon grains kept oscillatory zoning and a few grains show hydrothermal alteration structures; zircon and coexisting minerals show significant O isotope disequilibrium. In particular, garnet from the Wozicun

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granite has very negative $\delta^{18}O$ values of −14.4 to −10.0‰ whereas zircon $\delta^{18}O$ values are 0.5 to 2.7‰. These results suggest multiple (at least two) episodes of high temperature water-rock interactions in the Beihaiyang granites. The first episode led to the formation of low $\delta^{18}O$ magma and thus low $\delta^{18}O$ zircons. The second episode decreases the $\delta^{18}O$ values of rock-forming minerals and perhaps a few zircon grains. In this regard, the time of water-rock interaction should be at 780 Ma and 750 Ma, respectively.

Further CAMECA zircon U-Pb dating and O isotope analysis was made on the Yaolinghe Group in South Qinling (Liu et al., 2013), providing new constraints on the time of low $\delta^{18}O$ magmatism in South China. The analyzed zircon grains were derived from metarhyolite in different units of the Yaolinghe Group. Zircon $\delta^{18}O$ values for the meta-rhyolite of lower unit range from -4.1 to 10‰ whereas low $\delta^{18}O$ zircons are scarce in the uppr unit. Only two negative $\delta^{18}O$ values of -4.1‰ and -0.9‰ were obtained in these samples, with concordant U-Pb ages of 758±11 and 746±11 Ma, respectively. The U-Pb ages of zircons with $\delta^{18}O$ values lower than 4‰ fall in the range of 780-690 Ma. The high $\delta^{18}O$ values are generally associated with Paleoproterozoic U-Pb ages and are interpreted as detrital zircon. Thus, the U-Pb ages of 719-790 Ma for the lower unit are used to represent the time of low $\delta^{18}O$ magmatism, looking as if they are somewhat outside the previous range of 740-780 Ma.

Studies on the Neoproterozoic rocks from the other areas of South China provide more constraints on the temporal and spatial distribution of low $\delta^{18}O$ magmatism. The ~825 Ma granitoids in the western Jiangnan orogen have high zircon $\delta^{18}O$ values of 8.7-10.4‰ and negative $\varepsilon_{Hf}(t)$ values, whereas the 760-750 Ma bimodal rocks in the western Sichuan have zircon $\delta^{18}O$ values of 4.2-6.2‰ and positive $\varepsilon_{Hf}(t)$ values (Zheng et al., 2007b). Similarly, zircon $\delta^{18}O$ values of 3.9±0.9‰ and 4.0±0.9‰ for ~800 Ma rocks and 4.6±0.4‰ to 6.7±5.7‰ for 810-820 Ma granites were reported for the Baoxing complex in the western Sichuan (Fu et al., 2013). These results imply that low $\delta^{18}O$ magmatism did not develop at about 825 Ma. No negative $\delta^{18}O$ values occurs in magmatic zircon of >800 Ma. CAMECA O isotope and U-Pb ages were analyzed by Wang et al. (2011) for detrital zircons from the Cryogenian sedimentary sequences in the western Jiangnan Orogen. Although zircon $\delta^{18}O$ values lower than 4‰ began to occur scarcely at about 850 Ma, their abundant occurrence are limited to the age range of 790-750 Ma. This implies that high-temperature water-rock interaction did not occur intensively until 790 Ma. Because of the poorly constrained source for these detrital zircons and the absence of negative $\delta^{18}O$ zircon, these low $\delta^{18}O$ zircons in the western Jiangnan orogen might be either the remelting product of either low $\delta^{18}O$ caldera collapse in rifting zones such as Yellowstone (e.g., Bindeman and Valley, 2001) or seawater-hydrothermally altered gabbro in oceanic subduction zone (e.g., Wei et al., 2002).

Abundant zircon Hf-O data were further acquired from Neoproterozoic granitoids in the western and eastern Jiangnan orogens (Wang et al., 2013). All the zircon $\delta^{18}O$ values range from 6 to 12‰ and many grains show $\delta^{18}O$ variations of 3–6‰ from core to rim. Zircon $\varepsilon_{Hf}(t)$ values are negative for the western Jiangnan orogen and positive for the eastern Jiangnan orogen, consistent with previously published results (e.g., Wu et al., 2006, Wang et al., 2006, 2008, 2012d; Zheng et al., 2007b, 2008; Zhou et al., 2009; Zhang et al., 2012). Thus, low $\delta^{18}O$ magmatism did not occurr in the middle Neoproterozoic magmatism of the Jiangnan orogen. However, low $\delta^{18}O$ values of 1.8-9.3‰ for quartz were reported for the ~780 Ma Shi'ershan granite in the eastern Jiangnan orogen (Zheng et al., 2008), suggesting that high-temperature water-rock interaction would still take place at restricted localities in South China.

