https://doi.org/10.3799/dqkx.2022.808

大地幔楔如何影响深部地幔过程和大陆岩石圈演化?

章军锋[1],许文良[2]

1. 中国地质大学地球科学学院,湖北武汉 430074
2. 吉林大学地球科学学院,吉林长春 130061

全球地震层析成像显示,俯冲板片进入地幔过渡带之后主要有两种形式:一种是直接穿越地幔过渡带进入下地幔,甚至可能到达核幔边界;另外一种是平躺滞留在地幔过渡带(Goes *et al.*, 2017).根据板片俯冲的深度及其在地幔中的形态,可以把板片与地幔相互作用的区域划分为由俯冲板片—上地幔—岩石圈地幔—岛弧构成的小地幔楔系统;以及从小地幔楔系统发展而来,由俯冲/滞留板片—地幔过渡带—软流圈地幔—岩石圈构成的大地幔楔系统.大地幔楔是地球内部的常见构造,全球有近一半的深俯冲板片在地幔过渡带附近出现了几百到上千千米的滞留(Goes *et al.*, 2017),其中以东亚地区最为显著(Huang and Zhao, 2006; Zhao, 2017).

1 核心思想

大地幔楔形成及其在东亚大陆边缘演化和成矿中的作用已引起学术界的高度重视,并取得了一系列突出成果,主要表现在:揭示了华北克拉通破坏与华南大陆再造的动因,即显著受到了(古)太平洋板块俯冲作用的制约(Li and Li, 2007; Zhu *et al.*, 2012; Zheng *et al.*, 2018; Wu *et al.*, 2019);阐明了东亚大陆边缘中—新生代岩浆作用与成矿成藏作用机制,与(古)太平洋板块俯冲及壳幔相互作用密切相关(Wu *et al.*, 2011; Xu *et al.*, 2013; Wang *et al.*, 2020, 2022);明确了东亚大地幔楔形成演化过程中地幔碳、水循环机制及其对新生代板内岩浆作用的制约(Kuritani *et al.*, 2011; Li *et al.*, 2017; Xu *et al.*, 2018, 2020; Xia *et al.*, 2019);地球物理研究工作刻画了大地幔楔内不同圈层的波速和电导结构,发现了起伏的复杂多重地震反射界面(LAB、410 km和660 km地震不连续面)、起源于地幔过渡带的上地幔低速体(高导体)(Huang and Zhao, 2006; Chen and Ai, 2009; Ye *et al.*, 2011; Li *et al.*, 2013, 2020; Guo *et al.*, 2014; Tian *et al.*, 2016)和地幔过渡带底部及下地幔顶部的横波低速体(e.g., Li *et al.*, 2013; Shen *et al.*, 2014; Liu *et al.*, 2016; Tauzin *et al.*, 2017).

这些地质学和地球物理学的研究成果,使东亚大地幔楔成为了解地球内部不同圈层物质属性和相互作用的良好天然实验室.虽然近年来大地幔楔形成与演化的研究已取得了许多重要成果,但仍有一系列核心科学问题没有得到很好的解决,主要包括:大地幔楔深部物质结构与属性如何?着重体现在各圈层(岩石圈、软流圈、地幔过渡带和下地幔)界面的物质属性、地球物理探测所发现的复杂多重地震反射界面和高导低速异常体的地质意义、以及俯冲板片在地幔过渡带大量滞留的机制和条件;大地幔楔深部物质循环过程与机理是什么?着重体现在再循环洋壳物质如何改造地幔、板块俯冲过程中的重要挥发分(H、C、S等)如何循环及其对深部物质循环有什么效应和启示、各圈层间相互作用的机

基金项目:国家自然科学基金项目(Nos. 41888101, 41730210).

作者简介:章军锋(1977—),男,教授,博士生导师,主要从事壳幔矿物和岩石的变形与实验岩石学研究.E-mail: jfzhang@cug.edu.cn

引用格式:章军锋,许文良,2022.大地幔楔如何影响深部地幔过程和大陆岩石圈演化?地球科学,47(10):3784—3786.

Citation: Zhang Junfeng, Xu Wenliang, 2022. How does Big Mantle Wedge Affect Deep Mantle Processes and Evolution of the Continental Lithosphere? *Earth Science*, 47(10): 3784—3786.

制是什么;大地幔楔深部地球动力学过程如何?着重体现在地球动力学的驱动机制是什么、再循环物质与成矿成藏作用、地震和火山活动之间有什么成因联系.

