1000-0569/2016/032(09)-2609-27 *Acta Petrologica Sinica* 岩石学报

# 东亚原特提斯洋(Ⅰ):南北边界和俯冲极性*

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2016-05-22 收稿, 2016-07-16 改回.

**Li SZ, Zhao SJ, Li XY, Cao HH, Liu X, Guo XY, Xiao WJ, Lai SC, Yan Z, Li ZH, Yu SY and Lan HY. 2016. Proto-Tehtys Ocean in East Asia (I): Northern and southern border faults and subduction polarity. *Acta Petrologica Sinica*, 32(9):2609-2627**

**Abstract** The Proto-Tethys Ocean is a complicately-originated oceanic basin originated from Supercontinent Rodinia breakup and existed from Neoproterozoic to the end of the Early Paleozoic. It was located in the range of north of the Yunnan-Burma-Thailand/Baoshan (Sibumasu) micro-continental blocks and south of the Tarim-North China Block. There is still controversy for a long time on the southern and northern border faults and the late Early Paleozoic subduction polarity of the Proto-Tethys Ocean. It is important for understanding tectonic background, restoration and reconstruction of Supercontinent Pangea assembly. Therefore, this paper used the integrated methods for the latest results of field geology, tectonics, magmatism, sedimentology, geochemistry and tectonic chronology and tomographic imaging, to identify the positions of the southern and northern border faults of the Proto-Tethyan Tectonic Domain, and determine the subduction polarity of the Proto-Tethys Ocean. Integrated analysis results show that to the north is bounded by the paleo-Luonan-Luanchuan Suture (or Kuanping Suture) and its extension to West Kunlun; the southern boundary is the Longmu Co-Shuanghu-Changning-Menglian Suture. The Tarim-Alax-North China Block in the north of the Proto-Tethys Ocean had a southward subduction polarity and collided with the Gondwana along the northern margin of the Gondwana in the Early Devonian, forming a giant orocline now preserved in the Qilian-Altyn Tagh-Qaidam segment of the Central China Orogen. The south branch of the Proto-Tethys Ocean may be closed, making the Greater South China Block including the North Qiangtang, Ruoergai, Yangtze and Cathaysia, Bureya-Jiamusi and Indochina blocks a southward subduction and accretion to the northern margin of the Gondwana in Devonian.
**Key words** Proto-Tethys Ocean; Border faults; Early Paleozoic; East Asia; Subduction polarity

**摘 要** 原特提斯洋是从新元古代 Rodinia 裂解到早古生代发育于滇缅泰/保山微陆块以北、塔里木-华北陆块以南的一个

* 本文受国家自然科学基金重大项目(41190072、41190070)、国家杰出青年基金项目(41325009)、泰山学者特聘教授项目和鳌山卓越科学家计划联合资助.

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复杂成因的洋盆。长期以来对原特提斯洋的南、北边界及其早古生代末俯冲极性还存在争论,而这是恢复重建 Pangea 超大陆聚合前构造背景的关键。本文综合利用野外地质、构造、岩浆、沉积学、地球化学、构造年代学和层析成像等最新成果,以期界定原特提斯域的南、北边界位置,确定原特提斯洋边界俯冲极性。集成分析结果表明,北界为古洛南-栾川缝合线(或宽坪缝合线)及其直至西昆仑的西延部分;南界为龙木措-双湖-昌宁-孟连缝合线。原特提斯洋北部在华北-阿拉善-塔里木陆块泥盆纪向南俯冲并与冈瓦纳大陆北缘拼合过程中,形成了一个巨型弯山构造,现保存在祁连-阿尔金-柴达木地区的中国中央造山带内。原特提斯洋南部分支也可能在泥盆纪闭合,使得包括羌北、若尔盖、扬子、华夏、布列亚-佳木斯等在内的大华南陆块、印支陆块等也向南俯冲与冈瓦纳北缘发生了聚合。

**关键词** 原特提斯;边界断裂;早古生代;东亚;俯冲极性

**中图法分类号** P542

## 1 引言

东亚早古生代一系列蛇绿岩带和高压-超高压变质带,如北祁连高压带、柴北缘超高压带、阿尔金超高压带、北秦岭超高压带、龙木措-双湖构造带、西昆仑构造带等(图1),记录了原特提斯洋内复杂的陆块运动与结构状态。近年的研究已表明,除印支期以外,早古生代也是东亚部分陆块/微陆块间聚合的重要时期,也更为广泛地形成了一系列的蛇绿岩带、高压-超高压带和花岗岩带(图1)。中国学者在这些构造带的岩石学、地球化学和年代学方面作了大量工作(李兴振等,1990;蔡立国等,1993;潘裕生,1994;陈智梁,1994;潘桂棠等,1997,2004;钟大赉,1998;陆松年, 2001;郭福祥,2001;李兴振和尹福光, 2002;肖序常等,2003;Xiao *et al.*, 2003, 2009;高长林等, 2005;Li *et al.*, 2008;李文昌等,2010;Dong *et al.*, 2011a, b; Wang *et al.*, 2011;付长垒等,2014),取得长足进展。但是迄今,关于原特提斯洋南部和北部遗迹界线、俯冲极性和古板块运动学特征均存在巨大争议(向鼎璞, 1982;郑健康,1992;冯益民等,1994;夏林圻等, 1996;杨经绥等, 1998, 2000, 2005;葛肖虹和刘俊来, 1999;张雪亭等, 1999;李怀坤等,1999;于海峰等, 1999;赵风清等,2000;张招崇等,2001;陆松年, 2002;王惠初等,2001, 2005;庄儒新和李峰,2006;张建新等,2007,2015; 刘良等,2009;林宜慧等, 2010;张贵宾和张立飞,2011),而对这些问题的准确厘定与理解不仅可以丰富原特提斯的研究内容,而且是 Pangea 东亚重建的重要基础,同时可为构建 Pangea 东亚重建新方案和建立 Pangea 东亚重建动态演化模型提供科学依据。

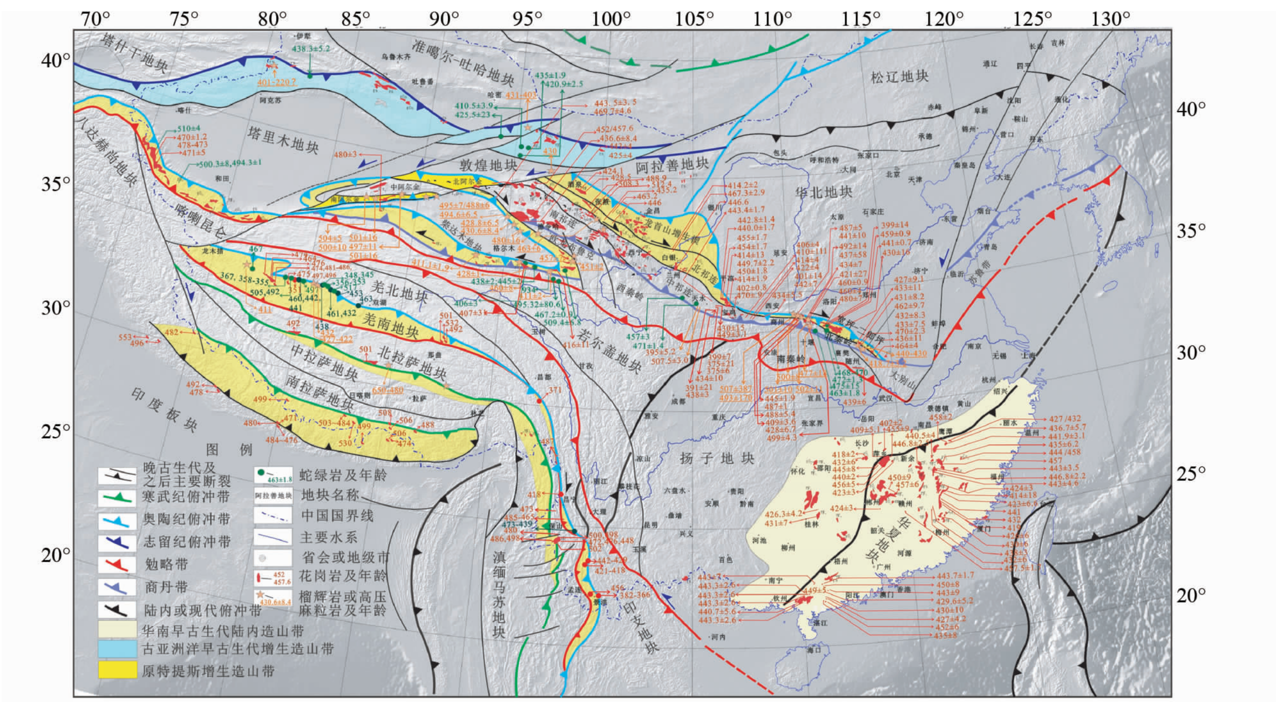


图1 原特提斯构造域南、北边界分布(据李三忠等,2016d 补充,数据来自大量文献,不一一列举)

