南天山—北山—索伦—长春缝合带的性质与演化

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内容提要: 南天山—北山—索伦—长春缝合带作为古亚洲洋的最终闭合位置,其形成与演化特征一直以来都是中亚造山带相关研究的焦点与热点问题。对于该缝合带形成时代以及俯冲极性等方面的研究,有利于揭示中亚造山带的增生与演化历史,为古亚洲洋构造演化模型的建立提供理论支持。笔者等依据南天山—北山—索伦—长春缝合带内的大地构造背景、构造岩石组成、闭合方式和闭合时代的差异,自西向东将其分为4段:① 南天山缝合带位于缝合带西段,形成于塔里木板块向北俯冲与哈萨克斯坦—伊犁地块发生拼贴的过程中,根据高压变质年龄、钉合岩体以及不整合盖层等证据来综合分析,其闭合时代应为晚石炭世;② 北山缝合带位于缝合带中段,形成于敦煌地块和阿拉善地块向北俯冲与北部图瓦—蒙古板块发生拼贴的过程中,根据带内蛇绿岩的年代学证据限定其闭合时代应为早—中二叠世。阿拉善地块北缘的两条蛇绿岩带作为北山缝合带与索伦—长春缝合带之间的连接带,分别代表了古亚洲洋在该区域闭合时形成的缝合带和弧后盆地,其形成时代应当为中二叠世—晚二叠世早期;③ 索伦—长春缝合带位于缝合带中—东段,古亚洲洋在该地区同时发生了南北两侧的双向俯冲,两侧地块在中二叠世—早三叠世完成拼贴;④长春—延吉缝合带形成于中三叠世前后华北板块与佳木斯—兴凯地块的俯冲增生过程中,其较西侧索伦—长春缝合带的形成时间(270~250 Ma)晚20~30 Ma。因此长春—延吉缝合带与索伦—长春缝合带的形成时代与构造背景存在显著的差异,不属于其东延部分。在上述分析基础上,笔者等认为古亚洲洋沿南天山—北山—索伦—长春缝合带自西向东发生了4个阶段的演化过程,闭合时代自西向东逐渐变年轻,整个过程从晚石炭世一直持续到了三叠世,其中长春—延吉缝合带记录了古亚洲洋和古太平洋构造域叠加与转换的地质过程。

关键词: 中亚造山带;南天山—北山—索伦—长春缝合带;分段演化;俯冲极性;构造域转换

中亚造山带是全球规模最大的增生型造山带(Windley et al., 2007),它西起里海,东临西太平洋北部,位于西伯利亚克拉通、塔里木克拉通和华北克拉通之间,跨度达5500 km,最宽处超过了1100 km(Windley et al., 1990; Şengör et al., 1991; Xiao Wenjiao et al., 2003; Kröner et al., 2007; Jian Ping et al., 2013; 杨高学等,2021)。中亚造山带的演化是一个漫长而又复杂的过程,向前可追溯至~1 Ga(Khain et al., 2002),并一直持续到~250 Ma(Windley et al., 2007; Xiao Wenjiao et al., 2018)。甚至有学者认为直至白垩纪才沿狼山—阴山一线最终闭合(吕洪波等,2018)。近些年来,许多学者对中亚造山带进行了详尽的研究,在构造细分、沉积学、年代学、地球化学、岩浆作用、变质作用、构造变形作用等方面取得了显著的进展(Khain et al., 2003; Wilde, 2003; Demoux et al., 2009; Zhou Jianbo et al., 2010a; Wu Fuyuan et al., 2011a; Kröner et al., 2013; Xiao Wenjiao et al., 2013; Degtyarev et al., 2015; Buriánek et al., 2017; Chen Long et al., 2021)。然而由于缺乏整体性的讨论,学者们对于古亚洲的闭合特征仍然有诸多争议。南天山—北山—索伦—长春缝合带作为中亚造山带最南端的缝合带,它对于限定古亚洲洋的形成和演化特征来说有着非常重要的意义。笔者等依据大地构造背景以及闭合时代的不同,将该缝合带自西向东分为了4段,并依次对其闭合特征进行讨论,从而为揭示中亚造山带的增生与演化历史、构建古亚洲洋的构造演化模型提供理论支持。

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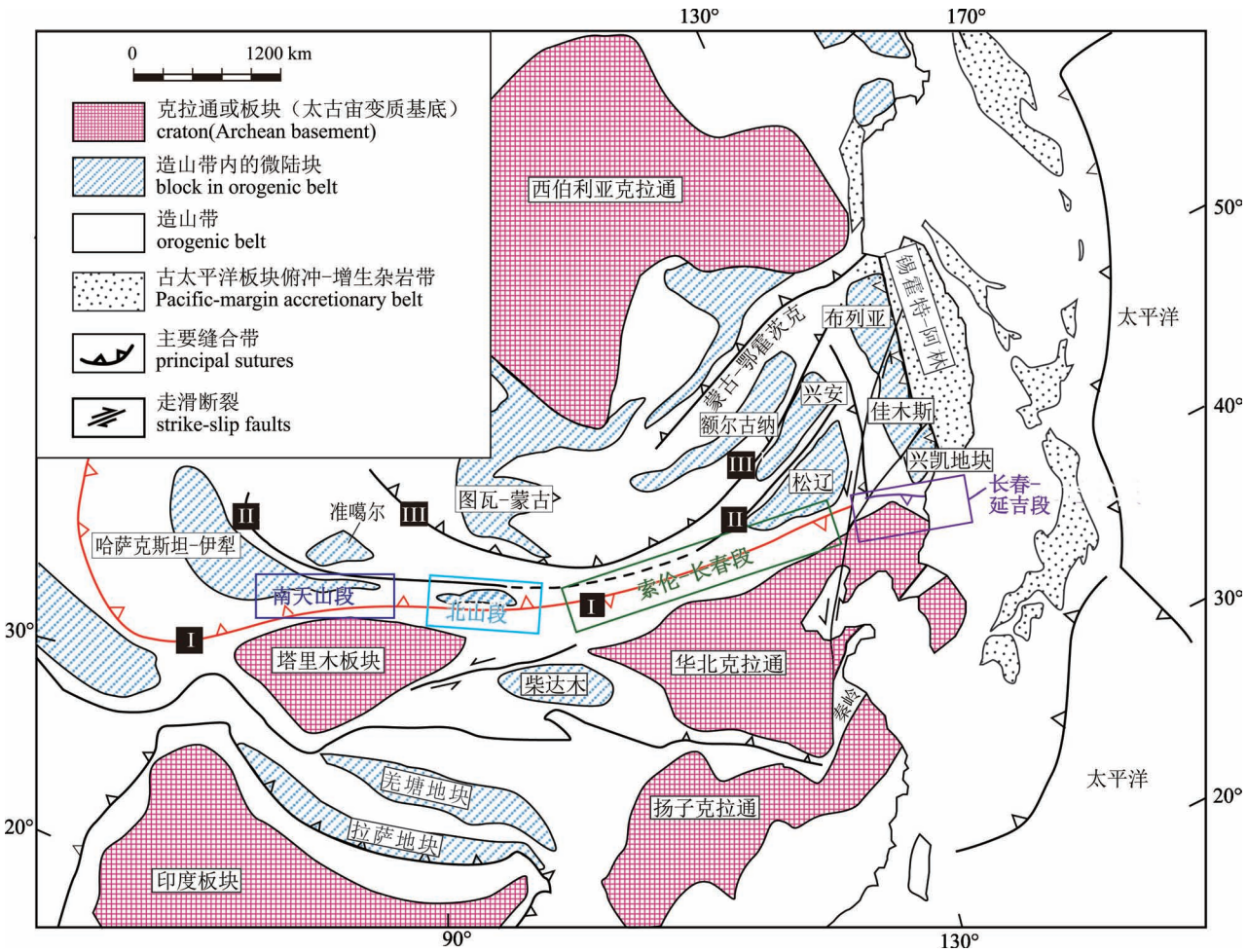

图 1 中东亚主要构造分区示意图(据 Zhou Jianbo et al. , 2018 修改)

Fig. 1 Schematic tectonic map showing the main subdivisions of the central—eastern Asia (modified from Zhou Jianbo et al. , 2018)

主要缝合带:I—南天山—北山—索伦—长春缝合带(SBSC 缝合带);II—北天山—索伦—贺根山—黑河缝合带(NSHH 缝合带);III—额尔齐斯—南蒙古—头道桥—新林缝合带(ESTX 缝合带)

Suture zones: I—South Tianshan Mts. —Beishan Mts. —Solonker—Changchun suture (SBSC suture); II—North Tianshan Mts. —Solonker—Hegen Mts. —Heihe suture (NSHH suture); III—Erqis—South Mongolian—Toudaoqiao—Xinlin suture (ESTX suture)

1 区域构造单元

中亚造山带同世界上其他著名造山带一样,不同学者给予了不同的划分方案。笔者等为了便于论述,在结合前人划分结果的基础上(Zhou Jianbo et al. , 2018),自北向南将其划分为四个主要的拼合块体(图 1):图瓦—蒙古和额尔古纳块体;准噶尔和兴安块体;哈萨克斯坦—伊犁、北山和松辽块体;以及环太平洋的佳木斯—兴凯(布列亚)块体,他们之间存在着 3 条大型缝合带,从北到南依次为:额尔齐斯—南蒙古—头道桥—新林缝合带(ESTX 缝合带)、北天山—索伦—贺根山—黑河缝合带(NSHH 缝合带)和南天山—北山—索伦—长春缝合带(SBSC 缝合带)。南天山—北山—索伦—长春缝合带位于中亚造山带最南端,是古亚洲洋最终闭合的位置所在。

