内蒙古索伦山蛇绿岩带早二叠世放射虫动物群的发现及其地质意义

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摘要 位于中蒙边境地区的索伦山蛇绿岩带, 是古生代存在于西伯利亚板块与华北板块之间的古亚洲洋闭合之后形成的索伦山缝合带的重要组成部分. 索伦山蛇绿岩的研究, 对认识古亚洲洋演化具有重要意义, 但其时代一直是学术界争论的焦点问题之一. 本次工作采集索伦山蛇绿岩带硅质岩样品, 对其进行了放射虫化石的分选与鉴定. 在内蒙古乌拉特中旗北部靠近中蒙边境线的索伦山蛇绿岩带硅质岩中发现早二叠世放射虫动物群, 包括5个属6个种, 其中有4个未定种和1个新种: *Pseudoalbaillella bulbosa*, *Ps. solonensis* Wang sp. nov., *Stigmatosphaerostylus* sp., *Ruzhencevispongus* sp., *Cenosphaera* sp., *Latentifistula* sp. 等. *Pseudoalbaillella bulbosa* 这个种在日本、泰国、智利、北美西海岸和中国华南等地发现在晚石炭世-早二叠世硅质岩相地层中, 在中国作为早二叠世早期的一个带种, 成为广海相硅质岩相区石炭系与二叠系分界的标志. 这套放射虫硅质岩属索伦山蛇绿岩的组成部分, 该动物群的发现为索伦山蛇绿岩形成时间持续到早二叠世提供了关键证据. 这些新证据证实了古亚洲洋在早二叠世时仍存在, 古亚洲洋通过俯冲消减最终闭合应是在早二叠世之后.

关键词 放射虫, 早二叠世, 蛇绿岩, 索伦山, 古亚洲洋

索伦山蛇绿岩作为消失在华北板块与西伯利亚板块之间的古亚洲洋存在的重要证据, 记录了古亚洲洋复杂的构造演化历史^[1~11], 受到了国内外学者的广泛关注. 索伦山蛇绿岩的研究, 对认识古亚洲洋演化、恢复洋陆格局、了解华北板块与西伯利亚板块拼合时间与过程等, 具有重要的科学意义.

目前科学界普遍认为索伦山缝合带是华北板块与西伯利亚板块最终对接的位置^[1,2,4,9~12]. 前人对保存在其中的大洋岩石圈残片——索伦山蛇绿岩做了较多研究, 但是多侧重于对蛇绿岩中镁铁质-超镁铁

质岩组成部分的同位素测年和岩石地球化学研究, 对其共生的深海远洋沉积盖层(放射虫硅质岩)中的放射虫动物群组成及其时代研究还很薄弱, 对索伦山蛇绿岩的形成时代还存在不同看法. 因而, 对上述两大板块之间古亚洲洋的闭合时间及构造演化的认识尚存在分歧.

对于索伦山蛇绿岩的形成时代主要有以下几种观点: (1) 形成于早石炭世^[13,14]; (2) 晚泥盆世-早石炭世或更早^[15]、早泥盆世或之前^[16,17]; (3) 张旗等人^[18]认为索伦山蛇绿岩时代是志留纪-泥盆纪; (4)

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陈志勇^[19]获得索伦山蛇绿岩东延部分巴彦敖包蛇绿岩中橄榄辉长岩TIMS锆石U-Pb年龄为 385.6 ± 1.7 Ma, 为早泥盆世; (5) 陶继雄等人^[20]根据索伦山蛇绿岩橄榄辉长岩的U-Pb年龄 433.6 ± 3.6 Ma, 认为该套蛇绿岩形成时代为早志留世晚期; (6) Miao等人^[6]获得索伦山地区堆晶辉长岩SHRIMP锆石U-Pb年龄为 279 ± 10 Ma, Jian等人^[21]获得索伦山蛇绿岩中辉长岩SHRIMP锆石U-Pb年龄为 $296.6 \pm 1.7 \sim 291.8 \pm 2.3$ Ma, 认为索伦山蛇绿岩形成于早二叠世。王惠等人^[22]根据索伦山蛇绿岩带东延部分巴彦敖包地区发现的早二叠世晚期-中二叠世早期的放射虫化石, 认为索伦山蛇绿混杂岩带混杂堆积的时间为中二叠世早期。