Fig. 1 Northern and southern border faults of the Proto-Tethyan Tectonic Domain(revised after Li *et al.*, 2016d; Data from many references)

## 2 东亚原特提斯洋南、北边界界定

针对中国境内主要早古生代构造带,前人的研究主要集中在岩石学、地层学、生物古地理、地球化学和年代学等方面(图1),但这些研究还没能回答:1)哪条构造带代表原特提斯洋的最北界和最南界? 2)东亚原特提斯洋的具体范围如何? 这两个问题是重建 Pangea 超大陆东亚陆块/微陆块早古生代古地理位置的重要基础,也是系统研究"Pangea 东亚聚合"的第一个核心科学问题。

5 年来通过消化国内外已有研究成果(图 1),本文分别针对原特提斯域北部和南部边界,开展了下列深入综合集成研究:

① 原特提斯洋北界主要构造遗迹界线厘定

大多数研究表明,北秦岭构造带是中央造山带东部原特提斯洋已知的最北界,其向西延,过徽成、共和盆地,却出现北祁连、中祁连、柴北缘、昆北、昆中、昆南等有加里东期变形变质记录的构造带,因此确定北秦岭构造带与前述何者衔接是界定中央造山带西段原特提斯北界的关键。

(a)大地构造单元配置分析:确定北秦岭构造带及商丹带向西和北祁连带、中祁连带、柴北缘带的连接关系;厘定各构造带地表地质特征,确定其岩石组合类型,综合厘定其主要界线物质记录和其它对比标志(杨朝等,2015;李涛等,2015;熊莉娟,2014);分析其形成构造环境和构造属性,为大地构造单元厘定、划分、配置研究提供基础。

(b)古俯冲-拼合带深部结构:揭示地壳古俯冲带结构,结合地表野外地质考察,确定原特提斯洋内各微陆块、古老构造带深部结构或残存特征(Sun *et al.*, 2015b),探讨原特提斯洋俯冲板块运动学。

通过对原特提斯洋北界从地表到深层结构的深入研究与确认,从而达到厘定原特提斯洋北界范围,为探讨原特提斯北部陆块/微陆块的多块体拼合动力学机制提供板块边界条件,为探讨原特提斯洋形成演化的动力学模式提供约束,为查明 Pangea 超大陆聚合前早古生代构造背景奠定基础。

②原特提斯洋南部地质记录

已知原特提斯洋南部广泛经历了加里东期构造变形,但蛇绿岩、相关岛弧型火山岩建造较少报道。本文在全面理解掌握和消化吸收前人资料(钟大赉,1998;许志琴等,2007,2013;Zhu *et al.*, 2013; Nie *et al.*, 2015)的基础上,进一步就前人发表的早古生代蛇绿岩出露点或蛇绿岩剖面进行深入甄别工作。由于这些蛇绿岩分布零星,所以主要研究工作侧重加里东期变形和岩石记录的寻找与研究,确定其变形期次、几何学构造样式与运动学特征,探讨其动力学演化。最终试图勾勒出加里东期变形的最南部界线(安慧婷,2014),根据变形南界的确定从而初步约束原特提斯南界。

(a)选择可能的原特提斯洋地质记录,如景洪变质岩带(团梁子岩组)和华南加里东期岩浆岩分布,进行系统的同位素年代学、岩石学、岩石地球化学集成分析,进一步寻找原特提斯洋南部地质记录,结合岩石年龄和构造拓展的空间分布规律,探讨原特提斯洋南部地质演化和块体拼合历史;

(b)针对出露于八布构造带的蛇绿岩(钟大赉,1998),开展岩石学、精细的锆石 U-Pb 或全岩 Ar-Ar 定年以及元素 Sr-Nd-Pb 同位素组成研究,并进行区域追踪,明确其延展;

(c)在昌都加里东造山带开展早古生代碎屑岩碎屑锆石 LA-ICP-MS 年代学和沉积岩元素-同位素地球化学研究,开展物源示踪;尽可能对越南马江一带蛇绿岩和高压蓝片岩(钟大赉,1998)及相关花岗岩,开展 SHRIMP 锆石 U-Pb 年代学和岩石地球化学研究;

(d)通过原特提斯域南部深部结构探测,揭示地壳古俯冲带结构,探讨原特提斯洋可能的南界深部构造特征,探讨原特提斯洋南部的构造属性。

但遗憾的是因种种原因,后三部分没能实现,今后将加强研究。有幸的是,近来相关工作不断报道(Zhu *et al.*, 2013; Nie *et al.*, 2015),为甄别和确定原特提斯南界提供了线索。

### 2.1 原特提斯北部边界

前人研究笼统地指出,原特提斯洋的北界应该在华北-塔里木陆块以南(李兴振等,1990;陈智梁,1994;潘桂棠等,1997;陆松年, 2001;郭福祥,2001;Xiao *et al.*, 2003, 2009;von Raumer and Stampfli,2008;李文昌等,2010)。最近,Liu *et al.* (2015)依据 Th/U 比值,揭示出特提斯地幔域(高 Th/U 比)与古亚洲洋地幔域(低 Th/U 比)之间的界限在华北-塔里木地块北缘。然而,对于前一观点,该界限是固定的一条构造带还是不同时期变迁的构造带? 具体是哪条构造带或断裂? 都没有详细证明和结论。通常认为,华北-塔里木陆块以南的扬子陆块、柴达木、中祁连等微陆块是在新元古代-早古生代早期从冈瓦纳大陆北缘裂离出来的,这些陆块/微陆块之间以多岛洋分割,分散在大洋中间(高长林等, 2005;Li *et al.*, 2008),在早古生代末可能经历了陆块/微陆块两两之间的复杂俯冲与拼合过程,并伴随多条复杂的蛇绿岩带和高压-超高压变质带的形成,如北秦岭构造带(Dong *et al.*, 2011a, b; Wang *et al.*, 2011)、北祁连构造带(向鼎璞,1982;郑健康, 1992;冯益民等,1994;许志琴等,1994;夏林圻等, 1996;葛肖虹和刘俊来, 1999;张招崇等,2001;林宜慧等,2010)、柴北缘构造带(杨经绥等, 1998, 2000;张雪亭等,1999;李怀坤等,1999;陆松年, 2002;于海峰等, 1999;赵凤清等, 2000;王惠初等,2001, 2005;庄儒新和李峰,2006;张贵宾和张立飞,2011)、阿尔金构造带(杨经绥等,2005;张建新等, 2007;刘良等,2009)等。这些蛇绿岩带和高压-超高压变质带记录了地壳物质从俯冲到构造折返的一个完整的动力学过程,是研究早古生代末陆块/微陆块拼贴及原特提斯北部边界的重要载体(张旗和周国庆, 2001)。