依据大地构造背景以及闭合时代的差异,又可以将南天山—北山—索伦—长春缝合带划分为 4 段(图 1),自西向东依次为:南天山缝合带,北山缝合带,索伦—长春缝合带和长春—延吉缝合带。

2 南天山缝合带

南天山缝合带位于中亚造山带西南缘,呈近东西向延伸,为哈萨克斯坦—伊犁板块与塔里木板块之间长期俯冲—拼贴的产物,是一条由前寒武纪微陆块、古生代岛弧、高压变质岩石和增生楔等共同构

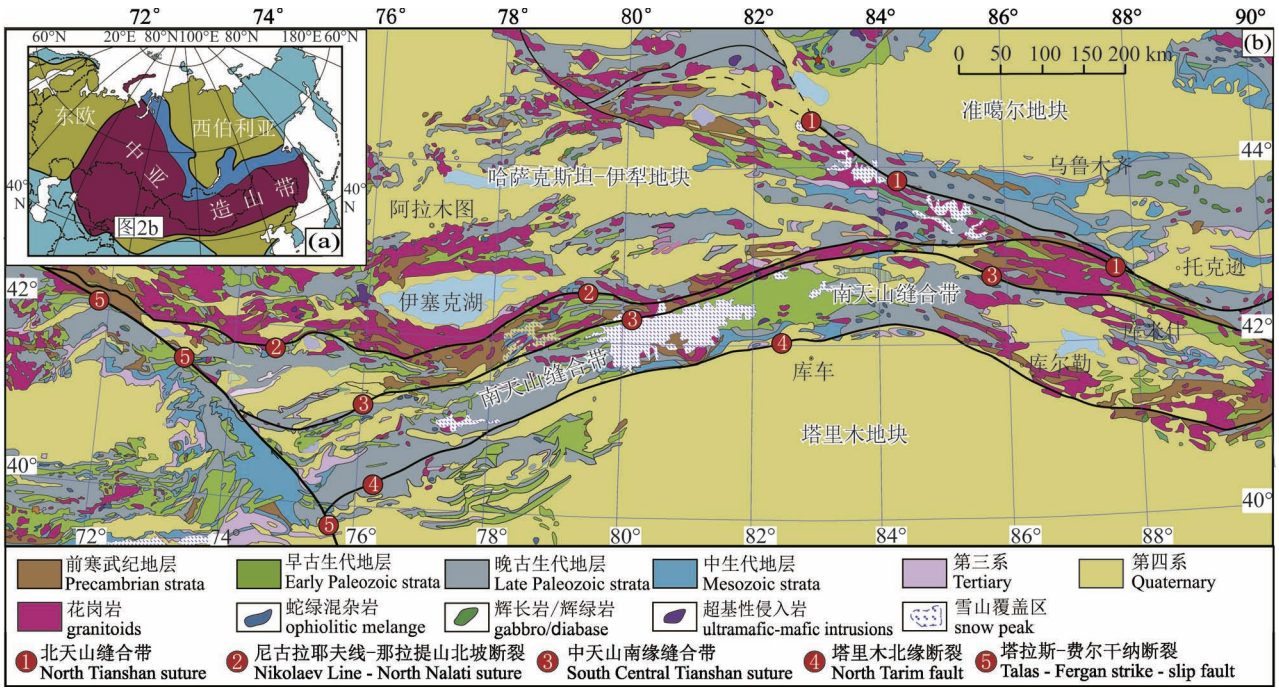

图 2 中亚造山带构造示意图,标注了南天山缝合带的位置(a, 据 Yakubchuk, 2004; Gao Jun et al., 2011 修改)和南天山缝合带及邻区地质图(b, 据高俊等,2009; Gao Jun et al., 2011 修改)

Fig. 2 Tectonic sketch map of the Central Asian Orogenic Belt and the location of South Tianshan Suture (a, modified from Yakubchuk, 2004; Gao Jun et al., 2011) and the geological map of the South Tianshan Suture (b, modified from Gao Jun et al., 2009&, 2011)

成的构造杂岩带(高俊等,2009; Gao Jun et al., 2011; Zhou Jianbo et al., 2018)。南天山缝合带是古亚洲的分支—南天山洋俯冲消亡的产物,以保存大量的榴辉岩和蓝片岩等高压变质岩为特征,它属于南天山—北山—索伦—长春缝合带的西段,代表了古亚洲洋在该区域的最终闭合位置(Gao Jun et al., 2003; 艾永亮等,2005; John et al., 2008; 左国朝等,2008)。

目前学者们对于南天山洋的最终闭合时间存在有争议。部分学者认为其最终闭合于晚泥盆世—早石炭世(Xia Linqi et al., 2008; Xu Xueyi et al., 2013; 白建科等,2015),然而缝合带内 430~330 Ma 蛇绿岩的发现(徐学义等,2006; Jiang Tuo et al., 2014; Li Chao et al., 2015)表明南天山洋在晚志留世—早石炭世期间还未完全关闭。有部分学者认为南天山洋的演化一直持续到了早三叠世,他们对南天山北缘高压变质带内的榴辉岩中的锆石进行了 SHRIMP 定年,获得了 230~220 Ma 的锆石边部年龄值(张立飞等,2005; Zhang Lifei et al., 2007),以及李曰俊等(2002)在南天山西侧发现了被认为来自于晚二叠世的放射虫化石。然而也有学者认为较年轻的锆石的出现可能是由于锆石在后期流体作用下继续生长所造成的(Rasmussen, 2005; Jong et al., 2008),不能代表碰撞造山事件的真正年龄(高俊等,2009)。张立飞等(2013)也随后将南天山榴辉岩的峰期变质年龄修正为 320.0 ± 3.7 Ma,与区域内广泛报道的 310~320 Ma 的榴辉岩变质年龄达成了共识(Su Wen et al., 2010; Klemd et al., 2011; Li Qiuli et al., 2011)。舒良树等(2007)认为晚二叠世放射虫化石由于保存较差,无法准确进行种类鉴定,同样无法作为南天山洋闭合时代判定的依据。

还有部分学者认为南天山洋闭合时代为晚石炭世。上二叠统陆相磨拉石的相关报道(李向东等,2000; 卢华复等,2001)以及古地磁证据(Bazhenov et al., 2003; Wang Bo et al., 2007)证明塔里木板块和哈萨克斯坦—伊犁地块在早二叠世就已经拼合在了一起,自二叠纪开始南天山的区域构造背景由汇聚碰撞变为区域性扩张(李锦轶等,2006),南天山洋的闭合时代应当不晚于二叠世。南天山周围地区还分布着广泛的二叠纪陆相磨拉石沉积记录(王作勋等,1990; 王宝瑜等,1994; Gao Jun et al., 1998),表明南天山地区在二叠纪期间已经由海相

转变为了陆相。分布于南天山地区和塔里木北缘的石炭纪浅海碳酸盐地层沉积被二叠纪硅质碎屑—火山沉积所覆盖(Han Yigui et al., 2016),记录了晚石炭世至二叠纪南天山洋残余洋盆向湖泊河流相过渡的过程。Gao Jun 等(2011)报道了在南天山中部发现的年龄为 285 Ma 的花岗岩岩脉,其切割了南天山洋在俯冲过程中所形成的高压—低温变质围岩,地球化学数据显示其形成于碰撞后地壳折返过程中,表明南天山洋的闭合应当发生在二叠纪之前。南天山长阿吾子地区在峰期榴辉岩相变质之后发生了广泛的异剥钙榴岩化(Li Xuping et al., 2007),后者的退变质年龄为 291 Ma(高俊等,2006),限定了南天山缝合带形成于早二叠世之前。在南天山高压变质岩中获得的 335~310 Ma 的白云母 Ar—Ar 坪年龄(高俊等,2006)和 313~302 Ma 的白云母全岩等时线年龄(Klemd et al., 2005),代表了高压变质岩折返到浅构造层次(蓝片岩相)的时间。笔者等支持南天山洋在晚石炭世闭合的观点,随后南天山地区进入到了后造山演化阶段。

对于南天山洋的俯冲极性存在有两种观点:一些学者根据区域性构造特征如不整合等主张哈萨克斯坦—伊犁板块发生了南向俯冲(Charvet et al., 2011; Wang Bo et al., 2011; Lin Wei et al., 2013; Alexeiev et al., 2015);另外一些学者则主张塔里木板块发生了北向俯冲(Windley et al., 1990; Gao Jun et al., 2008; Han Baofu et al., 2011; Xiao Wenjiao et al., 2013; Han Yigui et al., 2016)。区域地质特征显示,在泥盆世—晚石炭世期间,塔里木板块北缘主要为被动大陆边缘环境,以沉积岩为主,罕见弧岩浆作用(Xiao Wenjiao et al., 2013);而同时期北侧的伊犁—中天山地块内发育有广泛的弧岩浆作用(Han Yigui et al., 2016)和大面积的增生杂岩(高俊等,2009),并随后发生了 LP—HT 麻粒岩相变质作用(Lü Zeng et al., 2012; Zhang Lifei et al., 2013),这是塔里木板块北向俯冲的产物。因此我们认为在南天山洋闭合过程中,塔里木板块发生了北向俯冲。

3 北山缝合带

北山缝合带属于南天山—北山—索伦—长春缝合带中段,东侧以巴丹吉林沙漠为界与兴蒙造山带相接,西侧以星星峡断裂为界与中天山相接,北侧为图瓦—蒙古板块,南侧为敦煌地块,东南部为阿拉善地块(图 3;刘雪亚等,1995; Song Dongfang et al., 2014; 牛亚卓等,2018; 辛后田等,2020)。北山缝合带最初被认为是中天山的东延部分(李春昱,1980; 刘雪亚等,1995),然而现在许多学者认为北山是一个独立的地质单元,是不同类型和不用时期岩石混杂在一起而形成的杂岩体(Xiao Wenjiao et al., 2010a; Song Dongfang et al., 2013a; Liu Qian et al., 2015)。北山缝合带从寒武纪开始便开始了漫长的俯冲增生造山过程(Xiao Wenjiao et al., 2010a; Song Dongfang et al., 2015),具有多旋回复合造山带的特点(龚全胜等,2002; 聂凤军, 2002)。