2　科学价值

国际上先后启动了"边缘带"(MARGINS)、"地质棱镜"(GeoPRISMS)、"聚焦板块边界"(Zooming in between Plates)等重大研究计划或项目来推动对地幔楔结构、物质属性、元素循环、变形、地震和演化过程的研究.但这些研究多偏重小地幔楔系统,缺乏从地质、地球物理、高温高压实验与计算和数值模拟角度综合阐明大地幔楔系统的板片－地幔相互作用过程及其效应的相关研究.相对小地幔楔,大地幔楔作用范围更广,是研究地球深部板片与地幔相互作用的重要突破口.

对东亚大地幔楔的物质属性和深部过程开展深入研究,不仅有助于揭示东亚洋－陆俯冲对大陆岩石圈演化和深部地幔过程的影响,同时从全球构造研究的角度,对提升大地幔楔认知水平和建立跨圈层地球系统科学理论框架具有重要意义.因此,大地幔楔物质属性与深部过程是固体地球科学研究的重大前沿科学问题.

3　发展前景

实施高温高压实验与计算模拟、地质学分析和地球物理大地电磁测量联合攻关,是解决东亚大地幔楔形成和演化机制及其效应的有效途径.有望在以下方面取得突破:通过高温高压实验、计算模拟与地质和地球物理综合研究揭示东亚大地幔楔的结构、物质组成和深部过程;揭示大地幔楔物质循环与能量传输过程及其成矿－成藏－致灾机制;构建大地幔楔地球动力学模型,促进地球系统科学的创新发展.

参考文献

Chen, L., Ai, Y.S., 2009. Discontinuity Structure of the Mantle Transition Zone beneath the North China Craton from Receiver Function Migration. *Journal of Geophysical Research*, 114(B6): B06307. https://doi. org/10.1029/2008jb006221

Goes, S., Agrusta, R., van Hunen, J., et al., 2017. Subduction-Transition Zone Interaction: A Review. *Geosphere*, 13(3): 644－664. https://doi.org/10.1130/ges01476.1

Guo, Z., Cao, Y.L., Wang, X.G., et al., 2014. Crust and Upper Mantle Structures beneath Northeast China from Receiver Function Studies. *Earthquake Science*, 27(3): 265－275. https://doi. org/10.1007/s11589-014-0076-x

Huang, J.L., Zhao, D.P., 2006. High-Resolution Mantle Tomography of China and Surrounding Regions. *Journal of Geophysical Research*, 111(B9): B09305. https://doi.org/10.1029/2005jb004066

Kuritani, T., Ohtani, E., Kimura, J.I., 2011. Intensive Hydration of the Mantle Transition Zone beneath China Caused by Ancient Slab Stagnation. *Nature Geoscience*, 4(10): 713－716. https://doi.org/10.1038/ngeo1250

Li, J., Wang, X., Wang, X.J., et al., 2013. P and SH Velocity Structure in the Upper Mantle beneath Northeast China: Evidence for a Stagnant Slab in Hydrous Mantle Transition Zone. *Earth and Planetary Science Letters*, 367: 71－81. https://doi.org/10.1016/j.epsl.2013.02.026

Li, S.G., Yang, W., Ke, S., et al., 2017. Deep Carbon Cycles Constrained by a Large-Scale Mantle Mg Isotope Anomaly in Eastern China. *National Science Review*, 4(1): 111－120. https://doi.org/10.1093/nsr/nww070

Li, S.W., Weng, A.H., Li, J.P., et al., 2020. Deep Origin of Cenozoic Volcanoes in Northeast China Revealed by 3-D Electrical Structure. *Science China Earth Sciences*, 63(4): 533－547. https://doi.org/10.1007/s11430-018-9537-2

Li, Z.X., Li, X.H., 2007. Formation of the 1 300-km-Wide Intracontinental Orogen and Postorogenic Magmatic Province in Mesozoic South China: a Flat-Slab Subduction Model. *Geology*, 35(2): 179－182. https://doi. org/10.1130/g23193a.1

Liu, Z., Park, J., Karato, S.I., 2016. Seismological Detection of Low-Velocity Anomalies Surrounding the Mantle Transition Zone in Japan Subduction Zone. *Geophysical Research Letters*, 43(6): 2480－2487. https://doi. org/10.1002/2015gl067097