30 多年来,前人对这些构造带开展了大量的研究,并取

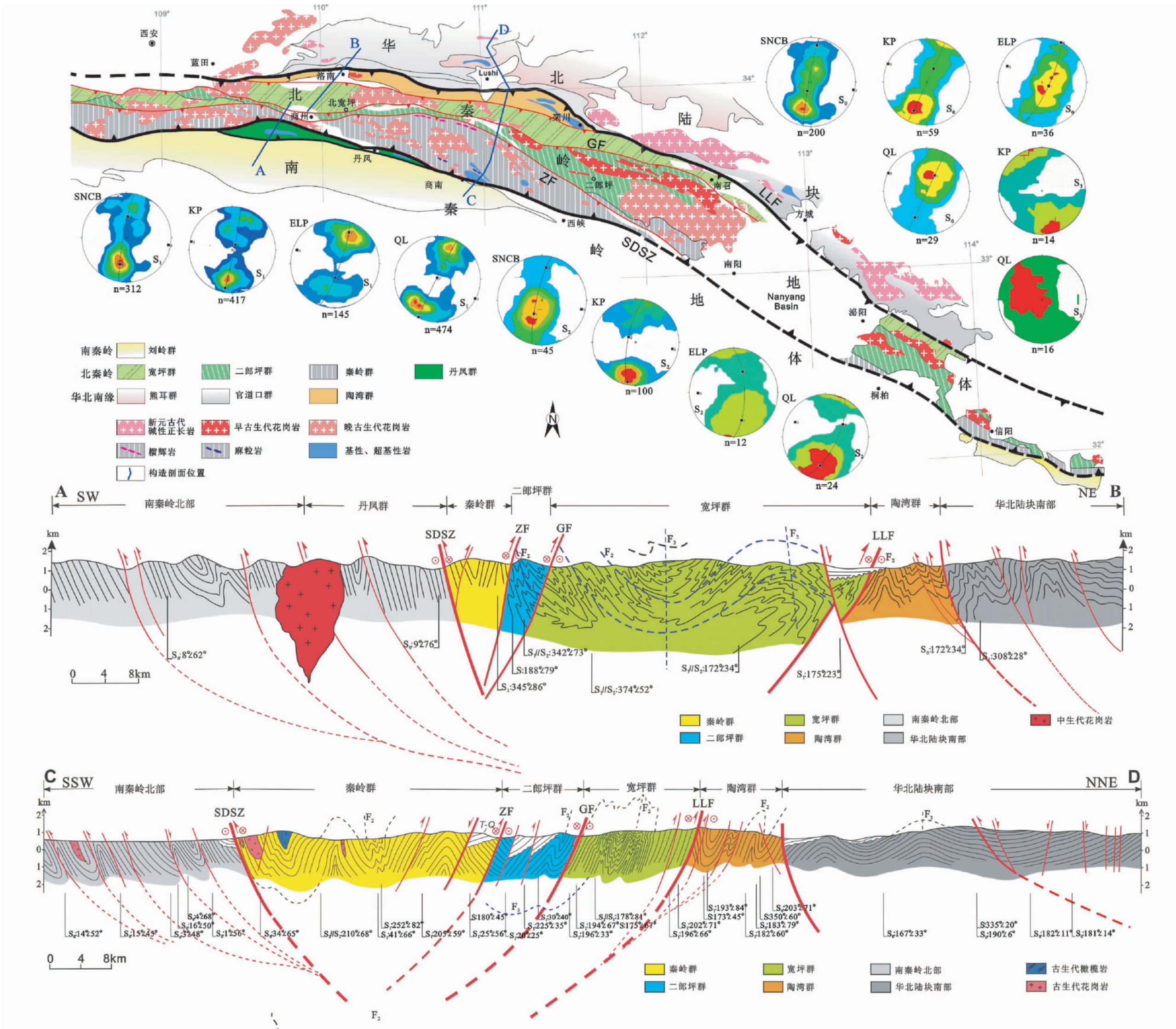


图 2 北秦岭构造带单元划分和不同时代岩体分布(据 Zhao *et al.*, 2015)

新元古代碱性正长岩皆位于古洛南-栾川断裂以北,侵入华北南缘的官道口群,剖面揭示原特提斯洋早古生代的向南俯冲极性

Fig. 2 Tectonic units and pluton distribution with different ages of the North Qinling Belt (after Zhao *et al.*, 2015)

Neoproterozoic alkaline synites emplaced into the Guandaokou Group north of Paleo-Luonan-Luanchuan Fault. Structural profiles reveal the southward subduction polarity of the Proto-Tethyan Ocean

得了丰富的成果。但是,目前有关北秦岭构造带的西延问题仍存在多种观点,如:1)通过宝鸡-天水断裂向北和北祁连衔接(肖序常等,1978;向鼎璞,1982;张建新和许志琴,1995;冯益民等,1994;宋忠宝等,2005;林宜慧等,2010);2)通过拉脊山-青海湖-武山-宝鸡-天水断裂与中祁连相连(杨钊等,2006;董云鹏等,2007);3)与柴北缘对接(杨经绥等,1998,2003;许志琴等,2003;Xu *et al.*, 2006; 张贵宾等,2005;王惠初等,2005; 张建新等,2007;刘良等,2009;宋述光等,2011;王宗起等,2009;闫臻等,2012);4)过共和盆地与东昆仑中带对接,而昆中断裂与商丹带相连(Ren and Xie, 1991;许效松等,1996;任纪舜等,2000; 陈能松等,2008)。北秦岭构造带究竟与上述哪条构造带相连是解决早古生代洋-陆基本格局的关键。此外,这些带继续西延与阿尔金和西昆仑的交接关系存在同样争论(肖序常等, 1986; 郑健康, 1992)。澄清这些问题也是认识 Pangea 超大陆最终聚合位置和过程的重要基础。

根据碎屑锆石(与其它类型锆石一同可视为地质基因(geo-gene))年龄谱(可视作地质 DNA)对比(Cao *et al.*, 2016),可以发现宽坪群碎屑岩和北祁连下古生界物源没有华北组成。由此可见,宽坪洋、北祁连洋、北阿尔金洋是个分割性的洋盆,自然也是沉积盆地物源区的分界。因而,原特提斯洋北界应当是宽坪群北界,但不是中生代洛南-栾川断裂带,而是我们称为古洛南-栾川断裂带及其西段对应的构造带(图 2;Zhao *et al.*, 2015;李三忠等,2016b)。虽然前人

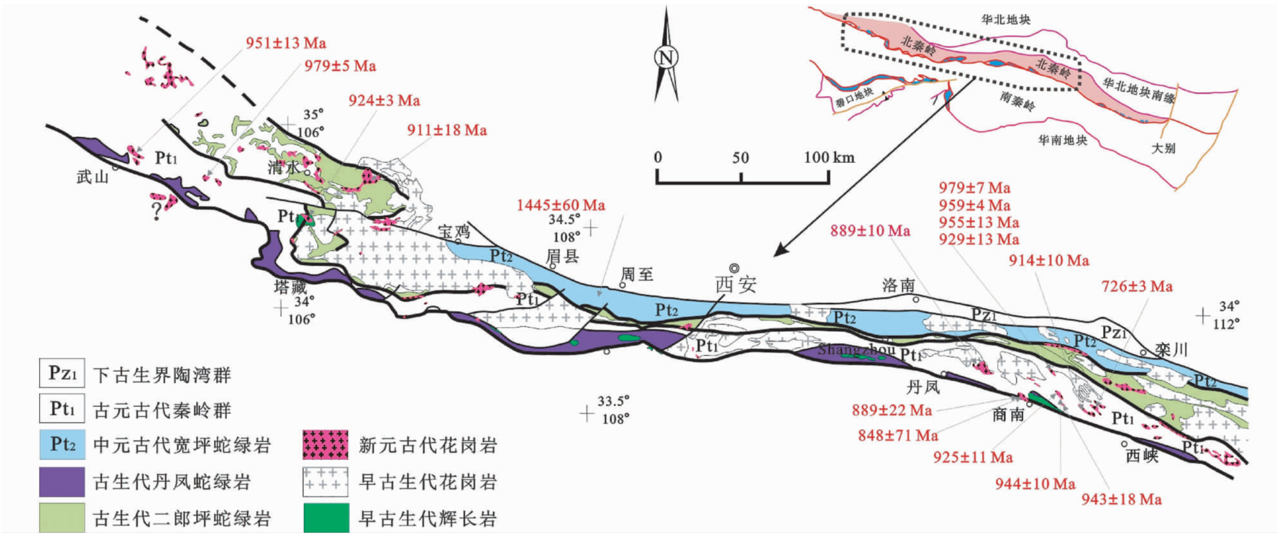


图 3 北秦岭新元古代花岗岩及构造地层单元分布(据 Dong *et al.*, 2014)

980 ~ 720Ma 的新元古代侵入岩不越过北秦岭-中祁连地块北界(年龄统计见 Dong *et al.*, 2014)

Fig. 3 Simplified map with the principal tectonostratigraphic units within the North Qinling Belt showing the distribution of the Kuanping mélange, Paleozoic mélange of the Shangdan Suture and Erlangping Basin, as well as the Neoproterozoic plutons and their published ages (after Dong *et al.*, 2014)