在北山缝合带内分布着四条蛇绿混杂岩带,自北向南依次为:红石山—百合山蛇绿混杂岩带、芨芨台子—石板井—小黄山蛇绿混杂岩带、红柳河—牛圈子—洗肠井蛇绿混杂岩带、辉铜山(柳园)—帐房山蛇绿混杂岩带,它们的形成时代差异较大,引起了学者们对于北山缝合带演化特征的广泛讨论。左国朝等(1990)认为芨芨台子—石板井—小黄山一线分布的早古生代蛇绿混杂岩代表了早古生代缝合带的位置,北山地区古洋盆在志留纪末至早泥盆世就已经闭合了。但是该构造带中辉长岩的最新同位素年龄研究显示该蛇绿岩形成年代为早石炭世(Wu Tairan et al., 2011b; 李向民等,2012),且布格重力异常(孟令顺等,1995; 李治等,2019)和磁测数据(余钦范等,1995)显示其可能是一条深大断裂而不是缝合带,因此该带可能与晚古生代后碰撞运动时期的陆内伸展作用有关(Xia Linqi et al., 2003, 2004, 2005)。红柳河—牛圈子—洗肠井蛇绿混杂岩带内辉长岩年龄为 536~520 Ma (Cleven et al., 2015; Shi Yuruo et al., 2018),杨合群等(2008, 2010)和孙立新等(2017)认为该带代表了早古生代北山洋最终的闭合位置,同时也认为较为年轻的红石山—百合山、柳园—账房山混杂岩带并不代表缝合带的位置,它们可能形成处于初始小洋盆形成之前"红海型"海槽环境下(杨合群等,2010)。然而从北山周围地区的大地构造演化特征来看,北山西部的南天山缝合带和东部的索伦—长春缝合带均被认为是晚古生代—早中生代的板块拼贴的产物(Gao Jun et al., 2003; Xiao Wenjiao et al., 2003, 2008, 2010b; Zhang Lifei et al., 2005),北山洋在早古生代完全闭合的观点则难以解释这一奇怪的现象,因此现在越来越多的学者认为早古生代并不是北山地区古大洋的最终拼合年代,北山缝合带是多期次碰撞拼合的产物(Xiao Wenjiao et al., 2010a; Song Dongfang et al., 2013a, b; Guo Qianqian et al.,

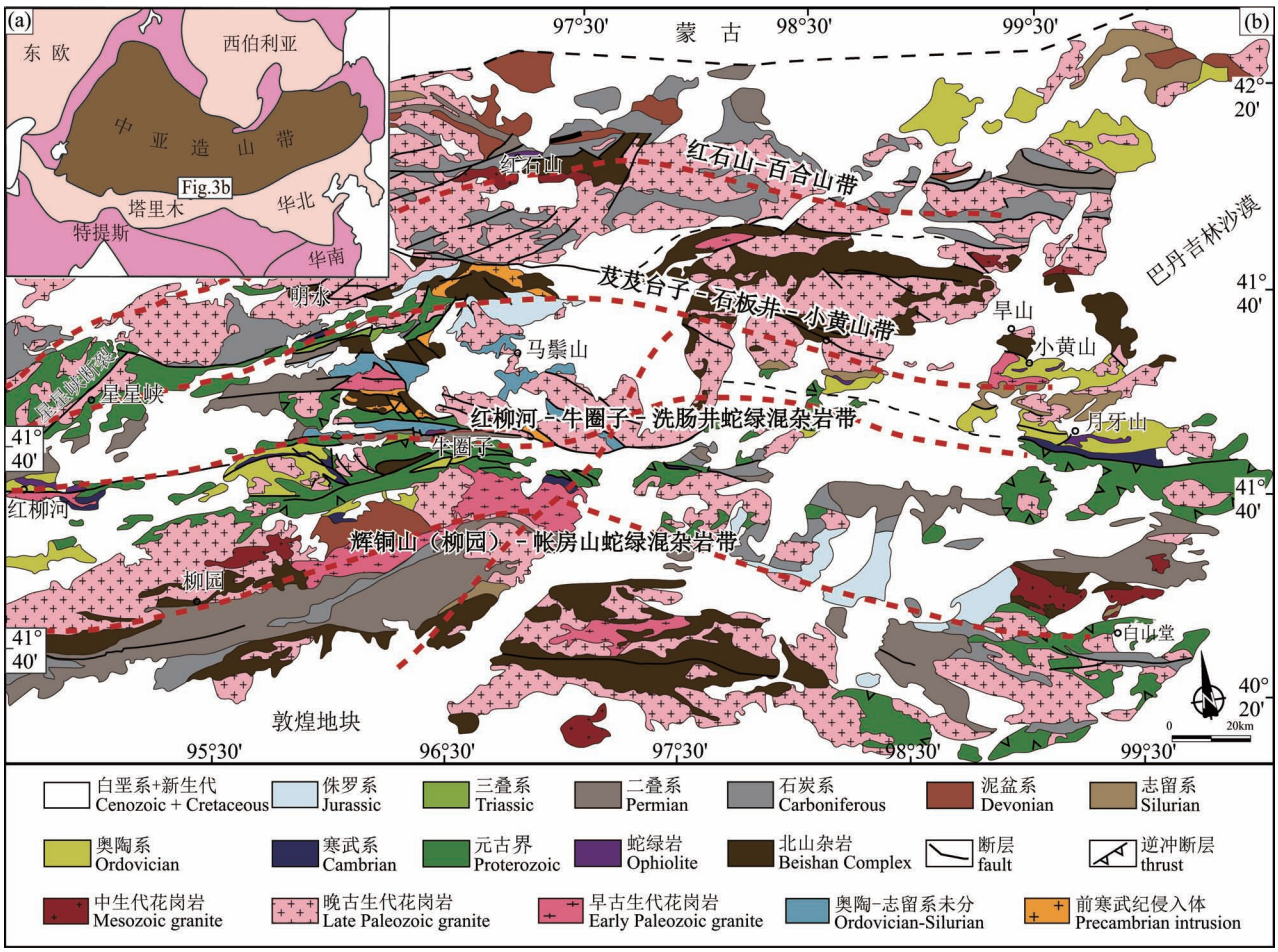

图 3 中亚造山带构造示意图,标注了北山缝合带的位置(a, 据王国强等,2021 修改)和北山缝合带区域地质图(b,据 Song Dongfang et al. , 2014 修改)

Fig. 3 Tectonic sketch map of the Central Asian Orogenic Belt and the location of the Beishan Suture (a, modified from Wang Guoqiang et al. , 2021&) and the geological map of the Beishan Suture (b, modified from Song Dongfang et al. , 2014)

2014; Tian Zhonghua et al. , 2014)。我们认为较晚形成的红石山—百合山蛇绿杂岩带和辉铜山(柳园)—帐房山蛇绿杂岩带可能代表着古亚洲洋在北山地区的最终闭合位置。

红石山—百合山蛇绿岩带位于北山北侧,黄增保等(2006a)对红石山—百合山带内的变质基性岩进行了测定,其地球化学特征显示其形成于洋中脊环境,来源于亏损的软流圈地幔,且具有密集的重力梯度带和局部磁力高异常,符合分割两个大陆缝合带的地球物理特征(何世平等,2002),地理上该带南侧为华南生物地理区,北侧为安加拉植物区(王元龙等,2001),符合板块缝合带的地理学特征。红石山蛇绿岩带普遍被认为形成于晚石炭世—二叠纪(龚全胜等, 2002; 魏志军等, 2004; 黄增保等, 2006a, b),红石山—百合山地区蛇绿岩混杂岩中的斜长花岗岩年龄为 297.3 ± 1.5 Ma(牛文超等, 2019),橄榄辉长岩的锆石加权平均年龄为 281.8 ± 2.6 Ma(Ao Songjian et al. , 2010),附近坡北地区蛇绿杂岩锆石年龄为 280~270 Ma(姜常义等, 2006; 李华芹等,2006),可见红石山地区较为年轻的蛇绿杂岩主要集中在早二叠世。根据造山带中最年轻的蛇绿混杂岩代表了洋盆最终的闭合位置与闭合时间理论(李继亮, 2004; 肖文交等,2019),红石山洋的闭合时间应当为早—中二叠世。

辉铜山(柳园)—帐房山蛇绿岩带位于北山南侧,其中柳园地区辉长岩锆石 U-Pb 加权平均年龄为 286 ± 2 Ma (Mao Qigui et al. , 2011),272.7 ± 4.4 Ma 和 291.4 ± 4.9 Ma(Zhang Yuanyuan et al. , 2011),上覆流纹岩的年龄为 277 ± 4 Ma(Wang et al. , 2016b),柳园枕状玄武岩内发现有煌斑岩侵入

体,其侵入时间为 240~220 Ma,代表了岩浆岩源区由亏损地幔向富集地幔的转变(刘畅等,2006),柳园地区所有火山岩均被上二叠统—下三叠统砂岩不整合覆盖(Wang Yu et al., 2016b),因此该蛇绿岩带同样也被认为形成于早—中二叠世(Xiao Wenjiao et al., 2010a, 2015; Mao Qigui et al., 2011)。北山地区在晚石炭世同时存在有红石山洋和柳园洋两个古洋盆(Xiao Wenjiao et al., 2010a),古亚洲洋北山段的完全闭合发生在早—中二叠世。