Shen, X.Z., Yuan, X.H., Li, X.Q., 2014. A Ubiquitous Low-Velocity Layer at the Base of the Mantle Transition Zone. *Geophysical Research Letters*, 41(3): 836－842. https://doi.org/10.1002/2013gl058918

Tauzin, B., Kim, S., Kennett, B.L.N., 2017. Pervasive Seismic Low-Velocity Zones within Stagnant Plates in the Mantle Transition Zone: Thermal or Compositional Origin? *Earth and Planetary Science Letters*, 477: 1－13. https://doi.org/10.1016/j.epsl.2017.08.006

Tian, Y., Zhu, H.X., Zhao, D.P., et al., 2016. Mantle Transi-

tion Zone Structure beneath the Changbai Volcano: Insight into Deep Slab Dehydration and Hot Upwelling near the 410 km Discontinuity. *Journal of Geophysical Research*: *Solid Earth*, 121(8): 5794－5808. https://doi.org/10.1002/2016jb012959

Wang, X., Zhang, J., Wang, C., et al., 2022. Experimental Constraint on Ca-Rich Carbonatite Melt-Peridotite Interaction and Implications for Lithospheric Mantle Modification beneath the North China Craton. *Journal of Geophysical Research*: *Solid Earth*, 127(9): e2022JB024769. https://doi.org/10.1029/2022jb024769

Wang, Z.C., Cheng, H., Zong, K.Q., et al., 2020. Metasomatized Lithospheric Mantle for Mesozoic Giant Gold Deposits in the North China Craton. *Geology*, 48(2): 169－173. https://doi.org/10.1130/g46662.1

Wu, F.Y., Sun, D.Y., Ge, W.C., et al., 2011. Geochronology of the Phanerozoic Granitoids in Northeastern China. *Journal of Asian Earth Sciences*, 41(1): 1－30. https://doi.org/10.1016/j.jseaes.2010.11.014

Wu, F.Y., Yang, J.H., Xu, Y.G., et al., 2019. Destruction of the North China Craton in the Mesozoic. *Annual Review of Earth and Planetary Sciences*, 47: 173－195. https://doi.org/10.1146/annurev-earth-053018-060342

Xia, Q.K., Liu, J., Kovács, I., et al., 2019. Water in the Upper Mantle and Deep Crust of Eastern China: Concentration, Distribution and Implications. *National Science Review*, 6(1): 125－144. https://doi. org/10.1093/nsr/nwx016

Xu, W.L., Chen, J.H., Weng, A., et al., 2020. Stagnant Slab Front within the Mantle Transition Zone Controls the Formation of Cenozoic Intracontinental High-Mg Andesites in Northeast Asia. *Geology*, 49 : 19－24.

Xu, W.L., Pei, F.P., Wang, F., et al., 2013. Spatial-Temporal Relationships of Mesozoic Volcanic Rocks in NE China: Constraints on Tectonic Overprinting and Transformations between Multiple Tectonic Regimes. *Journal of Asian Earth Sciences*, 74: 167－193. https://doi. org/10.1016/j.jseaes.2013.04.003

Xu, Y.G., Li, H.Y., Hong, L.B., et al., 2018. Generation of Cenozoic Intraplate Basalts in the Big Mantle Wedge under Eastern Asia. *Science China Earth Sciences*, 61(7): 869－886. https://doi.org/10.1007/s11430-017-9192-y

Ye, L.L., Li, J., Tseng, T.L., et al., 2011. A Stagnant Slab in a Water-Bearing Mantle Transition Zone beneath Northeast China: Implications from Regional SH Waveform Modelling. *Geophysical Journal International*, 186(2): 706－710. https://doi.org/10.1111/j.1365-246X.2011.05063.x

Zhao, D.P., 2017. Big Mantle Wedge, Anisotropy, Slabs and Earthquakes beneath the Japan Sea. *Physics of the Earth and Planetary Interiors*, 270: 9－28. https://doi. org/10.1016/j.pepi.2017.06.009

Zheng, Y.F., Xu, Z., Zhao, Z.F., et al., 2018. Mesozoic Mafic Magmatism in North China: Implications for Thinning and Destruction of Cratonic Lithosphere. *Science China Earth Sciences*, 61(4): 353－385. https://doi. org/10.1007/s11430-017-9160-3

Zhu, R.X., Xu, Y.G., Zhu, G., et al., 2012. Destruction of the North China Craton. *Science China Earth Sciences*, 55(10): 1565－1587. https://doi. org/10.1007/s11430-012-4516-y