980 ~ 720Ma of Neoproterozoic plutons (ages seen in Dong *et al.*, 2014) are not across the north margin of the Central Qilian-North Qinling Terrane

研究认为,商丹洋是原特提斯洋主大洋(张国伟等,2001),甚至最近 Liu *et al.* (2016)提出 500Ma 左右变质的北秦岭榴辉岩是商丹大洋俯冲期间北秦岭微陆块中原岩年龄为 800Ma 左右的岩石卷入深俯冲的结果,但北秦岭作为商丹洋俯冲的上部板片,难以想象如何发生深俯冲;而且这些观点还认为宽坪群和二郎坪群都代表其弧后盆地(Dong *et al.*, 2011a, b; Liu *et al.*, 2016),且南祁连下古生界与南秦岭具有可比性,因此,商丹带向西延应当对应中祁连地块南缘断裂,是一条重要分划性构造带(杨钊等,2006;董云鹏等,2007);但是本文认为商丹带也可能对应南祁连南部边界,因为南祁连下古生界主要是寒武系、奥陶系岛弧火山岩及相关蛇绿岩构成,志留系出露很少,主要是一套活动型浅海相-陆相沉积组合,与南秦岭还不一样,因此,在此段可能存在商丹俯冲带向南的跃迁,导致商丹带现今向西的分叉现象。昆中断裂带难以与商丹带直接相连,因为两者之间的西秦岭上千千米没有任何洋壳残存记录。昆中断裂带实际被后期瓦洪山断裂错移,应当与中祁连南缘断裂的西段、或者与武山断裂-青海南山断裂、或者与北宗务隆山断裂、南祁连山山前断裂衔接,这样便解决了商丹带西延的问题,但商丹洋是不是原特提斯洋主大洋还值得商榷。刘国惠等(1993)最早根据北秦岭变质岩群岩石学、岩石地球化学和年代学详细研究认为,新元古代时期北秦岭微陆块已经增生成为华北陆块南缘组成;Dong *et al.* (2011a, b)提出方城一带北西西向展布的碱性花岗岩(图 2)是北秦岭和华北南缘在 844Ma 左右(包志伟等,2008)拼合标志,进一步支持了刘国惠等(1993)的观点。但是,980 ~726Ma 的新元古代岩体主要分布在宽坪群南侧(Dong *et al.*, 2014)、北侧(包志伟等, 2008)两条构造带中,北带方城碱性正长岩形成年龄为 844Ma 左右(包志伟等,2008),包志伟等(2008)认为该碱性正长岩是北秦岭主体与 Rodinia 主体在 890Ma 拼合后转入伸展-裂解背景下就位的。实际上,这些碱性岩全部位于古洛南-栾川断裂带以北,并侵入到官道口群之中,而官道口群现被归属为华北陆块南缘(Wu *et al.*, 2008;Liu *et al.*, 2013),因而这些碱性岩不应当属于北秦岭构造带。南带新元古代岩体主要年代介于 980 ~ 728Ma 之间(图 3;陆松年等,2003; Dong *et al.*, 2014),且空间上严格约束在北秦岭-中祁连微陆块中,即宽坪群-二郎坪群以南、商丹带以北,属 S 型同碰撞造山花岗岩(陆松年等,2003),这显然不同于华北南缘碱性岩和阿拉善伸展型 A 型花岗岩(耿元生和周喜文,2010)。特别是,介于这两条新元古代花岗岩带之间的宽坪群中没有任何新元古代花岗岩分布(图 2、图 3),因此,北侧碱性岩带和南侧花岗岩带都不应当是宽坪洋消亡导致北秦岭与华北南缘(Dong *et al.*, 2014)或扬子北缘(包志伟等,2008)在新元古代早期碰撞拼合后转入伸展环境的标志。现今大量新的同位素年代学资料(Liu *et al.*, 2013; Zhao *et al.*, 2015)揭示,北秦岭新元古代原岩经历的主要变质事件是加里东期,也否定了新元古代变质事件(刘国惠等,1993)的广泛性。

前人基于北秦岭与华北南缘新元古代拼合的认识,提出了宽坪群和二郎坪群都是弧后盆地。高山(1989)根据地球化学物源示踪,提出宽坪群碎屑岩具有双向物源特征,并明确其分别为华北南缘太华群和北秦岭两个物源,这一认识似乎进一步证明了宽坪群碎屑岩代表宽坪洋消亡(或之后再打

开)的一个弧后盆地。宽坪群由基性岩和碎屑岩两部分组成。其中主体基性岩形成时代为 1400 ~ 1000Ma(张寿广等,1991;陆松年等,2003),但最新年代学揭示还存在 611Ma(闫全人等,2008)基性岩,同时宽坪群碎屑岩中还存在 540Ma 左右的碎屑锆石(第五春荣等,2013),因而 590Ma 左右开始启动的商丹洋俯冲(Liu *et al.*, 2004, 2013; Dong *et al.*, 2012)不可能产生比商丹洋俯冲时间还早的宽坪弧后盆地,最多也只能导致较晚的二郎坪弧后盆地;特别是宽坪群碎屑岩中碎屑锆石年龄谱与扬子完全一样(Liu *et al.*, 2004; Yu *et al.*, 2015; Cao *et al.*, 2016),这样就可能否定了宽坪群碎屑岩双向物源成因的认识,即所谓的华北太华群物源区可能不对,而是可能两种成因:1)来自崆岭群等扬子克拉通或冈瓦纳大陆某处而不是华北的太华群;2)华北属性的一些岩片后期卷入北秦岭构造带变形。

根据北秦岭-中祁连带状分布的早古生代花岗岩(图 1、图 3),可以判断早古生代宽坪洋是向南俯冲到中阿尔金-中祁连-北秦岭微陆块之下,或朝柴达木微陆块外侧的欧龙布鲁克(达肯达坂群)和昆中(金水口群)微陆块之下俯冲,宽坪洋-北祁连洋-北阿尔金洋南侧是活动大陆边缘,而北侧华北陆块南缘、塔里木陆块西南缘、柴达木微陆块内南北侧残存的下古生界都为显著的被动陆缘沉积建造。此外,从北秦岭,到陇西地区通关河东侧、中祁连还发育有低压相系变质作用(肖思云等,1988),从祁连地区的分析结果(张建新等,2015)来看,一些低压变质发生时代可能也是加里东期;而同期北祁连蓝片岩、榴辉岩等高压-超高压变质(张建新等,2015)和北秦岭中压变质相系主要分布在这条低压变质相系北侧(肖思云等,1988)。这些双变质带特征的岩石学标志也进一步指示宽坪洋向南的俯冲极性。对泥盆系不整合之下的第一幕构造解析以及北祁连志留-泥盆系沉积盆地原型恢复也表明,宽坪洋-北祁连洋皆向南俯冲(Yan *et al.*, 2007, 2010; Xiao *et al.*, 2009; Zhao *et al.*, 2015; Sun *et al.*, 2015b; Yuan and Yang, 2015);而且向西延伸,在北祁连门源(张建新等,2015)、柴北缘乌兰都发现双变质带(李秀财等,2015),再到西昆仑,构造解析也揭示早古生代是向南俯冲(Mattern and Schneider, 2000; 曹颖等,2016)。