阿拉善地块位于北山缝合带东南部,其通常被认为是华北板块的西段。在阿拉善地块北缘发育有两条主要的蛇绿混杂岩带:恩格尔乌苏混杂岩带与查干楚鲁混杂岩带,他们分别沿恩格尔乌苏断裂带和巴丹吉林断裂带呈北东东向延伸,是连接北山缝合带和索伦—长春缝合带的过渡带(Xiao Wenjiao et al., 2018),前者被认为代表了古亚洲洋在该地区主要缝合线的位置,后者则代表着弧后盆地(Zheng Rongguo et al., 2014),二者对于约束古亚洲洋的闭合特征有着重要的意义。恩格尔乌苏蛇绿混杂岩带主要由碳酸盐岩基质以及辉长岩、玄武岩等镁铁—超镁铁质岩构造块体所组成,从玄武岩中获得的锆石 U-Pb 年龄为 302±14 Ma。查干楚鲁蛇绿混杂岩带主要由微碎屑岩基质以及辉长岩、超镁铁质岩构造块体所组成,从辉长岩样本中获得的锆石 U-Pb 年龄为 275±3 Ma(Zheng Rongguo et al., 2014)。结合从恩格尔乌苏蛇绿混杂岩带中发现的中二叠世晚期放射虫化石证据(谢力等,2014),以及区域内指示碰撞后伸展构造环境的中—晚二叠世钙碱性花岗岩证据(Chen Yan et al., 2021; Hui Jie et al., 2021),我们认为古亚洲洋在阿拉善地块北缘的俯冲闭合活动可能持续到了中二叠世—晚二叠世早期。

据前人研究结果显示,古亚洲洋北山段的闭合是南侧敦煌地块与阿拉善地块发生了向北的俯冲所导致的。在北山地区自南向北依次发育有牛圈子—洗肠井蛇绿岩带、勒巴泉变质杂岩和公婆泉群火山碎屑岩,它们代表着敦煌地块向北俯冲过程中形成的洋壳残片、弧前增生杂岩和岩浆弧(Song Dongfang et al., 2014, 2015)。宋东方等(2018)观察到北山地区的韧性变形事件自北向南逐渐变年轻,这是地体在北向俯冲过程中,其边缘不断发生增生作用所导致的。此外,北山地区的地球物理剖面显示该地区的大部分逆冲断层均为向南推覆的趋势(Xiao Wenjiao et al., 2010a),同样表明在北山洋的闭合过程中,南侧陆块发生了向北的俯冲。

4 索伦—长春缝合带

索伦—长春缝合带位于南天山—北山—索伦—长春缝合带的中—东段,它被三个构造单元所包围,北侧为西伯利亚板块,南侧为华北板块,东侧为东北陆块群(图 4; Natalin, 1991; Şengör et al., 1993; Jahn et al., 2000; Li Jinyi, 2006),它西侧与北山缝合带相接,东部可一直延伸至东北陆块群之内,北侧为一条长达数千千米的超岩石圈深大断裂带:西拉木伦河断裂带,南侧通过一条增生杂岩带与华北板块相接(李益龙等, 2009; Xiao Wenjiao et al., 2003)。该地区邻近古亚洲洋构造域和古太平洋构造域的交汇部位,对于两大构造域的启动、终止和转换等方面的研究来说都极为重要。

对于该地区缝合带的具体位置,目前人们存在有争议。部分学者认为贺根山—黑河断裂带代表了该地区的最终缝合带,古亚洲洋沿该断裂带最终发生闭合(Zhang Yunping et al., 1989; Mueller et al., 1991; Zorin, 1999; Kravchinsky et al., 2002)。然而东北地区发生了广泛的 500 Ma 左右的泛非期高级变质事件,而类似的变质事件在华北板块和华南板块中没有出现,中国东北地区的构造属性不同于华北和华南板块的构造属性。贺根山—黑河断裂带作为松辽地块和兴安地块之间的断裂带,应当只是东北陆块群内部的断裂带,而不具有板块缝合带的属性(周建波等,2012; Zhou Jianbo et al., 2013)。在贺根山蛇绿岩带南侧发现的海相地层(尚庆华,2004)和在西拉木伦河北岸发现的远洋古生物化石(王玉净等,1997)也能证明真正缝合带的位置应当在更南的索伦—长春一带。板块缝合带还应当具有生物种群分割线的特征,这一点在索伦缝合带两侧的生物分布特征中得到了体现(孙跃武等,2018)。因此大部分学者认为索伦—长春缝合带才是华北板块和西伯利亚板块间的缝合带(Wang Quan et al., 1986; Xiao Wenjiao et al., 2003; Wu Fuyuan et al., 2007; Jian Ping et al., 2008; Miao Laicheng et al., 2008; Chen Bin et al., 2009; Zhang Xiaohui et al., 2009)。

对于索伦—长春缝合带的闭合时间同样存在争议,具体包括泥盆—早石炭世(Tang Kedong, 1990; 邵济安, 1991; Hong Dawei et al., 1995; 徐备等, 1997)、二叠—三叠纪(Şengör et al., 1993; Robinson et al., 1999; Badarch et al., 2002; Xiao Wenjiao et

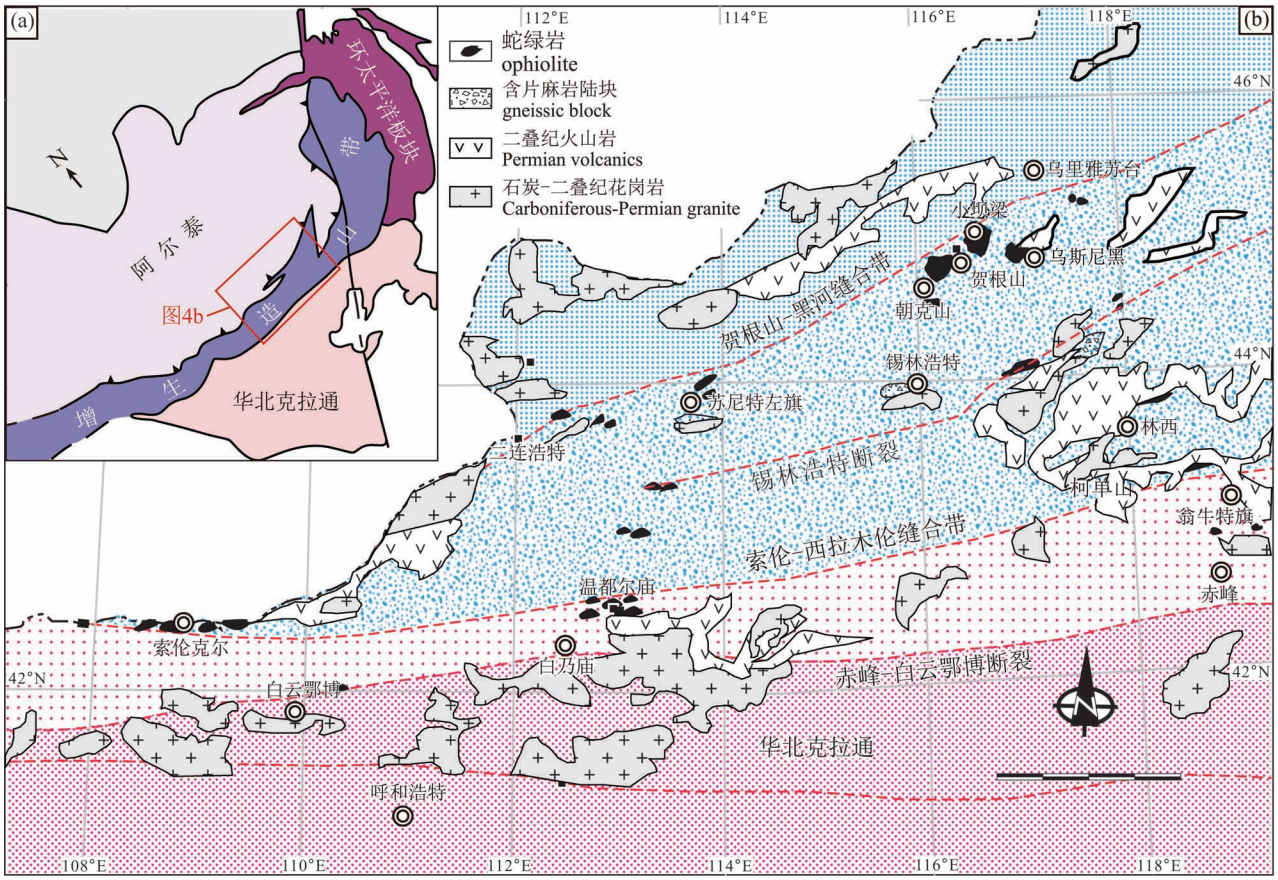

图 4 中亚造山带大地构造背景图,标注了索伦—长春缝合带的位置(a, 据 Şengör, 1996; Han Jie et al., 2017b 修改)及索伦—长春缝合带区域地质图(b, 据 Xiao Wenjiao et al., 2003; Han Jie et al., 2017a 修改)