本文的研究是在武警黄金第二支队开展的内蒙古索伦山地区六幅1:50000区域地质矿产调查工作的基础上, 对索伦山蛇绿岩的物质组成、产出状态和相互接触关系等进行了系统调查研究, 采集了索伦山蛇绿岩带硅质岩样品, 对其进行放射虫化石的分选

与鉴定, 以确定蛇绿岩的形成时代, 进而探讨古亚洲洋形成和演化的时限。

1 地质概况

索伦山蛇绿岩带位于内蒙古乌拉特中旗北部中蒙边境线附近, 呈近东西向分布, 西起索伦敖包西哈布塔盖, 向东经索伦敖包、乌珠尔少布特, 到满都拉地区哈尔陶勒盖, 向北延入蒙古国, 境内出露宽1~6 km, 长约100 km, 为区域上中亚造山带中一条重要的蛇绿构造混杂岩带。索伦山蛇绿岩组成以超镁铁质岩为主, 辉长岩、辉绿岩、枕状玄武岩和放射虫硅质岩等均有出露, 岩块之间及与围岩均为构造接触。索伦山蛇绿岩的基质为一套强片理化砂泥质和硅泥质等细碎屑岩(图1)。

超镁铁质岩主要包括方辉橄榄岩、二辉橄榄岩和纯橄榄岩等, 均遭受强烈蛇纹石化; 辉长岩可能代表堆晶岩部分; 玄武岩见枕状构造, 应为蛇绿岩顶部部

图1 内蒙古乌拉特中旗索伦山地区蛇绿岩分布区地质简图与采样位置

Figure 1 Simplified geological map showing the distribution of ophiolite in the Solon Obo area of Urad Middle Banner, Inner Mongolia, with sample location

分;含放射虫硅质岩代表蛇绿岩深海沉积部分.

2 放射虫化石特征及时代

含放射虫硅质岩样品采自准索伦北东约25 km处苏布尔根呼都格地区,样品编号PM55b2,采样位置坐标为42.23°N, 109.23°E, 硅质岩颜色为深灰色,呈小岩块产出,与超镁铁质岩呈断层接触(图1(b), (c)和2).本次填图工作中在索伦山蛇绿岩带中发现的硅质岩有紫红色、灰绿色、青灰色、深灰色和灰黑色等5类,硅质岩岩石薄片多处见到放射虫化石,但大多保存不好,仅在上述采样点硅质岩中发现保存较完好的个体(图2(b)).经中国科学院南京地质古生物研究所王玉净研究员鉴定,这个放射虫动物群包括5个属6个种,其中有4个未定种和1个新种: *Pseudoalbaillella bulbosa*, *Ps. solonensis* Wang sp. nov., *Stigmosphaerostylus* sp., *Ruzhencevispongus* sp., *Cenosphaera* sp., *Latentifistula* sp. 等(图3).新种 *Pseudoalbaillella solonensis*(索伦假阿尔拜虫)与 *Ps. u-forma* 不同的主要特征是假腹节末端有孔. *Pseudoalbaillella bulbosa* 这个种在日本被Ishiga认为是晚石炭世-早二叠世的^[23,24],而在泰国、智利、北美西海岸和中国华南都发现在早二叠世硅质岩相地层中,因此,这个种已成为早二叠世早期的一个带种^[25~27],并成为广海相硅质岩相区石炭系和二叠系分界的标志.

该放射虫动物群以假阿尔拜虫类和内射虫类最为丰富,约各占动物群的45%.假阿尔拜虫类多由顶锥和假胸节组成,完整个体较少.内射虫类个体较多,刺细长,多数折断不完整.隐管虫类、空球虫类和鲁仁采夫海绵虫类数量较少.整个放射虫化石约占岩石的50%以上,属于真正的放射虫岩(radiolite),是蛇绿岩的组成部分,因此,放射虫化石所确定的时

代可以代表蛇绿岩形成的时代.这套放射虫硅质岩属索伦山蛇绿岩的组成部分,该动物群的发现为索伦山蛇绿岩形成时间持续到早二叠世提供了关键证据.