迄今,多数人认可秦岭从北向南存在宽坪、商丹和勉略三条缝合带(Dong *et al.*, 2014),且都认可勉略洋是晚古生代打开的洋盆,石炭纪启动俯冲,印支期闭合(Meng and Zhang, 1999)。现在存在问题的焦点是:原特提斯洋主洋盆是宽坪洋还是商丹洋,也就是原特提斯洋北界是二者中的何者,这必然涉及何者代表原特提斯洋封闭的问题。商丹带南侧分布有泥盆纪刘岭群,是一套以细碎屑岩为主夹少量碳酸盐岩、石英砂岩和(变质)火山碎屑岩组合的滨-浅海和三角洲相沉积,沉积物源来自于其北侧(杜定汉,1986;Yan *et al.*, 2006, 2012;闫臻等,2007);吴涛等(2014)认为主要是浅海-滨海相沉积,古流向一致指示向北,基本受南侧南秦岭被动陆缘控制;Dong *et al.* (2014)等认为是深水复理石建造,并根据碎屑锆石认为其物源来自其南、北两侧,且南侧扬子板块是其重要的物源区之一。向西对比,对应天水以南分布的泥盆纪大草滩群,则相变为紫红色间夹杂色砂砾岩、粗砂岩、砂岩和页岩等,不整合在李子园群之上(霍福臣和李永军,1995;闫臻等,2002);再往祁连、祁漫塔格等地,泥盆系直接角度不整合在下伏地层之上,以巨厚的河流相砾岩、粗砂岩沉积为特征,标志海相沉积历史结束,被认为是造山末期的磨拉石建造(黄第藩,1966;金松桥等,1985;杜远生等,2004)或者古岛弧隆升剥蚀沉积于其弧前盆地产物(Yan *et al.*, 2007; Xiao *et al.*, 2009;Yuan and Yang, 2015);东部的泥盆系被认为是古生代连续增生的沉积增生楔一部分(Ratschbacher *et al.*, 2003; Yan *et al.*, 2012; 陈龙耀等,2014)。这可能意味着"商丹带"西段(祁连段)加里东期曾经闭合,且后期可能再裂解,但没打开出现新的晚古生代大洋;而东段在整个古生代期间尽管有间断和角度不整合,但是个逐步关闭过程,特别是南秦岭没有任何加里东期变形记录,直到中三叠世南秦岭才卷入强烈变形,因此,商丹洋可能是原特提斯洋或古亚洲洋在东段的延续存在(图 4)。相反,宽坪洋、北祁连洋、北阿尔金洋及可比的洋盆此时则已经关闭,二郎坪群被早古生代花岗岩侵入(图 2),而且晚古生代花岗岩不仅侵入北秦岭、宽坪群,而且侵入到华北南缘,这不仅表明这个洋盆在早古生代闭合,而且表明这个洋盆在早古生代是向南俯冲的,而商丹洋晚古生代期间是向北俯冲的,且影响到华北南缘。

早古生代期间,华北和华南是不是南、北向并置关系值得讨论。如果泥盆纪之前原特提斯洋是介于华北与华南陆块之间的一个大洋,那么加里东期华北、华南陆块南北向拼合期间,为什么现今南秦岭乃至华北东部没有保留任何加里东期变形和变质作用?因此,我们提出早-中泥盆世华北、华南陆块空间关系为东、西向"串联"关系,而非南、北向"并联"关系,武关岩群、刘岭群、大草滩群实际是晚泥盆世华北-北秦岭-中祁连-中阿尔金-柴达木-塔里木与冈瓦纳北缘拼合后,晚期裂离或向东平移而一同移置到南秦岭北部,与南部早-中泥盆世的舒家坝群等属于南秦岭被动陆缘的沉积建造大不相同(闫臻等,2009,2012),与刘岭群等相关沉积体之间也为断裂分割,且沿该断裂还分布有一系列基性-超基性岩块(郭现轻等,2014; Sun *et al.*, 2015a),可能为增生到增生楔中的海山等建造。据此,不排除晚泥盆世华北板块向东北漂移,使得华北、华南转变为南、北关系。这在 Kroner *et al.* (2016)的 370Ma 全球板块重建中也得到了体现。

### 2.2 原特提斯南部边界

近 20 年来,原特提斯洋地质记录在我国青藏高原及邻区也被零星揭示(图 5),但迄今对原特提斯南界却存在模糊认识和巨大争论(李兴振等,1990;蔡立国等,1993;潘裕生,1994;钟大赉,1998;李兴振和尹福光, 2002;肖序常等,2003;潘桂棠等,2004)。目前对原特提斯洋的南界认识有 4 种观

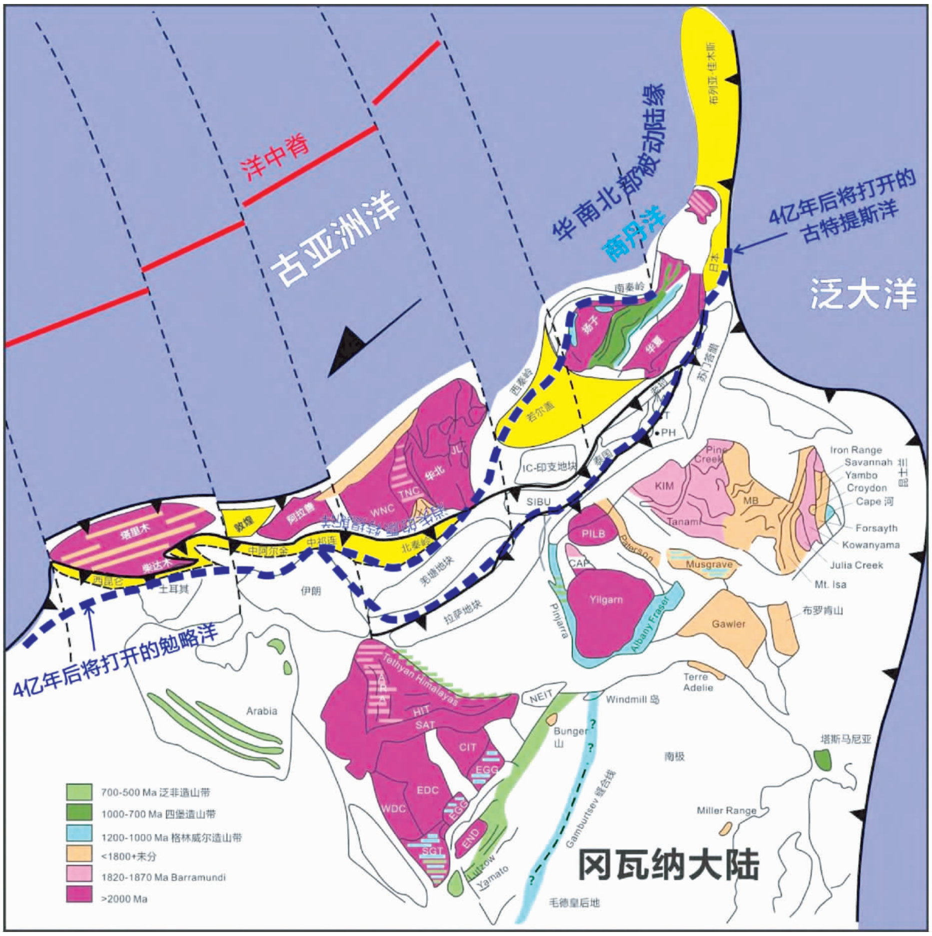


图 4 大华南陆块在早古生代 450～400Ma 全球构造格架最可能的状态(据李三忠等,2016c 修改)

ARA-阿拉瓦利-德里; CIT-印度中央地体; EDC-达瓦尔东部克拉通; EGG-高止东部麻粒岩; END-恩德比地; IC-印支地块; JL-胶-辽-吉带; KIM-金伯利; M-马来西亚半岛(西); MB-麦克阿瑟盆地; NEIT-印度东北地块; PH-普吉岛, 泰国南部; SAT-萨特布拉; SIBU-滇缅马苏地块; T-达鲁岛, 泰国南部; TNC-华北中部带; WDC-达瓦尔西部克拉通; WNC-华北西部地块; XI-熊耳

Fig. 4 The most possible state of the Greater South China Block under Early Paleozoic (450～400Ma) global tectonic framework (revised after Li *et al.*, 2016c)

ARA-Aravalli-Delhi; CIT-Central Indian Terrane; EDC-Eastern Dhawar Craton; EGG-Eastern Ghats Granulite; END-Enderby Land; IC-Indochina; JL-Jiao-Liao-Ji Belt; KIM-Kimberley; M-Peninsular Malaysia (west); MB-McArthur Basin; NEIT-North East India Terrane; PH-Phuket Island, southern Thailand; SAT-Satpura; SIBU-Sibumasu Terrane; T-Tarutao Island, southern Thailand; TNC-Trans-North China Craton Orogen; WDC-Western Dharwar Craton; WNC-Western North China; XI-Xionger