Fig. 4 Tectonic sketch map of the Central Asian Orogenic Belt and the location of Solonker—Changchun Suture (a, modified from Şengör, 1996; Han Jie et al., 2017b) and the regional geological map of the Solonker—Changchun Suture(b, modified from Xiao Wenjiao et al., 2003; Han Jie et al., 2017a)

al., 2003; 王競繁等, 2021)、中生代中期(Nozaka et al., 2002)等不同的认识。据前人研究资料显示,在早二叠世,区域内岩浆弧活动发育(Xiao Wenjiao et al., 2003; Zhang Shuanhong et al., 2009; 张拴宏等, 2010; Shi Yuruo et al., 2016; Yuan Lingling et al., 2016; Tian Dexin et al., 2018; Wei Ruihua et al., 2018),沉积相主要以海相和浅海相为主(朱俊宾, 2015, 2017; Eizenhofer et al., 2018),表明此时古亚洲洋仍然处于俯冲消减阶段,并未完全闭合。进入晚二叠世后,区域内进入了洋陆转换阶段,南北两侧的板块开始发生拼贴,在晚二叠世—早三叠世缝合带北部地区开始有华北板块物源记录(赵英利等,2016),在早—中三叠世区域内由海相沉积转变为了湖泊河流和冲积扇等陆相沉积(Li Shan et al., 2014; 朱俊宾, 2015, 2017)。在中—晚三叠世,区域沉积相全部为陆相沉积(Li Shan et al., 2014),伸展盆地发育,华北克拉通岩石圈发生减薄(Yang Jinhui et al., 2008),这些证据指示此时区域内已经进入了后造山运动时期。

沿索伦—长春缝合带一线分布有一系列的蛇绿杂岩,其中索伦地区弧前火山岩中的辉绿岩的年龄区间为 274~250 Ma(Jian Ping et al., 2010),堆晶辉长岩的锆石年龄为 279 ± 10 Ma(Miao Laicheng et al., 2007, 2008)。温都尔庙地区出露有 260 Ma 的枕状玄武岩(Miao Laicheng et al., 2007),变质基性岩中较年轻的锆石加权平均年龄为 246 ± 3 Ma(Chu Hang et al., 2013)。内蒙古东部五道石门枕状玄武岩谐和年龄为 277 ± 3 Ma(王炎阳等, 2014),半砬山堆晶辉长岩年龄为 256 ± 3 Ma(Miao Laicheng et al., 2007, 2008)。以上证据表明索伦—长春缝合带的形成时间可能为中二叠世—早三叠世。Xiao Wenjiao 等(2003)进一步指出,在晚二

叠世古亚洲洋东段仍然有安第斯型岩浆活动的痕迹,同时区域内缺乏三叠纪的沉积记录(内蒙古地质矿产局, 1991),这可能与三叠纪区域内的碰撞隆升活动有关。此外,种种证据表明在索伦—长春缝合带形成过程中,西段的形成时间要略早于东段:源区为增厚地壳的高 Sr/Y 碰撞花岗岩在西段的年龄(264~256 Ma,柳长峰等,2011)要早于东段(251~245 Ma,Li Shan et al., 2017);西段岩浆活动的年龄峰值要早于东段(吴迪迪等,2021);沉积记录显示深海相沉积记录在东段地区持续的时间比西段久(赵英利等,2016);古地磁数据亦显示在二叠纪晚期松辽地体和华北板块之间的纬度差在逐渐缩小(Ren Qiang et al., 2020)。因此,我们认为索伦—长春缝合带在中二叠世—早三叠世发生了闭合。

关于古亚洲洋东段的俯冲极性,目前主要有两种争议:一部分学者认为其发生了向南的俯冲,在缝合带北侧发育有双峰式火山作用(Li Jinyi, 2006; Jian Ping et al., 2008, 2010);另外一部分学者认为沿索伦—长春缝合带发生了双向俯冲,缝合带两侧的南、北增生带最终于晚古生代发生拼合 (Xiao Wenjiao et al., 2003, 2015; Eizenhoefer et al., 2014; Eizenhofer and Zhao Guochun, 2018; Song Dongfang et al., 2021)。经过综合分析,我们支持第二种观点。首先,在研究区内没有明显的逆冲推覆和地壳增厚现象,也没有高压麻粒岩相变质作用的相关报道 (Song Shuguang et al., 2016),该特征更加符合"软碰撞"模式,在该模式中不存在有被动大陆边缘,大洋岩石圈两侧均发育俯冲带 (Draut and Clift, 2001, 2013)。其次,在缝合带两侧发育有大量的蛇绿混杂岩,记录了该地区的双向俯冲作用过程,但是,北侧蛇绿混杂岩的年龄多集中在石炭世(Miao Laicheng et al., 2007, 2008; Chen Bin et al., 2009; Zhang Shuanhong et al., 2014; Zhou Jianbo et al., 2015; Pei Shenghui et al., 2016; Song Shuguang et al., 2016),而南侧蛇绿混杂岩的年龄多集中在中二叠世—早三叠世(Miao Laicheng et al., 2007, 2008; Jian Ping et al., 2010; Song Shuguang et al., 2016),二者之间相差大约 50 Ma, 推测这可能是由于南向俯冲结束时间稍晚于北向俯冲所致。

5 长春—延吉缝合带

长春—延吉缝合带也被称之为长春—延吉增生杂岩带,它呈北西—南东向延伸,是佳木斯—兴凯地块与华北板块之间的一条典型的增生杂岩带(图 5; Zhou Jianbo et al., 2013)。它处于中亚造山带的最东缘,既受到古亚洲洋构造域的影响(Şengör, 1996; Wu Fuyuan et al., 2002; Windley et al., 2007; Zhou Jianbo et al., 2013; Kröner et al., 2014),又受到了古太平洋构造域的叠加影响(Faure et al., 1992; Maruyama, 1997; 任纪舜等, 1999; Wilde et al., 2003; Zhou Jianbo et al., 2009, 2010c),是研究古亚洲洋和古太平洋构造域叠加转换过程的关键区域。

呼兰群杂岩、色洛河群杂岩、青龙村群杂岩和开山屯杂岩是沿长春—延吉缝合带自西向东出露的典型增生杂岩(周建波等,2013,2020; Zhou Jianbo et al., 2017),它们由不同时代和不同性质的岩石混杂而成(Wu Fuyuan et al., 2007, 2011a),以发育高压变质矿物组合为特征,能为我们提供板块俯冲活动的关键信息(周建波等,2020)。呼兰群杂岩中的碎屑沉积物的年龄为 287~237 Ma(Wu Fuyuan et al., 2007; 张春艳等,2009; Lu Linsu et al., 2011; 周建波等,2013; Cao Jialin et al., 2019),其中最年轻的是从烟筒山红帘石片岩中获得的 237±5 Ma 的原岩年龄(Cao Jialin et al., 2019),而该地区变质岩的变质年龄区间为 229~188 Ma(郗爱华等,2003; 刘金玉等,2010; 刘志宏等,2016),以上数据表明呼兰群杂岩主要受二叠纪—早三叠世构造活动的影响。色洛河群杂岩中碎屑沉积物的年龄为 265~255 Ma(Zhang Yanbin et al., 2008; Zhou Jianbo et al., 2013),与板块俯冲有关的高镁安山岩的年龄为 252 ± 5 Ma(李承东等,2007),表明色洛河群杂岩应当形成于晚二叠世—早三叠世。青龙村群变质岩的原岩年龄为 250~248 Ma(周建波等,2013),开山屯杂岩中碎屑锆石的年龄为 292~234 Ma(周建波等,2013),表明它们均形成于早三叠世。此外,在烟筒山红帘石片岩中发现的未变质长英质侵入体的加权平均年龄为 217 ± 5 Ma(Cao Jialin et al., 2019),限定了俯冲活动年龄的上限。增生杂岩带上覆大酱缸组地层中发育有指示陆相沉积的磨拉石建造(辛玉莲等,2011),从中获得的最年轻锆石加权平均年龄为 225 ± 1 Ma(图 6b;Wang Bin et al., 2016a),表明长春—延吉地区的古洋盆在晚三叠世就已经关闭了,结合大酱缸组中发现的晚三叠世陆相植物化石(辛玉莲等,2011),进而我们认为长春—延吉缝合带的的形成时代应当在中三叠纪前后(220 ~ 240 Ma)。