3 讨论

1977~1980年内蒙古第一区域地质调查队在索伦山地区开展“1:20万桑根达来等4幅区域地质调查”时,认为索伦山地区出露的超基性岩为侵入成因,根据灰岩透镜体中化石等证据将索伦山蛇绿混杂岩归为中石炭统本巴图组和侵入其中的超基性岩,并初步认为可能存在混杂堆积.朱绅玉等人^[28]提出索伦山超基性岩为蛇绿岩,之后许多研究者从板块构造角度对该蛇绿岩带做了大量工作,对该套蛇绿岩的岩石类型、分布、产出状态等作了报道^[9,15,17,20,29~31],但是对其详细的物质组成、构造特征等还缺少系统的调查研究,对其形成时代还存在较大争议.索伦山缝合带向东延伸位置,也存在与二连-贺根山缝合带相连^[1,15,16,32~35],与西拉木伦(林西)缝合带相连^[3,4,7,36~38]等不同认识.

本次1:50000地质填图从原1:20万区调划分的“本巴图组+超基性岩”中解体出方辉橄榄岩、二辉橄榄岩、纯橄榄岩、辉长岩、辉绿岩、玄武岩和放射虫硅质岩等蛇绿岩组合,和早-中二叠世砂泥质、硅泥质基质(图1(b)),本巴图组仅在区内南部出露,与蛇绿混杂岩呈断层接触.本次获得的早二叠世放射虫化石与区内测得的蛇绿岩中辉长岩 280.7 ± 5.3 Ma的锆石U-Pb年龄(另文发表)吻合较好,二者相互印证,表明索伦山蛇绿岩形成时代持续到早二叠世.

王惠等人^[22]在索伦山蛇绿岩东延部分满都拉地区巴彦敖包硅质岩中发现早二叠世晚期-中二叠世早

图2 索伦山蛇绿岩放射虫硅质岩野外地质特征(a)及显微照片(b)

Figure 2 Geological features (a) and photomicrograph (b) of the radiolarian cherts of Solon Obo ophiolite belt

图 3 内蒙古乌拉特中旗索伦山地区索伦山蛇绿岩硅质岩中放射虫化石。1, 2, *Ruzhencevisponus* sp. 鲁任采夫海绵虫(未定种); 3, 4, *Cenosphaera* sp. 空球虫(未定种); 5~9, *Pseudoalbaillella bulbosa*球茎形假阿尔拜虫; 10~13, *Pseudoalbaillella solonensis* Wang sp. nov. 索伦假阿尔拜虫(新种); 14~20, *Stigmospaerostylus* sp. 斑点球桩虫(未定种)

Figure 3 The radiolarian fossils in the cherts of Solon Obo ophiolite belt of Urad Middle Banner, Inner Mongolia. 1, 2, *Ruzhencevisponus* sp.; 3, 4, *Cenosphaera* sp.; 5~9, *Pseudoalbaillella bulbosa*; 10~13, *Pseudoalbaillella solonensis* Wang sp. nov.; 14~20, *Stigmospaerostylus* sp.

期的放射虫化石, 尚庆华^[39]在满都拉地区混杂岩带沉积岩块中发现中二叠世放射虫化石, Miao等人^[6]报道了索伦山地区堆晶辉长岩的SHRIMP锆石U-Pb年龄为 279 ± 10 Ma, Jian等人^[21]获得索伦山蛇绿岩中辉长岩SHRIMP锆石U-Pb年龄为 $296.6 \pm 1.7 \sim 291.8 \pm 2.3$ Ma, 反映了索伦山-满都拉一带在早-中二叠世时仍处于洋盆形成与发展阶段。

王玉净等人^[36]在内蒙古西拉木伦河北部杏树洼蛇绿岩带硅质岩中发现了*Ormistonella robusta* De

Wever et Caridroit, *Pseudotormetus kamigoriensis* De Wever et Caridroit, *Ishigaum trifistis* De Wever et Caridroit等中二叠世中晚期的放射虫化石, 王荃等人^[13]在贺根山蛇绿岩基性熔岩所夹的硅质岩中发现放射虫*Entactinia* sp., *Tetrentactinia* sp., *Cenellipsis* sp.等, 时代为晚泥盆世。之前一些学者^[32~35]认为古亚洲洋最终闭合位置在索伦山-贺根山一带, 但随着研究的不断深入, 特别是近几年大量同位素年龄等证据的获得, 目前地学界多数学者认为古亚洲洋最终闭合位

置应在索伦山-林西^[6,11]或索伦山-西拉木伦一带^[5,36,40], 闭合时间在晚二叠世-早三叠世^[4,5,40,41]或晚二叠世-中三叠世^[11]. 很显然, 本次新获得的放射虫化石证据支持古亚洲洋在晚二叠世-早中三叠世闭合的观点.