点:1) 沿金沙江-澜沧江-哀牢山-马江一带为古生代连续洋盆(李兴振等,1990),扬子陆块与昌都-普洱-印支陆块发育连续的早古生代加里东期褶皱带-中生代早期增生造山带,表明原特提斯洋与古特提斯洋为连续过渡关系; 2) 昌宁-孟连缝合线可能代表原特提斯洋南部的消减俯冲带(越南马江蛇绿岩等;钟大赉,1998); 3) 位于保山(-羌北)微陆块以北,但没有明确界线,且原特提斯洋盆在晚古生代并没有完全消亡,与古特提斯洋为连续被动陆缘性质过渡(徐旭辉等,2009); 4) 班公湖-怒江缝合线(蔡立国等,1993;潘桂棠等,2004)不是原特提斯洋封闭的产物,近年获得该缝合带中蛇绿岩相关岩石锆石 U-Pb 年龄集中在 221～132Ma 之间(曲晓明等, 2009, 2010; 樊帅权等, 2010; 孙立新等, 2011),证明该洋开启较晚,多数学者对该缝合线几无疑惑。总之,大多数人认为原特提斯洋南部为被动陆缘,并与古特提斯洋为连续过渡关系(高长林等,2005;徐旭辉等, 2009)。

近 5 年来一批更为可靠的岩石学、地球化学资料研究(Zhu *et al.*, 2013)揭示,原特提斯南界在青藏地区并非上述四条缝合带中的任何一条,金沙江-澜沧江-哀牢山-马江一带并非为古生代连续洋盆,其打开较晚,是印支期缝合线, 甚至发育榴辉岩(Zhang *et al.*, 1993)。大量新的蛇绿岩、早古生代花岗岩、高压变质岩分布和年代学资料表明,原特提斯南北两侧也不都是被动陆缘,羌南地块处于活动陆缘(Zhu *et al.*, 2013),因此,原特提斯南界应是位于羌北地块与羌南地块之间,即龙木措-双湖缝合线(Zhu *et al.*, 2013;李才等,

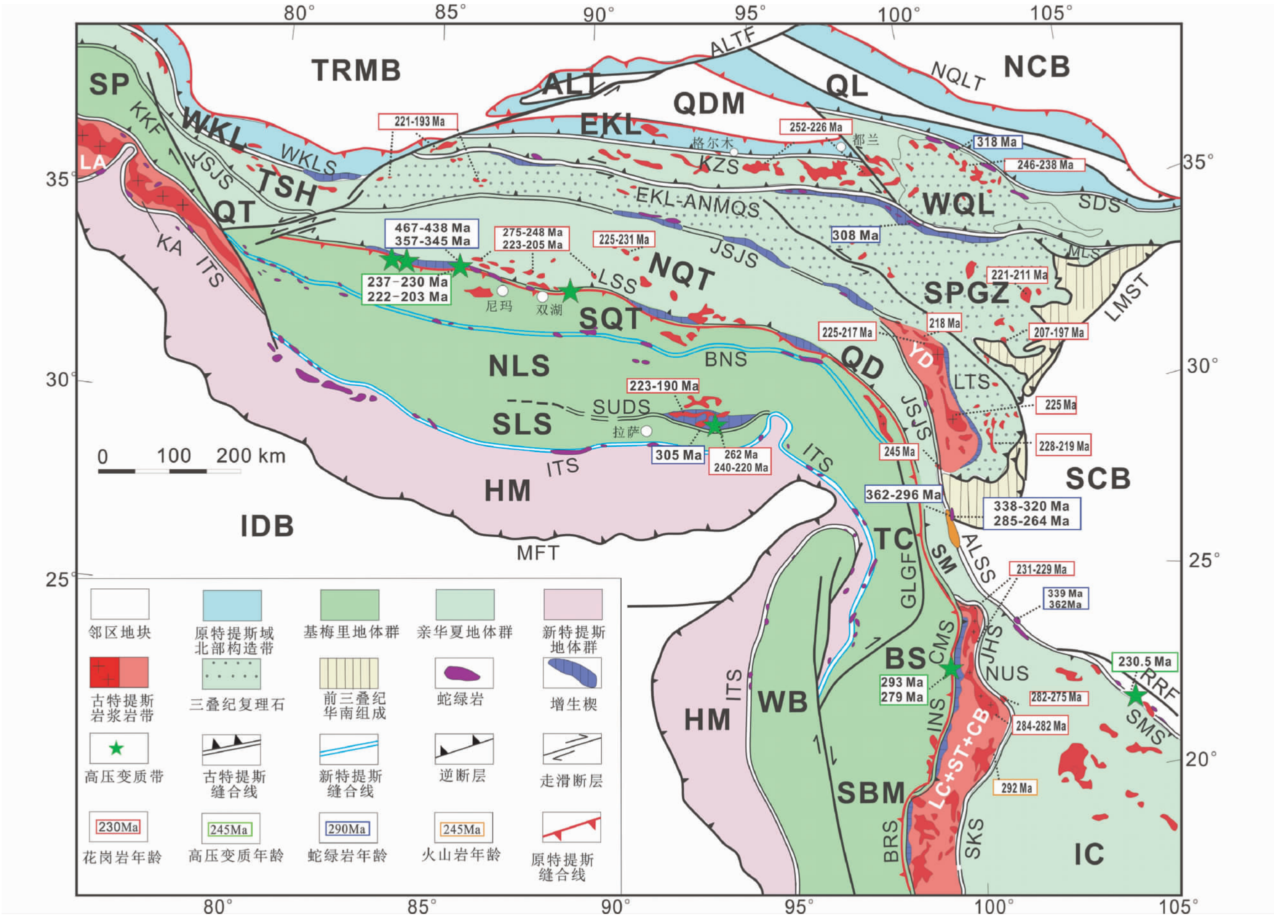


图5　可能的原特提斯域南界与古特提斯域龙木措-双湖-昌宁-孟连缝合线重合(年龄统计和底图据 Xu *et al.*, 2015)

地块或地体: NCB-华北陆块; SCB-华南陆块; TRMB-塔里木陆块; IDB-印度陆块; WQL-西秦岭地体; EKL-东昆仑地体;QDM-柴达木地体; QL-祁连地体; ALT-阿尔金地体; WKL-西昆仑地体; SPGZ-松潘-甘孜地体; NQT-QD-SM-IC-北羌塘-羌多-思茅-印支地体; SQT-BS-SBM-南羌塘-保山-滇缅马苏地体; NLS-北拉萨地体; SLS-南拉萨地体; TC-腾冲地体; TSH-甜水海地体; WB-西缅地体;HM-喜马拉雅地体. 缝合线: SDS-商丹缝合线; KZS-昆中缝合线; MLS-勉略缝合线; EKL-ANMQS-东昆仑-阿尼玛卿缝合线; WKLS-西昆仑缝合线; LTS-理塘缝合线; JSJS-ALS-SMS-金沙江-哀牢山-马江缝合线; LSS-CMS – INS-BRS-龙木措-双湖–昌宁-孟连-Inthanon-缅甸缝合线; JHS-NUS-SKS-景湖- Nan Uttaradit-Sra Kaeo 缝合线; BNS-班公湖-怒江缝合线; SQH-JLS-狮泉河-嘉黎缝合线; SDS-松多缝合线; ITS-印度斯-藏布缝合线. 岛弧型地体:BHDA-Bulhanbuda 岛弧地体; YD-义敦岛弧地体; LC-ST-CBA-临沧-Sukhothai-Chanthaburi 岛弧地体; KA- Kohistan 岛弧地体; LA- Ladakh 岛弧地体. 断裂:ALTF-阿尔金断裂; NQLT-北祁连逆冲断裂; LMST-龙门山逆冲断裂; RRF-红河断裂; KKF-喀喇昆仑断裂; MFT-主前缘断裂; SGF-实皆断裂; GLGF-高黎贡断裂

Fig. 5　Possible southern margin of the Proto-Tethyan Tectonic Domain overlapped by the Longmu Tso Shuanghu-Changning Menglian Suture of the Paleo-Tethyan Tectonic Domain (ages and base map from Xu *et al.*, 2015)