长春—延吉缝合带传统上被认为是索伦—长春

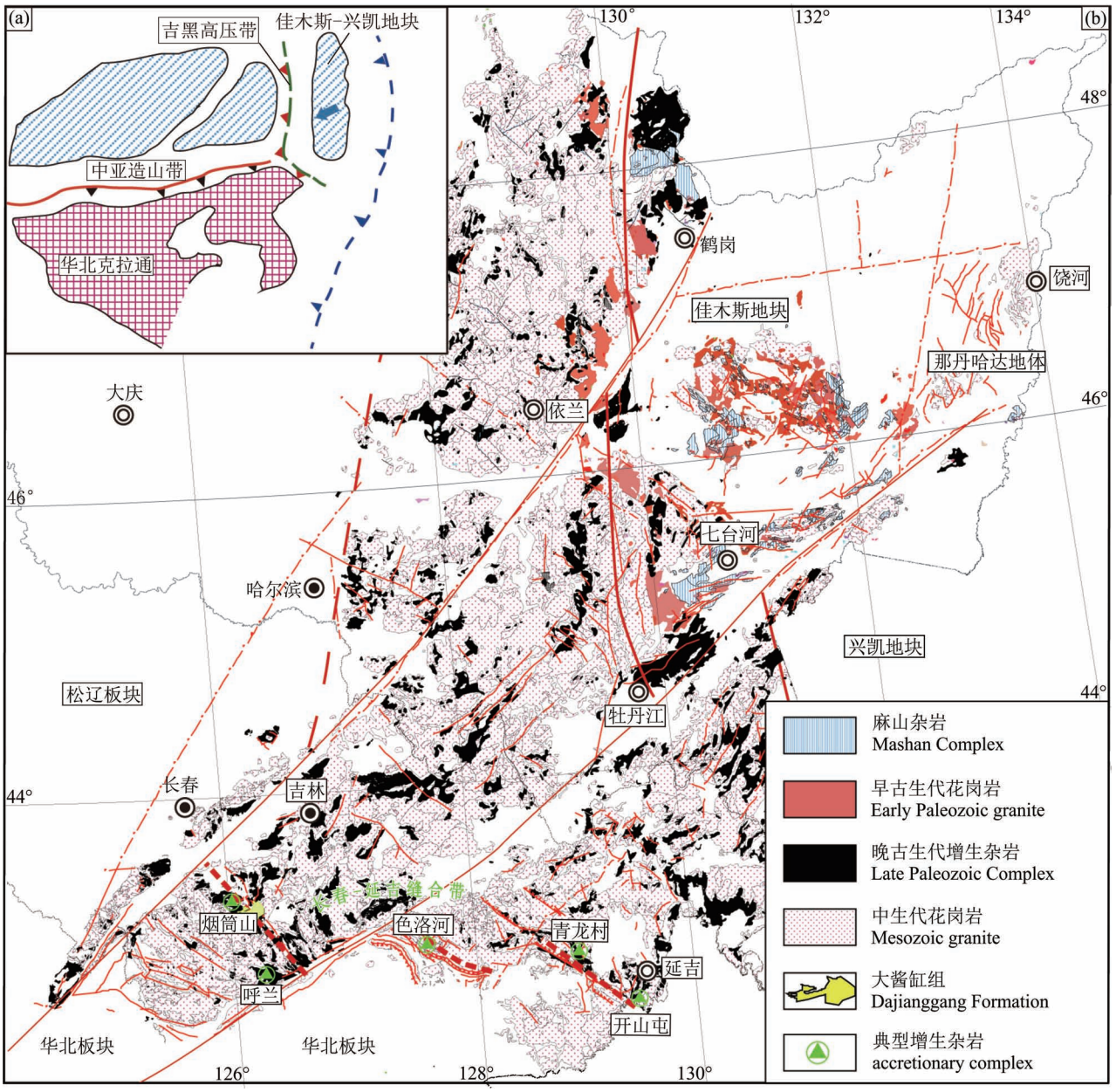

图 5 长春—延吉缝合带构造地质图,标注了主要增生杂岩的名称与位置(据周建波等,2013 修改)

Fig. 5 The regional geological map of the Changchun—Yanji Suture and showing the location of major accretionary complex (modified from Zhou Jianbo et al., 2013&)

缝合带的东延部分(吉林省地质矿产局, 1988; 唐克东等,1995; 王玉净等,1997; Li Jinyi, 2006; Wu Fuyuan et al., 2007),属于古亚洲洋闭合的产物。然而最新的研究观点认为,长春—延吉缝合带是佳木斯—兴凯地块受到古太平洋构造域影响,与华北板块发生拼贴的产物,其形成时代较西侧的索伦—长春缝合带的年龄(270~250 Ma)要晚 20~30 Ma (Zhou Jianbo et al., 2009, 2010b, 2014),因此长春—延吉缝合带记录了古亚洲洋和古太平洋构造域叠加与转换的地质过程(图 7a,b)。

6　结论

南天山—北山—索伦—长春缝合带位于塔里木—中朝地块与西伯利亚地块之间,为两大板块之间古亚洲洋的最终闭合位置所在,依据缝合带两侧的大地构造背景、构造岩石组成、闭合方式和闭合时代的差异,自西向东将该缝合带分为四段:南天山缝合带位于缝合带西段,形成于塔里木板块向北俯冲

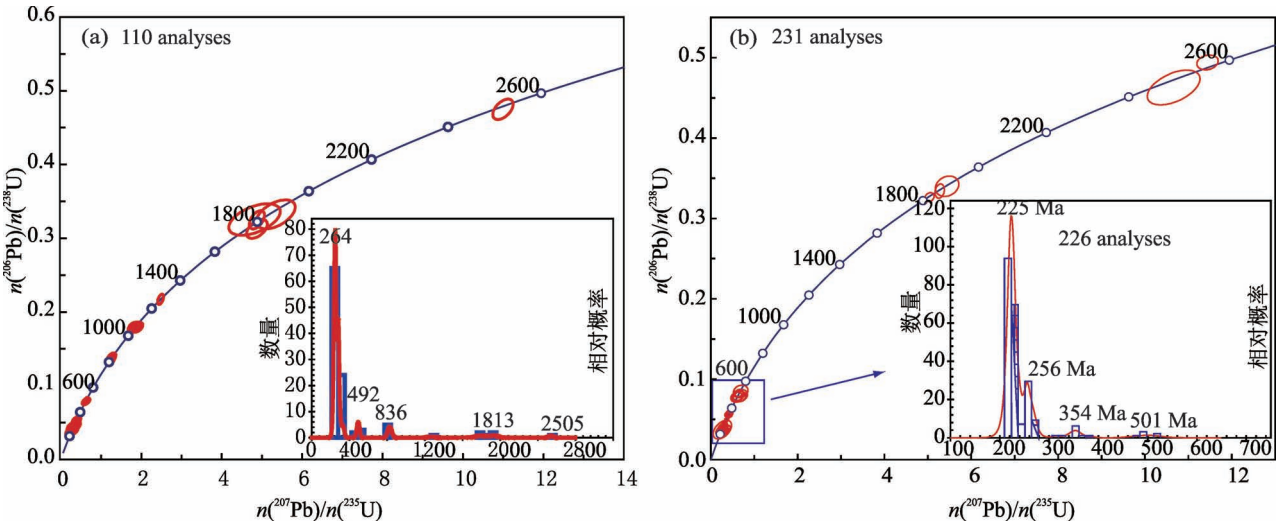

图 6 烟筒山杂岩锆石谐和年龄谱(a，据 Cao Jialin et al.，2019 修改)和大酱缸组磨拉石谐和年龄锆石 U-Pb 年龄谐和图与概率图(b，据 Wang Bin et al.，2016a 修改)

Fig. 6 U-Pb concordia diagram for zircon data from the Yantongshan Complex (a, modified from Cao Jialin et al., 2019); Concordia diagram and relative probability plot of all concordant zircon U-Pb ages for the Dajianggang Formation (b, modified from Wang Bin et al., 2016a)

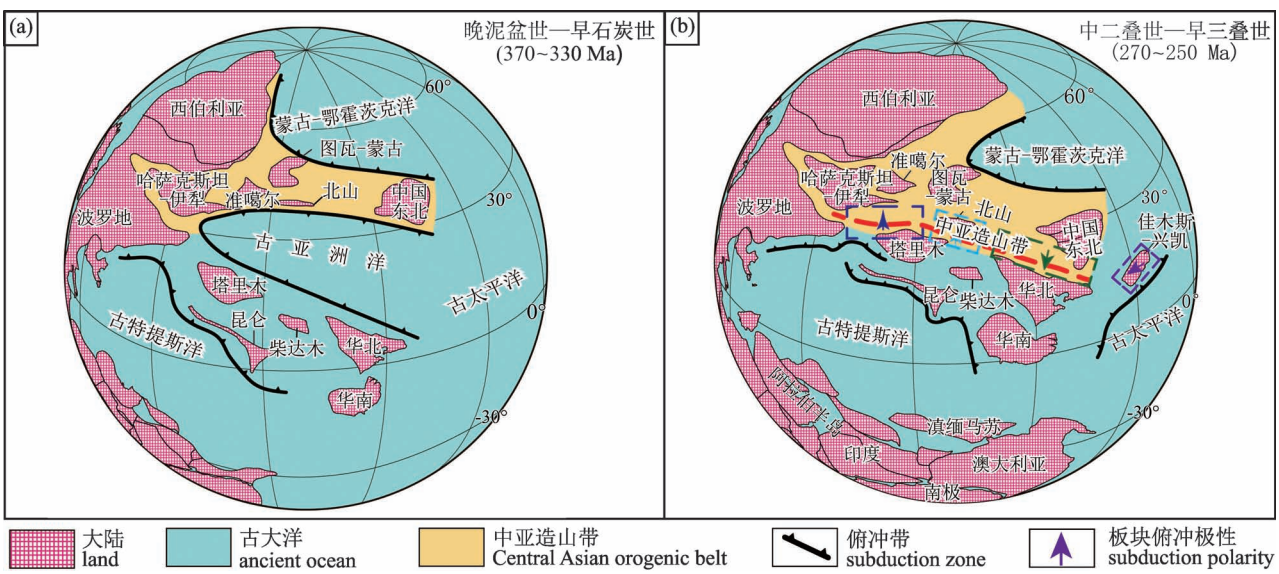

图 7 晚古生代—早中生代前后古亚洲洋与古太平洋构造域叠加转换的动力学模式(据 Zhou Jianbo et al.，2018 修改)

Fig. 7 Dynamical model of the superposition and transition of the Paleo-Asian Ocean and Paleo-Pacific tectonic domain around the Late Paleozoic—Early Mesozoic (modified from Zhou Jianbo et al., 2018)

与哈萨克斯坦—伊犁板块发生拼贴的过程中，根据高压变质年龄、钉合岩体以及不整合盖层等证据来综合分析，其闭合时代应为晚石炭世；北山缝合带位于缝合带中段，形成于敦煌地块与阿拉善地块向北俯冲与图瓦—蒙古板块发生拼贴的过程中，根据带内蛇绿岩的年代学证据限定其闭合时代应为早—中二叠世。阿拉善地块北缘的两条蛇绿岩带连接了北山缝合带和索伦—长春缝合带，代表了古亚洲在该区域闭合时形成的缝合带和弧后盆地，其形成时代应当为中二叠世—晚二叠世早期；索伦—长春缝合带位于缝合带中—东段，古亚洲洋在该地区同时发生了南北两侧的双向俯冲，两侧地块在中二叠世—早三叠世完成拼贴；长春—延吉缝合带形成于中三叠世前后华北板块与佳木斯—兴凯地块俯冲—增生

过程,较西侧索伦—长春缝合带的形成时间(270~250 Ma)晚 20~30 Ma,因此长春—延吉缝合带与索伦—长春缝合带形成时代与构造背景存在显著的差别。在总结了已有研究进展基础上,笔者等认为南天山—北山—索伦—长春缝合带自西向东发生了四阶段的演化过程,闭合时代自西向东逐渐变年轻,整个过程从晚石炭世一直持续到了三叠世(图 7a,b),其中长春—延吉缝合带记录了古亚洲洋和古太平洋构造域叠加与转换的地质过程。

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参 考 文 献 / References

(The literature whose publishing year followed by a "**&**" is in Chinese with English abstract; The literature whose publishing year followed by a "**#**" is in Chinese without English abstract)

艾永亮, 张立飞, 李旭平, 曲军峰. 2005. 新疆西南天山超高压榴辉岩、蓝片岩地球化学特征及大地构造意义. 自然科学进展, 15(11): 1346~1356.