In summary, the low $\delta^{18}O$ magmatism and negative $\delta^{18}O$ hydrothermal alteration are prominent in the northern margin of South China, but only low $\delta^{18}O$ hydrothermal alteration sporadically occurred elsewhere in South. In either case, the time of high-temperature water-rock interaction are constrained in the period of 780-740 Ma. The most plausible tectonic setting for the mid-Neoproterozoic low $\delta^{18}O$ magmatism is continental rifting.

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Key words: oxygen isotope anomaly, magmatic rocks, middle Neoproterozoic, water-rock interaction, continental rifting

References

Bindeman, I.N. and Valley, J.W., 2000. Formation of low-^{18}O rhyolites after caldera collapse at Yellowstone, Wyoming, USA. *Geology*, 28(8): 719-722.

Chen, Y.-X., Zheng, Y.-F., Chen, R.-X., Zhang, S.-B., Li, Q., Dai, M., Chen, L., 2011. Metamorphic growth and recrystallization of zircons in extremely 18O-depleted rocks during eclogite-facies metamorphism: Evidence from U–Pb ages, trace elements, and O–Hf isotopes. *Geochimica et Cosmochimica Acta*, 75: 4877-4898.

Fu, B., Kita, N., Wilde, S., Liu, X., Cliff, J., Greig, A., 2013. Origin of the Tongbai-Dabie-Sulu Neoproterozoic low-δ 18O igneous province, east-central China. *Contributions to*

Mineralogy and Petrology, 165: 641-662.

Liu, J.B., Zhang, L., 2013. Neoproterozoic low to negative $\delta^{18}O$ volcanic and intrusive rocks in the Qinling Mountains and their geological significance. *Precambrian Research*, 230: 138-167.

Rumble, D., Giorgis, D., Ireland, T., Zhang, Z., Xu, H., Yui, T. F., Yang, J., Xu, Z. and Liou, J.G., 2002. Low $\delta^{18}O$ zircons, U-Pb dating, and the age of the Qinglongshan oxygen and hydrogen isotope anomaly near Donghai in Jiangsu Province, China. *Geochimica et Cosmochimica Acta*, 66: 2299-2306.

Tang, J., Zheng, Y.-F., Wu, Y.-B., Gong, B., Zha, X., Liu, X., 2008a. Zircon U-Pb age and geochemical constraints on the tectonic affinity of the Jiaodong terrane in the Sulu orogen, China. *Precambrian Research*, 161: 389-418.

Tang, J., Zheng, Y.-F., Gong, B., Wu, Y.-B., Gao, T.-S., Yuan, H. and Wu, F.-Y., 2008b. Extreme oxygen isotope signature of meteoric water in magmatic zircon from metagranite in the Sulu orogen, China: Implications for Neoproterozoic rift magmatism. *Geochimica et Cosmochimica Acta*, 72: 3139-3169.

Wang, X.-C., Li, Z.-X., Li, X.-H., Li, Q.-L., Tang, G.-Q., Zhang, Q.-R., Liu, Y., 2011. Nonglacial origin for low-$\delta^{18}O$ Neoproterozoic magmas in the South China Block: Evidence from new in-situ oxygen isotope analyses using SIMS. *Geology*, 39: 735-738.

Wang, X.L., Zhou, J.C., Qiu, J.S., Zhang, W., Liu, X., Zhang, G., 2006a. Petrogenesis of the Neoproterozoic strongly peraluminons granitoids from Northern Guangxi: constraints from zircon geochronology and Hf isotopes. *Acta Petrologica Sinica* (in Chinese with English abstract), 22: 326-342.

Wang, X.-L., Zhou, J.-C., Qiu, J.-S., Jiang, S.-Y., Shi, Y.-R., 2008. Geochronology and geochemistry of Neoproterozoic mafic rocks from western Hunan, South China: implications for petrogenesis and post-orogenic extension. *Geological Magazine*, 145: 215–233.

Wang, X.-L., Shu, L.-S., Xing, G.-F., Zhou, J.-C., Tang, M., Shu, X.-J., Qi, L., Hu, Y.-H., 2012. Post-orogenic extension in the eastern part of the Jiangnan orogen: Evidence from ca 800–760 Ma volcanic rocks. *Precambrian Research*, 222–223: 404-423.