总之, 本次工作在索伦山蛇绿岩带硅质岩中新发现早二叠世放射虫化石, 证实了在内蒙古索伦山地区, 古亚洲洋在早二叠世时仍存在, 其最终闭合的时间应是在早二叠世之后.

4 结论

综上所述, 可得出以下几点认识:

(1) 索伦山蛇绿岩带硅质岩中新发现放射虫动物群, 包括5个属6个种: *Pseudoalbaillella bulbosa*, *Ps. solonensis* Wang sp. nov., *Stigmatosphaerostylus* sp., *Ruzhencevispongia* sp., *Cenosphaera* sp., *Latentifistula* sp.等, 其时代为早二叠世. 这套放射虫硅质岩属索伦山蛇绿岩的组成部分, 该动物群的发现为索伦山蛇绿岩形成时间持续到早二叠世提供了关键证据.

(2) 索伦山蛇绿岩带硅质岩中早二叠世放射虫化石的发现, 证实索伦山地区古亚洲洋在早二叠世时仍存在, 古亚洲洋通过俯冲消减最终闭合的时间应是在早二叠世之后.

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参考文献

- 1 Sengor A M C, Natal'in B A, Burtman V S. Evolution of the Altaid tectonic collage and Paleozoic crustal growth in Eurasia. *Nature*, 1993, 364: 299–307
- 2 Sengor A M C, Natal'in B A. Paleotectonics of Asia: Fragments of a synthesis. In: Yin A, Harrison M, eds. *The Tectonic Evolution of Asia*. Cambridge: Cambridge University Press, 1996. 486–640
- 3 Dobretsov N L, Berzin N A, Buslov M M. Opening and tectonic evolution of the Paleo-Asian Ocean. *Int Geol Rev*, 1995, 37: 335–360
- 4 Li J Y. Permian geodynamic setting of Northeast China and adjacent regions: Closure of the Paleo-Asian Ocean and subduction of the Paleo-Pacific Plate. *J Asian Earth Sci*, 2006, 26: 207–224
- 5 Li J Y, Zhang J, Yang T N, et al. Crustal tectonic division and evolution of the southern part of the North Asian orogenic region and its adjacent areas (in Chinese). *J Jilin Univ*, 2009, 39: 584–605 [李锦轶, 张进, 杨天南, 等. 北亚造山区南部及其毗邻地区地壳构造分区与构造演化. 吉林大学学报, 2009, 39: 584–605]
- 6 Miao L, Zhang F, Fan W, et al. Phanerozoic evolution of the Inner Mongolia-Daxinganling orogenic belt in North China: Constraints from geochronology of ophiolites and associated formations. *Geol Soc Lond Spec Publ*, 2007, 280: 223–237
- 7 Jian P, Liu D Y, Kroner A, et al. Time scale of an early to middle-Paleozoic orogenic cycle of the long-lived Central Asian Orogenic Belt, Inner Mongolia of China: Implications for continental growth. *Lithos*, 2008, 101: 233–259
- 8 Zhang S H, Gao R, Li H Y, et al. Crustal structures revealed from a deep seismic reflection profile across the Solonker suture zone of the Central Asian Orogenic Belt, northern China: An integrated interpretation. *Tectonophysics*, 2014, 612–613: 26–39
- 9 Xiao W J, Windley B F, Hao J, et al. Accretion leading to collision and the Permian Solonker suture, Inner Mongolia, China: Termination of the Central Asian orogenic belt. *Tectonics*, 2003, 22: 1–18
- 10 Xiao W J, Windley B F, Huang B C, et al. End-Permian to mid-Triassic termination of the accretionary processes of the southern Altaids: Implications for the geodynamic evolution, Phanerozoic continental growth, and metallogeny of Central Asia. *Int J Earth Sci*, 2009, 98: 1189–1217
- 11 Xiao W J, Windley B F, Sun S, et al. A tale of amalgamation of three Permo-Triassic collage systems in Central Asia: Oroclines, sutures, and terminal accretion. *Annu Rev Earth Planet Sci*, 2015, 43: 477–507
- 12 Windley B F, Alexiev D, Xiao W J, et al. Tectonic models for accretion of the Central Asian Orogenic belt. *J Geol Soc Lond*, 2007, 164: 31–47
- 13 Wang Q, Liu X Y, Li J Y. Plate Tectonic Between Cathaysia and Angara (in Chinese). Beijing: Peking University Press, 1991. 1–151 [王荃, 刘雪亚, 李锦轶. 中国华夏与安加拉古陆间的板块构造. 北京: 北京大学出版社, 1991. 1–151]
- 14 Xiao X C, Tang Y Q, Li J Y, et al. On tectonic evolution of the southern margin of the Paleasian composite megasuture zone (in Chinese). In: Xiao X C, ed. *On Tectonic Evolution of the Southern Margin of the Paleasian Composite Megasuture Zone*. Beijing: Beijing Science & Technology Press, 1991. 1–29 [肖序常, 汤耀庆, 李锦轶, 等. 古中亚复合巨型缝合带南缘构造演化. 见: 肖序常, 编. 古中亚复合巨型缝合带南缘构造演化. 北京: 北京科学技术出版社, 1991. 1–29]
- 15 Shao J A. Crust Evolution in the Middle Segment of the Northern Margin of Sino-Korea Plate (in Chinese). Beijing: Peking University Press, 1991. 1–91 [邵济安. 中朝板块北缘中段地壳演化. 北京: 北京大学出版社, 1991. 1–91]