白建科, 李智佩, 徐学义, 李婷. 2015. 西天山早石炭世构造环境: 大哈拉军山组底部沉积地层学证据. 沉积学报, 33(3): 459~469.

高俊, 龙灵利, 钱青, 黄德志, 苏文, Klemd R. 2006. 南天山: 晚古生代还是三叠纪碰撞造山带? 岩石学报, 22(5): 1049~1061.

高俊, 钱青, 龙灵利, 张喜, 李继磊, 苏文. 2009. 西天山的增生造山过程. 地质通报, 28(12): 1804~1816.

龚全胜, 刘明强, 李海林, 梁明宏, 代文军. 2002. 甘肃北山造山带类型及基本特征. 西北地质, 35(3): 28~34.

何世平, 任秉琛, 姚文光, 付力浦. 2002. 甘肃内蒙古北山地区构造单元划分. 西北地质, 35(4): 30~40.

黄增保, 金霞. 2006a. 甘肃北山红石山蛇绿混杂岩带中基性火山岩构造环境分析. 中国地质, 35(5): 1030~1037.

黄增保, 金霞. 2006b. 甘肃红石山地区白山组火山岩地质特征及构造背景. 甘肃地质, 15(1): 19~24.

姜常义, 程松林, 叶书锋, 夏明哲, 姜寒冰, 代玉财. 2006. 新疆北山地区中坡山北镁铁质岩体岩石地球化学与岩石成因. 岩石学报, 22(1): 115~126.

吉林省地质矿产局. 1988. 吉林省区域地质志. 北京: 地质出版社.

李承东, 张福勤, 苗来成, 颉航强, 许雅雯. 2007. 吉林色洛河晚二叠世高镁安山岩 SHRIMP 锆石年代学及其地球化学特征. 岩石学报, 23(4): 767~776.

李春昱. 1980. 中国板块构造的轮廓, 中国地质科学院文集(2).

李华芹, 陈富文, 梅玉萍, 吴华, 程松林, 杨甲全, 代玉财. 2006. 新疆坡北基性—超基性岩带Ⅰ号岩体 Sm—Nd 和 SHRIMP U-Pb 同位素年龄及其地质意义. 矿床地质, 25(4): 463~469.

李继亮. 2004. 增生型造山带的基本特征. 地质通报, 23(9): 947~951.

李锦轶, 王克卓, 李亚萍, 孙桂华, 褚春华, 李丽群, 朱志新. 2006. 天山山脉地貌特征、地壳组成与地质演化. 地质通报, 25(8): 895~909.

李向东, 王克卓. 2000. 中国西天山南缘盆山构造转换解析. 新疆地质, 18(3): 211~219.

李向民, 余吉远, 王国强, 武鹏. 2012. 甘肃北山地区芨芨台子蛇绿岩 LA—ICP—MS 锆石 U-Pb 测年及其地质意义. 地质通报, 31(12): 2025~2031.

李益龙, 周汉文, 钟增球, 张雄华, 廖群安, 葛梦春. 2009. 华北与西伯利亚板块的对接过程: 来自西拉木伦缝合带变形花岗岩锆石 LA—ICP—MS U-Pb 年龄证据. 地球科学(中国地质大学学报), 34(6): 931~938.

李曰俊, 王招明, 买光荣, 吴浩若, 黄智斌, 谭泽金. 2002. 塔里木盆地艾克提克群中放射虫化石及其意义. 新疆石油地质, 23(6): 496~500.

李治, 朱文斌, 吴海林. 2019. 北山马鬃山地区野马泉和勒巴泉韧性剪切带构造变形特征与年代学约束. 高校地质学报, 25(6): 932~942.

刘畅, 赵泽辉, 郭召杰. 2006. 甘肃北山地区煌斑岩的年代学和地球化学及其壳幔作用过程讨论. 岩石学报, 22(5): 1294~1306.

刘金玉, 郗爱华, 葛玉辉, 孙洪涛, 龚鹏辉. 2010. 红旗岭 3 号含矿岩体地质年龄及其岩石学特征. 吉林大学学报(地球科学版), 40(2): 321~326.

刘雪亚, 王荃. 1995. 中国西部北山造山带的大地构造及其演化. 中国地质科学院地质研究所文集.

刘志宏, 王超, 宋健, 高翔, 孙理难. 2016. 华北板块北缘呼兰群 ^{40}Ar—^{39}Ar 定年及其构造意义. 岩石学报, 32(9): 2757~2764.

柳长峰, 周志广, 张华锋, 刘文灿, 张磊. 2011. 内蒙古四子王旗乌尔塔高勒庙岩体的侵位时代及岩石地球化学特征. 矿物岩石, (4): 34~43.

卢华复, 贾承造, 贾东, 陈楚铭, 刘志宏, 王国强, 王胜利. 2001. 库车再生前陆盆地冲断构造楔特征. 高校地质学报, 7(3): 257~271.

吕洪波 , 冯雪东, 王俊, 朱晓青, 董晓朋, 张海春, 章雨旭. 2018. 狼山发现蛇绿混杂岩——华北克拉通与中亚造山带碰撞边界的关键证据. 地质论评, 64(4): 777~805.

孟令顺, 管烨, 齐力, 高锐. 1995. 格尔木—额济纳旗地学断面及其邻区重力场与深部地壳构造. 地球物理学报, S2: 36~45.

内蒙古地质矿产局. 1991. 内蒙古自治区区域地质志. 北京: 地质出版社.

聂凤军. 2002. 北山地区金属矿床成矿规律及找矿方向. 北京: 地质出版社.

牛文超, 辛后田, 段连峰, 王根厚, 赵泽霖, 张国震, 郑艺龙. 2019. 内蒙古北山地区百合山蛇绿混杂岩带的厘定及其洋盆俯冲极性—基于 1∶5 万清河沟幅地质图的新认识. 中国地质, 46(5): 977~994.

牛亚卓, 卢进才, 刘池阳, 宋博, 史冀忠, 许伟. 2018. 甘蒙北山地区海相二叠系时代及其区域对比. 地质学报, 92(6): 1131~1148.

任纪舜, 牛宝贵, 刘志刚. 1999. 软碰撞、叠覆造山和多旋回缝合作用. 地学前缘, 6(3): 85~93.

尚庆华. 2004. 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, 49(24): 2574~2579.

邵济安. 1991. 中朝板块北缘中段地壳演化. 北京: 北京大学出版社.

舒良树, 王博, 朱文斌. 2007. 南天山蛇绿混杂岩中放射虫化石的时代及其构造意义. 地质学报, 81(9): 1161~1168.

宋东方, 肖文交, 韩春明, 田忠华, 李咏晨. 2018. 北山中部增生造山过程: 构造变形和 ^{40}Ar—^{39}Ar 年代学制约. 岩石学报, 34(7): 2087~2098.

孙立新, 张家辉, 任邦方, 牛文超, 任云伟, 张阔. 2017. 北山造山带白云山蛇绿混杂岩的地球化学特征、时代及地质意义. 岩石矿物学杂志, 36(2): 131~147.

孙跃武, 史骁, 李想, 郎嘉彬, 郑月娟, 张德军, 张艳. 2018. 东北地区二叠纪植物群及其地质意义, 中国古生物学会第十二次全国会员代表大会暨第 29 届学术年会论文摘要集.

唐克东, 王莹, 何国琦, 邵济安. 1995. 中国东北及邻区大陆边缘构造. 地质学报, (1): 16~30.

王宝瑜, 郎智君, 李向东. 1994. 中国天山西段地质剖面综合研究, 北京: 科学出版社.

王国强, 李向民, 徐学义, 余吉远, 武鹏, 计波. 2021. 北山造山带古生代蛇绿混杂岩研究现状及进展. 地质通报, 40(1): 71~81.

王競繁, 王继春, 周路路, 赵 鑫, 秦江东, 郭文军, 韩宏雨, 张晓欣, 刘洋. 2021. 内蒙古温都尔庙地区首次识别出古生代蛇绿混杂岩. 地质论评, 67(z1): 67z1163~67z1166.

王炎阳, 徐备, 程胜东, 廖闻, 邵军, 汪岩. 2014. 内蒙古克什克腾旗五道石门基性火山岩锆石 U-Pb 年龄及其地质意义. 岩石学报, 30(7): 2055~2062.

王玉净, 樊志勇. 1997. 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, (1): 60~71.

王元龙, 成守德. 2001. 新疆地壳演化与成矿. 地质科学, 36(2): 129~143.

王作勋, 邬继易, 吕喜朝, 刘成德, 张经国. 1990. 天山多旋回构造演化及成矿. 北京: 科学出版社.