Blocks and terranes: NCB-North China Block; SCB-South China Block; TRMB-Tarim Block; IDB-India Block; WQL-West Qinling terrane; EKL-East Kunlun terrane; QDM-Qaidam terrane; QL-Qilian terrane; ALT-Altyn terrane; WKL-West Kunlun terrane; SPGZ-Songpan-Ganze terrane; NQT-QD-SM-IC-North Qiangtang-Qamdo-Simao-Indochina terrane; SQT-BS-SB-South Qiangtang-Baoshan-Sibumasu terrane; NLS-North Lhasa terrane; SLS-South Lhasa terrane; TC-Tengchong terrane; TSH-Tianshuihai terrane; WB-West Burma terrane; HM-Himalaya terrane. Suture zones: SDS-Shangdan Suture; KZS-Kunzhong Suture; MLS-Mianlue Suture; EKL-ANMQS-East Kunlun-A'nyemaqen Suture; WKLS-West Kunlun Suture; LTS-Litang Suture; JSJS-ALS-SMS-Jinshajiang-Ailaoshan-Song Ma Suture; LSS-CMS-INS-BRS-Longmu Tso Shuanghu-Changning Menglian-Inthanon-Burma Suture; JHS-NUS-SKS-Jinghong-Nan Uttaradit-Sra Kaeo Suture; BNS-Bangonghu-Nujiang Suture; SQH-JLS-Siquanhe-Jiali Suture; SUDS-Sumdo Suture; ITS-Indus-Tsangbo Suture. Arc terranes: BHDA-Bulhanbuda Arc terrane; YD-Yidun Arc terrane; LC-ST-CBA-Lincang-Sukhothai-Chanthaburi Arc terrane; KA-Kohistan Arc terrane; LA-Ladakh arc terrane. Faults: ALTF-Altyn Tagh Fault; NQLT-North Qilian Thrust; LMST-Longmenshan Thrust; RRF-Red River Fault; KKF-Karakurum Fault; MFT-Main Frontal Thrust; SGF-Sagaing Fault; GLGF-Gaoligong Fault

2007; Fan *et al.*, 2015),向南延伸可能与昌宁-孟连缝合线相连(Nie *et al.*, 2015; 图5),整体构成一条安第斯型活动大陆边缘(Zhu *et al.*, 2013)。但是 Zhu *et al.* (2013)将拉萨地块作为南羌塘地块东延部分,因而,其如何与昌宁-孟连缝合线相连又出现问题。无论如何,从龙木措-双湖-昌宁-孟连这一线,都缺乏 400 ~ 380Ma 洋壳、岛弧等地质记录(图1),这一

事实可能表明原特提斯洋沿该带400Ma之前已经封闭,也就是说大华南板块(含扬子、华夏、羌北、若尔盖、布列亚-佳木斯等;李三忠等,2016c)拼合到冈瓦纳北缘,直到380Ma后才重新沿该带打开,形成古特提斯洋;同期,北侧勉略洋也打开,随后才可见367Ma(三岔四方坝)、340Ma左右(德尔尼)、283Ma(略阳庄科)的岛弧型火山岩等记录,其北侧广泛出露印支期220~206Ma的姜家坪、迷坝、张家坝等多类花岗岩(张国伟等,2015),指示印支期向北俯冲关闭。因而,该带也不是前人认为的沿该带原特提斯洋和古特提斯洋是连续俯冲或连续被动陆缘。

在原特提斯洋南、北边界之间,间杂着较多的早古生代陆块/微陆块及诸类型的洋-陆边界。其遗迹除上述主要构造带以外,还有西昆仑构造带内的早古生代各种地质记录(汪玉珍和方锡廉,1987;潘裕生,1989;Yao and Hsü,1994;李永安等,1995;李兴振等,1995;王元龙等,1995;邓万明,1995;丁道桂,1996;李继亮等,1999;姜耀辉等,1999;袁超等,2000;Xu *et al.*, 2005;王炬川等,2006;崔建堂等,2006;Xiao *et al.*, 2009;Sun *et al.*, 2011)、东昆仑构造带内(昆北、昆中和昆南)早古生代各种地质记录(郑健康,1992;徐强,1996;赖绍聪,1997;陈亮等,2000;张国伟等,2001;边千韬等,2001;陈隽璐等,2002;阿成业等,2003;范丽琨等,2009;冯建赟,2010;孙雨,2010)、华夏和扬子陆块间加里东期陆内造山带(刘宝珺等,1990;舒良树等,2008;Shu *et al.*, 2014;Wang *et al.*, 2010)等。现今研究揭示,西昆仑构造带内早古生代蛇绿岩为原特提斯洋向南俯冲产物(Marten and Schneider, 2000);东昆仑构造带内早古生代蛇绿岩年代学研究表明昆中洋盆在400Ma左右已经闭合,从而导致广泛发育400Ma左右变质作用(张建新等,2007),并随后转入伸展阶段(刘彬等,2012)。其南侧出现一系列类似刘岭群的建造,直到380 Ma之后再次沿昆南-阿尼玛卿-勉略构造带打开,并且石炭-二叠纪才出现洋壳,而华南陆内造山带是大华南陆块与冈瓦纳大陆拼合导致的远程效应(李三忠等,2016c)。同时,Yao and Li (2016)称该造山带为武夷-云开造山带,是奥陶纪-早志留世期间华南与冈瓦纳北缘的印度之间发生剪刀式拼合的结果。

总之,通过对原特提斯构造域南界从地表到深层结构的深入研究与确认,结合北部边界的厘定,可实现厘定原特提斯洋范围,以为探讨介于南、北边界之间的陆块/微陆块的拼合动力学机制提供板块边界条件,并为探讨原特提斯洋整体形成演化动力学模式提供约束,同时为查明Pangea超大陆聚合前的早古生代构造背景奠定基础。

## 3 原特提斯洋内涵

前人研究表明,原特提斯洋是一个东西向古大洋,地质记录主要分布于东亚地区,因而迄今还没有形成全球概念的原特提斯洋,对于原特提斯洋的认识始终非常模糊。在Scotese全球重建方案中没有原特提斯洋的概念(Scotese, 2004),而是将古生代大洋统称为古特提斯洋,并将其与西段的亚匹特斯(Iapetus)洋相连。部分学者的全球重建方案虽然体现了原特提斯洋,但仍将亚匹特斯洋与原特提斯洋相连(von Raumer and Stampfli,2008)。

尽管国内大多数学者认为原特提斯洋形成于震旦纪-早古生代,但对中国境内原特提斯洋的空间界定仍存在不同观点:1)原特提斯洋由北部古中亚洋或古亚洲洋(天山-蒙古-兴安主洋盆)、中部秦-祁-昆洋和南部有深水沉积记录的未定名大洋(以滇西和桂西地区为代表)组成(Ren and Xie, 1991;钟大赉,1998;陆松年,2001;郭福祥,2001)。其中古中亚洋被认为是Rodinia超大陆裂解过程产生的原特提斯主洋盆(陆松年,2001;von Raumer and Stampfli,2008);2)原特提斯洋由北部具复杂多岛洋特征的古中国洋(商丹洋为其东部分支)和南部相对干净的主大洋“原特提斯洋”共同构成(高长林等,2005;徐旭辉等,2009);3)原特提斯洋是一个位于华北-塔里木陆块以南、滇缅泰/保山地块以北的复杂大洋(李兴振等,1990;Xiao *et al.*, 2003, 2009)。其中,第三种观点中还存在不同看法,如有人认为原特提斯洋只是指秦-祁-昆洋以南的大洋(高长林等,2005;徐旭辉等,2009);也有人将泛华夏陆块群西南侧及其内部所有早古生代洋盆统称为原特提斯洋(陈智梁,1994;潘桂棠等,1997;许效松等,2004;李文昌等,2010)。迄今,如此众多的原特提斯洋认识必然限制对Pangea东亚聚合前早古生代构造背景理解,急需深化研究。