- 16 Tang K D. Tectonic development of Paleozoic foldbelts at the north margin of the Sino-Korean Craton. *Tectonics*, 1990, 9: 249–260
- 17 Tang K D. Structural Evolution and Metallogenic Regularity of Fold Belt in North Side of Sino-Korea Plate (in Chinese). Beijing: Peking University Press, 1992. 69–90 [唐克东. 中朝板块北侧褶皱带构造演化及成矿规律. 北京: 北京大学出版社, 1992. 69–90]
- 18 Zhang Q, Zhou G Q, Wang Y. The distribution of time and space of China ophiolites, and their tectonic setting (in Chinese). *Acta Petrol Sin*, 2003, 19: 1–8 [张旗, 周国庆, 王焰. 中国蛇绿岩的分布、时代及其形成环境. 岩石学报, 2003, 19: 1–8]
- 19 Chen Z Y. Tectonic evolution from middle-Proterozoic to Paleozoic in Guyang-Mandula area, Inner Mongolia (in Chinese). Doctor Dissertation. Beijing: China University of Geosciences, 2005. 1–129 [陈志勇. 内蒙古固阳-满都拉地区中元古代-古生代地质构造演化. 博士学位论文. 北京: 中国地质大学, 2005. 1–129]
- 20 Tao J X, Su M R, Baoyin W, et al. Characteristics and tectonic significance of the Solon mountain ophiolitic mélangé in the Mandula area, Darhan Muminggan, Inner Mongolia (in Chinese). *Geol Bull Chin*, 2004, 23: 1238–1242 [陶继雄, 苏茂荣, 宝音乌力吉, 等. 内蒙古达尔罕茂明安联合旗满都拉地区索伦山蛇绿混杂岩的特征及构造意义. 地质通报, 2004, 23: 1238–1242]
- 21 Jian P, Liu D Y, Kroner A, et al. Evolution of a Permian intraoceanic arc-trench system in the Solonker suture zone, China and Mongolia. *Lithos*, 2010, 118: 169–190
- 22 Wang H, Wang Y J, Chen Z Y, et al. Discovery of the Permian radiolarians from the Bayanaobao area, Inner Mongolia (in Chinese). *J Stratigr*, 2005, 29: 368–371 [王惠, 王玉净, 陈志勇, 等. 内蒙古巴彦敖包二叠纪放射虫化石的发现. 地层学杂志, 2005, 29: 368–371]
- 23 Ishiga H. Late Carboniferous and Permian radiolarian biostratigraphy of Southwest Japan. *J Geosci*, 1986, 29: 89–100
- 24 Ishiga H. Paleozoic radiolarians. In: Ichikawa K, Mizutani S, Hara I, et al., eds. *Pre-Cretaceous Terranes of Japan*. Osaka: Nippon Satsu, 1990. 285–295
- 25 Wang Y J, Yang Q. Carboniferous-Permian radiolarian biozones of China and their Palaeobiogeographic implication. *Acta Micropalaeontol Sin*, 2007, 24: 337–345 [王玉净, 杨群. 中国石炭-二叠纪放射虫化石带及古生物地理学意义. 微体古生物学报, 2007, 24: 337–345]
- 26 Yao A, Kuwahara K. Radiolarian fossils from the Permian-Triassic of China. *News Osaka Micropaleontol*, 2004, 13: 29–45
- 27 Mikiko S, Yao A. Lower-Middle Permian radiolarian biostratigraphy in the Qinzhou area, South China. *J Geosci*, 2006, 49: 31–47
- 28 Zhu S Y, Li B Y. The ophiolites in Solon Obo area, Inner Mongolia (in Chinese). In: *Plate Tectonics Corpus in the North of China* (1). Beijing: Chinese Academy of Geological Sciences, 1983. 105–114 [朱绅玉, 李宝玉. 内蒙古索伦敖包地区蛇绿岩. 见: 中国北方板块构造文集(第一集). 北京: 中国地质科学院, 1983. 105–114]
- 29 Liang R X. The features of ophiolites in the gentral sector of Inner Mongolia and its geological significance (in Chinese). *Region Geol China*, 1994, 1: 37–45 [梁日暄. 内蒙古中段蛇绿岩特征及地质意义. 中国区域地质, 1994, 1: 37–45]