Wang, X.-L., Zhou J.-C., Wan, Y.-S., Kitajima, K., Wang, D., Bonamici, C., Qiu, J.-S., Sun, T., 2013. Magmatic evolution and crustal recycling for Neoproterozoic strongly peraluminous granitoids from southern China: Hf and O isotopes in zircon. *Earth and Planetary Science Letters*, 366: 71-82.

Wei, C.S., Zheng, Y.F., Zhao, Z.F. and Valley, J.W., 2002. Oxygen and neodymium isotope evidence for recycling of juvenile crust in northeast China. *Geology*, 30: 375-378.

Wu, R.-X., Zheng, Y.-F., Wu, Y.-B., Zhao, Z.-F., Zhang, S.-B., Liu, X. and Wu, F.-Y., 2006. Reworking of juvenile crust: Element and isotope evidence from Neoproterozoic granodiorite in South China. *Precambrian Research*, 146: 179-212.

Wu, Y.-B., Zheng, Y.-F., Tang, J., Gong, B., Zhao, Z.-F. and Liu, X., 2007. Zircon U-Pb dating of water-rock interaction during Neoproterozoic rift magmatism in South China. Chemical *Geology*, 246: 65-86.

Zhang, S.-B., Wu, R.-X., Zheng, Y.-F., 2012. Neoproterozoic continental accretion in South China: Geochemical evidence from the Fuchuan ophiolite in the Jiangnan orogen. *Precambrian Research*, 220–221: 45-64.

Zhang, S.-B., Zheng, Y.-F., 2013. Formation and evolution of Precambrian continental lithosphere in South China. *Gondwana Research*, 23: 1241-1260.

Zheng, Y.F., Fu, B., Gong, B., Li, L., 2003a. Stable isotope geochemistry of ultrahigh pressure metamorphic rocks from the Dabie-Sulu orogen in China: implications for geodynamics and fluid regime. *Earth-Sci. Rev.*, 62: 105-161.

Zheng, Y.F., Gong, B., Zhao, Z.F., Fu, B., Li, Y.L., 2003b. Two types of gneisses associated with eclogite at Shuanghe in the Dabie terrane: carbon isotope, zircon U-Pb dating and oxygen isotope. *Lithos*, 70: 321-343.

Zheng, Y.F., Wu, Y.B., Chen, F.K., Gong, B., Li, L., Zhao, Z.F., 2004. Zircon U-Pb and oxygen isotope evidence for a large-scale ^{18}O depletion event in igneous rocks during the Neoproterozoic. *Geochim. Cosmochim. Acta*, 68: 4145-4165.

Zheng, Y.-F., Zhao, Z.-F., Wu, Y.-B., Zhang, S.-B., Liu, X., Wu, F.-Y., 2006. Zircon U-Pb age, Hf and O isotope constraints on protolith origin of ultrahigh-pressure eclogite and gneiss in the Dabie orogen. *Chem. Geol.*, 231: 135-158.

Zheng, Y.-F., Wu, Y.-B., Gong, B., Chen, R.-X., Tang, J., Zhao, Z.-F., 2007a. Tectonic driving of Neoproterozoic glaciations: Evidence from extreme oxygen isotope signature of meteoric water in granite. *Earth Planet. Sci. Lett.*, 256: 196-210.

Zheng, Y.-F., Zhang, S.-B., Zhao, Z.-F., Wu, Y.-B., Li, X., Li, Z., Wu, F.-Y., 2007b. Contrasting zircon Hf and O isotopes in the two episodes of Neoproterozoic granitoids in South China: Implications for growth and reworking of continental crust. *Lithos*, 96: 127-150.

Zheng, Y.-F., Wu, R.-X., Wu, Y.-B., Zhang, S.-B., Yuan, H., Wu, F.-Y., 2008b. Rift melting of juvenile arc-derived crust: Geochemical evidence from Neoproterozoic volcanic and granitic rocks in the Jiangnan Orogen, South China. *Precambrian Res.* , 163: 351-383.

Zheng, Y.F., Gong, B., Zhao, Z.F., Wu, Y.B., Chen, F.K., 2008a. Zircon U-Pb age and o isotope evidence for Neoproterozoic low-18O magmatism during supercontinental rifting in South China: Implications for the snowball earth event. *Am. J. Sci.*, 308: 484-516.

Zheng, Y.-F., Chen, R.-X., Zhao, Z.-F., 2009. Chemical geodynamics of continental subduction-zone metamorphism: Insights from studies of the Chinese Continental Scientific Drilling (CCSD) core samples. *Tectonophysics*, 475 : 327-358.