本文综合近10年来的研究成果发现,Rodinia裂解过程中,华北陆块可能于844Ma后(包志伟等,2008)、阿拉善微陆块可能于950Ma后(耿元生和周喜文,2010)先裂离Rodinia超大陆或冈瓦纳大陆。随后,塔里木-柴达木、阿拉善-敦煌微陆块裂离冈瓦纳大陆北缘,向北漂移,并与从西伯利亚陆块裂离并向南迁移的华北陆块于晚奥陶世-早泥盆世之间或中奥陶世对接(李锦轶等,2012;Xu *et al.*, 2015),形成西方学者称谓的亚洲匈奴地体群(von Raumer and Stampfli,2008)。至此,这个地体群南部形成的小洋盆称作原特提斯洋,北部才是传统称为的古亚洲洋。由此可见,原特提斯洋应当起源于新元古代Rodinia裂解,其洋壳组成可能复杂,中国境内可分为东、西两段,东段包括一部分我们称为原亚洲洋(Proto-Asian Ocean,前人称作古中亚洋)洋壳,可能始于新元古代以前;西段才是新元古代-早古生代新形成的洋壳,并可能与欧洲亚匹特斯洋和后来的瑞克洋(Rheic)相通。随后,该洋自奥陶纪开始闭合,最终使得统一的塔里木-柴达木-敦煌-阿拉善-华北陆块群最终于400Ma前拼合于冈瓦纳北缘(李三忠等,2016a, b, c, d)。380Ma之后,沿原特提斯南界重新打开,出现古特提斯洋。因而,南部原特提斯洋与古特提斯洋不具有连续性。

为此,本文基于前人认识和前述最新进展(李三忠等,2016a, b, c, d)界定原特提斯洋为“起始于新元古代,闭合

于早古生代末期,位于塔里木-华北陆块以南,滇缅马苏/保山微陆块以北,与 Rodinia 超大陆的裂解密切相关的一个古洋盆”。特别强调的是,它不是前人认为的大洋(李兴振等,1990;陈智梁,1994;潘桂棠等,1997;陆松年, 2001;郭福祥,2001;Xiao *et al.*, 2003, 2009;von Raumer and Stampfli,2008;李文昌等,2010),而是一个小洋盆。这个洋盆的开启、闭合及随后相关陆块/微陆块拼贴,导致了东亚乃至全球洋-陆格局的巨大转换(李文昌等,2010),这正是 Pangea 超大陆形成过程的一个重要环节。

## 4 俯冲极性

前人研究表明,原特提斯洋可能存在复杂的俯冲极性。判断古大洋板块消减极性一直是造山带研究中一个难以解决的问题,甚至产生矛盾认识。这是由于可靠构造运动学证据缺乏、洋壳残片属性难于区分、缝合带两侧古陆块和增生体亲缘性难以判断、大地构造单元乱序配置等因素,导致有关洋壳俯冲极性的认识还存在分歧。这些研究差异或缺失严重阻碍了对早古生代陆块/微陆块聚合方式与过程的认识,乃至影响整个原特提斯洋演化认识和 Pangea 超大陆聚合前早古生代地球动力学机制探讨。由于对俯冲极性不同的判断,进而不同学者得出不同的微陆块聚合方式。如,对西昆仑的构造解释就存在开合模式和消减增生模式之争(姜春发等,1992;李向东,1995; 丁道桂,1996;Yao and Hsü,1994;李继亮等, 1999;潘裕生, 2000),阿尔金-柴北缘-北秦岭高压-超高压变质带就有可能代表穿时渐进拼合方式或间断式离散拼合方式(张建新等,2007;刘良等,2009)。

对于华北-塔里木陆块南侧多条早古生代构造带的属性、块体拼合方式和时序同样还存在巨大争论,暗示了其复杂性。这些原特提斯域不同类型的洋-陆边界不仅记录了不同动力学背景和大地构造环境,而且经历了不同程度演化历程。如从南阿尔金经柴北缘到北秦岭的高压-超高压变质带,是否构成同一条巨型高压-超高压变质岩带?代表了早古生代时期简单的南、北两大板块简单穿时的俯冲碰撞作用(杨经绥等,2005;张建新等, 2007)还是可能与多陆块或弧-陆之间的分散式对接碰撞有关(刘良等,2009)?是多个陆块或微陆块依次向北俯冲与塔里木-阿拉善-华北陆块拼贴(Song *et al.*, 2014),还是一次性向南与冈瓦纳大陆拼贴(李三忠等,2016b)?这些问题是早古生代多微陆块拼合方式研究的核心内容,还需要开展构造地质学等方面的深入综合研究。因此,针对原特提斯北部,应集中解决复杂陆块/微陆块拼合时序、方式,这是最终重建 Pangea 超大陆聚合前早期演化的基础。

最新研究揭示,从南阿尔金经柴北缘到北秦岭的高压-超高压变质带并非一条几何形态简单的巨型高压-超高压变质岩带,而是北秦岭高压-超高压变质带西延与北祁连高压-超高压变质带、北阿尔金构造带相连(张建新等,2015);南阿尔金经柴北缘被瓦洪山后期断裂切割,可能转而向东昆仑-祁漫塔格延伸(李三忠等,2016b)。它们共同构成了华北-阿拉善-敦煌-塔里木-柴达木陆块群南缘的一条统一的高压-超高压构造带;第一幕构造变形分析揭示,这条构造带整体向南俯冲(Xiao *et al.*, 2009; Zhao *et al.*, 2015; 李三忠等,2016b),因而这些陆块群与冈瓦纳不同地段拼合方式变得非常简单。沿这个构造带不同地段可以发生陆-陆碰撞,也可能发生洋-陆俯冲-增生。只是在加里东运动后期围绕柴达木微陆块发生了弯山构造,是的祁连-柴达木-东昆仑地区,该高压超高压带变成 3 条。这条“S”型双弯山构造的格局完全可以和西欧华力西期造山带的对比(Shaw and Johnston,2016)。最终,结合前文论述,确定原特提斯域多个陆块/微陆块间的拼合特征就是陆块/微陆块通过俯冲-增生向南拼合到了冈瓦纳大陆北缘(图 4),其时限总体介于 450 ~ 400Ma 之间。特别是,华北陆块在早古生代后期整体抬升运动,而整个中国西部和华南泥盆系与下伏地层的不整合非常普遍(李兴振等,1990;蔡立国等,1993;潘裕生,1994;钟大赉,1998;李兴振和尹福光, 2002;肖序常等,2003;潘桂棠等,2004;徐旭辉等,2009),且下-中泥盆统在中国东南大部地区广泛缺失,标志加里东期造山运动最终结束于志留纪末-泥盆纪初,至此,华南陆内造山带形成(舒良树等,2008;郝义,2010; Wang *et al.*, 2010)。这些都可能表明加里东运动的广泛性和整体聚合性,时间上可以与劳伦古陆上的老红砂岩层角度不整合对比。

但是,也有部分研究认为,华北、华南、塔里木和印支自寒武纪至泥盆纪始终作为一个整体陆块运动(Ziegler *et al.*, 1979),原特提斯洋并不复杂。或认为上述陆块/微陆块实际是一个内部发育多个裂陷的独立而统一的板块,称为西域板块(葛肖虹和刘俊来,1999)。或认为,直至早古生代末,华北、塔里木、扬子、华夏(包括黄海-东海-南海)、柴达木、(昆仑-羌北-昌都-)印支陆块等曾一度拼贴在一起,虽局部保留有坳拉槽和晚古生代连续沉积,但总体已形成具独立性和统一性的泛华夏大陆群(李兴振等,1990;蔡立国等,1993;潘裕生,1994;钟大赉,1998;李兴振和尹福光, 2002;肖序常等,2003;潘桂棠等,2004)。然而,这些结果与现今碎屑锆石年龄谱揭示的块体早古生代的亲缘性存在巨大差异(Yu *et al.*, 2015; Cao *et al.*, 2016)。

## 5 结论

围绕 Pangea 聚合过程中原特提斯洋-陆格局与微陆块早古生代聚合这一核心科学问题,本文以北秦岭、北祁连、中祁连、柴北缘及阿尔金构造带为重点研究对象,采用构造地质学、沉积学、岩石学、元素-同位素地球化学和同位素年代学等综合集成的研究手段,基于现有研究进展,对比上述构造带中已有高压-超高压变质带、蛇绿岩带研究成果和原特提斯域其它构造带特征,得出以下几点新认识:

1)原特提斯洋北界为古洛南-栾川缝合线(或宽坪缝合线)及其西延,南界为龙木措-双湖-昌宁-孟连缝合线。

2)原特提斯洋俯冲极性是整体向南俯冲,最终拼合于冈瓦纳大陆北缘。

**致谢** 近5年来,我们主要集中研究原特提斯洋的演化,本文主要介绍了研究背景、相关进展和初步认识,供专家批评指正。同时,谨以此文祝贺第一作者的导师杨振升教授85华诞。感谢舒良树教授和刘福来研究员提出的宝贵审稿意见。

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