- 30 Chen B, Ma X H, Liu A K. Zircon U-Pb ages of the Xilinhote metamorphic complex and blueschist, and implication for tectonic evolution of the Solonker suture (in Chinese). *Acta Petrol Sin*, 2009, 25: 3123–3129 [陈斌, 马星华, 刘安坤, 等. 锡林浩特杂岩和蓝片岩的锆石 U-Pb 年代学及其对索伦缝合带演化的意义. 岩石学报, 2009, 25: 3123–3129]
- 31 Li Y L, Zhou H W, Brouwer F M, et al. Tectonic significance of the Xilin Gol complex, Inner Mongolia, China: Petrological, geochemical, and U-Pb zircon age constraints. *J Asian Earth Sci*, 2011, 42: 1018–1029
- 32 Cao C Z. The plate framework of northeastern China (in Chinese). *Bull Shenyang Inst Geol Min Res Chin Acad Geol Sci*, 1987, 16: 60–67 [曹从周. 中国东北部的板块构造格局. 中国地质科学院沈阳地质矿产研究所文集, 1987, 16: 60–67]
- 33 Hsu K J, Wang Q, Li L, et al. Geologic evolution of the Neimontides: A working hypothesis. *Eclogae Geol Helv*, 1991, 84: 1–31
- 34 Chen B, Jahn B M, Wilde S, et al. Two contrasting Paleozoic magmatic belts in northern Inner Mongolia, China: Petrogenesis and tectonic implications. *Tectonophysics*, 2000, 328: 157–182
- 35 Nozaka T, Liu Y. Petrology of the Hegenshan ophiolite and its implication for the tectonic evolution of north China. *Earth Planet Sci Lett*, 2002, 202: 89–104
- 36 Wang Y J, Fan Z Y. Discovery of Permian radiolarians in ophiolite belt on northern side of Xar Moron River, Inner Mongolia and its geological significance (in Chinese). *Acta Palaeontol Sin*, 1997, 36: 58–69 [王玉净, 樊志勇. 内蒙古西拉木伦河北部蛇绿岩带中二叠纪放射虫的发现及其地质意义. 古生物学报, 1997, 36: 58–69]
- 37 Li J Y, Gao L M, Sun G H, et al. Shuangjingzi Middle Triassic syn-collisional crust-derived granite in the east Inner Mongolia and its constraint on the timing of collision between Siberian and Sino-Korean paleo-plate (in Chinese). *Acta Petrol Sin*, 2007, 23: 565–582 [李锦轶, 高立明, 孙桂华, 等. 内蒙古东部双井子中三叠世同碰撞壳源花岗岩的确定及其对西伯利亚与中朝古板块碰撞时限的约束. 岩石学报, 2007, 23: 565–582]
- 38 Jian P, Kroner A, Windley B F, et al. Carboniferous and Cretaceous mafic-ultramafic massifs in Inner Mongolia (China): A SHRIMP zircon and geochemical study of the previously presumed integral “Hegenshan ophiolite”. *Lithos*, 2012, 142–143: 48–66
- 39 Shang Q H. Occurrences of Permian radiolarians in central and eastern Nei Mongol (Inner Mongolia) and their geological significance to the Northern China Orogen. *Chin Sci Bull*, 2004, 49: 2613–2619 [尚庆华. 北方造山带内蒙古中、东部地区二叠纪放射虫的发现及意义. 科学通报, 2004, 49: 2574–2579]
- 40 Eizenhofer P R, Zhao G C, Zhang J, et al. Final closure of the Paleo-Asian Ocean along Solonker suture zone: Constraints from geochronological and geochemical data of Permian volcanic and sedimentary rocks. *Tectonics*, 2014, 33: 441–463
- 41 Zhang S H, Zhao Y, Kroner A, et al. Early Permian plutons from the northern North China Block: Constraints on continental arc evolution and convergent margin magmatism related to the Central Asian Orogenic Belt. *Int J Earth Sci*, 2009, 98: 1441–1467

Summary for “内蒙古索伦山蛇绿岩带早二叠世放射虫动物群的发现及其地质意义”

Discovery of Early Permian radiolarian fauna in the Solon Obo ophiolite belt, Inner Mongolia and its geological significance

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The Solon Obo ophiolite belt in Inner Mongolia is located close to the border between China and Mongolia. It is an integral part of the Solon Obo tectonic suture formed by the closure of the Paleo-Asian Ocean between Siberia Craton and North China Craton in the Paleozoic. This ophiolite belt is a rare remnant of the Paleo-Asian Ocean and thus provides important samples for the study of tectonic evolution in the eastern part of the Central Asian Orogenic Belt in North China. The age of the tectonic event of the Solon Obo tectonic suture has been debated for a long time. Some researchers believe that it was from Silurian to Devonian whereas other researchers believe it was from Early Carboniferous to Early Permian. Here we report the first discovery of Early Permian radiolarians in the cherts of the ophiolite belt.

The Solon Obo ophiolite belt is E-W trending, with a total length of ~100 km. It is mainly composed of ultramafic intrusive rocks such as harzburgite, lherzolite, dunite and pyroxenite, and gabbro, diabase, basalts and cherts. On the base of the field geological investigation and 1:10000 structure-lithology mapping in the Solon Obo area, we took cherts samples from the Solon Obo ophiolite belt in the Subuergen Hudag area of northern Urad Middle Banner, Inner Mongolia, and carried out studies including petrologic characteristics of cherts, separation and identification of the radiolarian fossils in cherts. Early Permian radiolarian fauna is first found in the chert of Solon obo ophiolite belt. This fauna is composed of 5 genera and 6 species (including 4 unidentified species and 1 new species), *Pseudoalbaillella bulbosa*, *Ps. solonensis* Wang sp. nov., *Stigmatosphaerostylus* sp., *Ruzhencevispongus* sp., *Cenosphaera* sp., *Latentifistula* sp. etc. The new species, *Pseudoalbaillella solonensis* can be distinguished from *Ps. u-forma* by its holes in the end of the pseudoabdominal segment. *Pseudoalbaillella bulbosa*, found in Late Carboniferous-Early Permian cherty strata of Japan, Thailand, Chile, Western Coast of North America and South China is regarded as a zonal species of early Early Permian time in China and has become one mark of the boundary between Carboniferous and Permian cherty strata in open marine facies. This radiolarian fauna is characterized by rich *Pseudoalbaillellids* and *Entactinids* which have possessed about 45% of this fauna respectively. The *Pseudoalbaillellids* are mostly composed of the apical cones and many pseudothoraxes with smaller entire individuals. The *Entactinids* are numerous in number and their spines are longer, but incomplete due to break. Other radiolarians, such as *Latentifistulids*, *Cenosphaerids* and *Ruzhencevispongids* are rare. These radiolarian fossils possessing over 50% in whole rocks are considered as the radiolite which is a component of the ophiolite. Therefore, the time determined by radiolarian fossils may represent forming age of the ophiolites and this set of radiolite is known as a part of the Solon Obo ophiolite belt. The discovery of this radiolarian fauna has provided a key evidence about forming age of the Solon Obo ophiolite lasted until Early Permian.

This new discovery, together with the previously reported zircon U-Pb ages of 279–296 Ma for the associated mafic-ultramafic rocks in the Solon Obo ophiolite belt, confirms that the final closure of the Paleo-Asian Ocean took place no early than Early Permian.

radiolarian, Early Permian epoch, ophiolite, Solon Obo, Paleo-Asian Ocean

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