魏志军, 黄增保, 金霞, 孙永君, 火军昌. 2004. 甘肃红石山地区蛇绿混杂岩地质特征. 西北地质, 37(2): 13~18.

吴迪迪, 李舢, Chew D, 刘铁翊, 郭东海. 2021. 中亚造山带东南缘二叠纪—三叠纪花岗质岩浆演化对增生—碰撞过程的制约. 中国科学(地球科学), 51(6): 906~926.

郗爱华, 任洪茂, 张宝福, 王永祥, 史书宝, 支学军. 2003. 吉林中部呼兰群同位素年代学及其地质意义. 吉林大学学报(地球科学版), 33(1): 15~18.

谢力, 尹海权, 周洪瑞, 张维杰. 2014. 内蒙古阿拉善地区恩格尔乌苏缝合带二叠纪放射虫及其地质意义. 地质通报, (5): 691~697.

肖文交, 李继亮, 宋东方, 韩春明, 万博, 张继恩, 敖松坚, 张志勇. 2019. 增生型造山带结构解析与时空制约. 地球科学(中国地质大学学报), 44(5): 1661~1687.

辛后田, 牛文超, 田健, 滕学建, 段霄龙. 2020. 内蒙古北山造山带时空结构与古亚洲洋演化. 地质通报, 39(9): 1297~1316.

辛玉莲, 任军丽, 彭玉鲸, 孙喜庆. 2011. 中国东北兴蒙—吉黑造山带造山作用结束的标志—来自晚三叠世磨拉石(大地构造相)的证据. 地质与资源, 20(6): 413~419.

徐备, 陈斌. 1997. 内蒙古北部华北板块与西伯利亚板块之间中古生代造山带的结构及演化. 中国科学(D 辑: 地球科学), (3): 227~232.

徐学义, 夏林圻, 马中平, 王彦斌, 夏祖春, 李向民, 王立社. 2006. 北天山巴音沟蛇绿岩斜长花岗岩 SHRIMP 锆石 U-Pb 年龄及蛇绿岩成因研究. 岩石学报, 22(1): 83~94.

杨高学, 李永军, 司国浩, 李海, 佟丽莉, 王祚鹏. 2021. 中亚造山带西段俯冲起始时限及机制探讨. 地球科学与环境学报, 43(2): 244~261.

杨合群, 李英, 李文明, 杨建国, 赵国斌, 孙南一, 王小红, 谭文娟. 2008. 北山成矿构造背景概论. 西北地质, 41(1): 22~28.

杨合群, 李英, 赵国斌, 李文渊, 王小红, 姜寒冰, 谭文娟, 孙南一. 2010. 北山蛇绿岩特征及构造属性. 西北地质, 43(1): 26~36.

余钦范, 楼海, 胡中栋. 1995. 格尔木—额济纳旗地学断面岩石图结构的磁场分析. 地球物理学报, 38(A02): 58~70.

张春艳, 张兴洲, 夏庆贺. 2009. 吉林中部硅质岩中锆石 U-Pb 年龄及其地质意义. 现代地质, 23(2): 256~261.

张立飞, 艾永亮, 李强, 李旭平, 宋述光, 魏春景. 2005. 新疆西南天山超高压变质带的形成与演化. 岩石学报, 21(4): 1029~1038.

张立飞, 杜瑾雪, 吕增, 杨鑫, 苟龙龙, 夏彬, 陈振宇, 魏春景, 宋述光. 2013. 新疆西南天山超高压变质带的空间分布、峰期变质时代和 P—T 轨迹特征. 科学通报, 58(22): 2107~2112.

张拴宏, 赵越, 刘建民, 胡健民, 宋彪, 刘健, 吴海. 2010. 华北地块北缘晚古生代—早中生代岩浆活动期次、特征及构造背景. 岩石矿物学杂志, 29(6): 824~842.

赵英利, 李伟民, 温泉波, 梁琛岳, 冯志强, 周建平, 申亮. 2016. 内蒙东部晚古生代构造格局: 来自中、晚二叠—早三叠世砂岩碎屑锆石 U-Pb 年代学的证据. 岩石学报, 32(9): 2807~2822.

周建波, 曾维顺, 曹嘉麟, 韩杰, 郭晓丹. 2012. 中国东北地区的构造格局与演化: 从 500 Ma 到 180 Ma. 吉林大学学报(地球科学版), 42(5): 1298~1316.

周建波, 韩杰, Wilde S A, 郭晓丹, 曾维顺, 曹嘉麟. 2013. 吉林—黑龙江高压变质带的初步厘定: 证据和意义. 岩石学报, 29(2): 386~398.

周建波, 曹嘉麟, 韩伟, 李功宇. 2020. 长春—延吉缝合带: 性质与意义. 岩石学报, 36(3): 635~643.

朱俊宾. 2015. 内蒙古东南部上石炭统—下三叠统的沉积环境和构造背景. 导师: 任纪舜. 北京: 中国地质大学(北京)博士学位论文: 1~122.

朱俊宾, 和政军. 2017. 内蒙古林西地区上二叠统—中三叠统沉积序列的碎屑锆石记录及对古亚洲洋(东段)闭合时间的制约. 地质学报, 91(1): 232~248.

左国朝, 张淑玲, 何国琦, 张杨. 1990. 北山地区早古生代板块构造特征. 地质科学, (4): 305~314.

左国朝, 张作衡, 王志良, 刘敏, 王龙生. 2008. 新疆西天山地区构造单元划分、地层系统及其构造演化. 地质论评, 54(6): 748~767.

Ai Yongliang, Zhang Lifei, Li Xuping, Qu Junfeng. 2005&. The geochemistry characters of the HP—UHP eclogites and blueschist and its tectonic significance, Southwestern Tianshan, Xinjiang. Progress in Natural Science, 15(11): 1346~1356.

Alexeiev D V, Biske Y S, Wang Bo, Djenchuraeva A V, Getman O F, Aristov V A, Kröner A, Liu Hongsheng, Zhong Linglin. 2015. Tectono—Stratigraphic framework and Palaeozoic evolution of the Chinese South Tianshan. Geotectonics, 49(2): 93~122.

Ao Songjian, Xiao Wenjiao, Han Chunming, Mao Qigui, Zhang Ji'en. 2010. Geochronology and geochemistry of Early Permian mafic—ultramafic complexes in the Beishan area, Xinjiang, NW China: implications for late Paleozoic tectonic evolution of the southern Altaids. Gondwana Research, 18(2~3): 466~478.

Badarch G, Cunningham W D, Windley B F. 2002. A new terrane subdivision for Mongolia: implications for the Phanerozoic crustal growth of Central Asia. Journal of Asian Earth Sciences, 21(1): 87~110.

Bai Jianke, Li Zhipei, Xu Xueyi, Li Ting. 2015&. Tectonic Environment of Western Tianshan during the Early Carboniferous: Sedimentary and stratigraphical evidence from the bottom of the Dahalajunshan Formation. Acta Sedimentologica Sinica, 33(3): 459~469.

Bazhenov M L, Collins A Q, Degtyarev K E, Levashova N M, Mikolaichuk A V, Pavlov V E, Voo R V D. 2003. Paleozoic northward drift of the North Tian Shan (Central Asia) as revealed by Ordovician and Carboniferous paleomagnetism. Tectonophysics, 366(1~2): 113~141.

Buriánek D, Schulmann K, Hrdličková K, Hanžl P, Janoušek V,

Gerdes A, Lexa O. 2017. Geochemical and geochronological constraints on distinct early Neoproterozoic and Cambrian accretionary events along southern margin of the Baydrag Continent in western Mongolia. Gondwana Research, 47: 200~227.

Cao Jialin, Zhou Jianbo, Li Long. 2019. The tectonic evolution of the Changchun—Yanji suture zone: Constraints of zircon U-Pb ages of the Yantongshan accretionary complex (NE China). Journal of Asian Earth Sciences, 194: SI.

Charvet J, Shu Liangshu, Laurent-Charvet S, Wang Bo, Faure M, Cluzel D, Chen Yan, Jong K D. 2011. Palaeozoic tectonic evolution of the Tianshan belt, NW China. Science China Earth Sciences, 54(2): 166~184.

Chen Bin, Jahn B M, Tian Wei. 2009. Evolution of the Solonker suture zone: constraints from zircon U-Pb ages, Hf isotopic ratios and whole-rock Nd—Sr isotope compositions of subduction- and collision-related magmas and forearc sediments. Journal of Asian Earth Sciences, 34(3): 245~257.

Chen Long, Liang Chenyue, Liu Yongjiang, Zheng Changqing, Zhang Qian, Song Zhiwei, Li Dongxue, Qu Shuyue, Liu Xiaojing. 2021. Tectonic evolution of Mohe area, North-east China: Evidence from the Early Ordovician to Early Cretaceous magmatism and tectonism. Geological Journal, 56(21): 5478~5505.

Chen Yan, Gan Lisheng, Wu Tairan. 2021. The Carboniferous—Permian tectonic setting for the southernmost Central Asian Orogenic Belt: Constraint from magmatic and sedimentary records in the Alxa area, NW China. Lithos, 398: 106350.

Chu Hang, Zhang Jinrui, Wei Chunjing, Wang Huichu, Ren Yunwei. 2013. A new interpretation of the tectonic setting and age of meta-basic volcanics in the Ondor Sum Group, Inner Mongolia. Chinese Science Bulletin, 58(28~29): 3580~3587.

Cleven N, Lin Shoufa, Guilmette C, Xiao Wenjiao, Davis B. 2015. Petrogenesis and implications for tectonic setting of Cambrian suprasubduction-zone ophiolitic rocks in the central Beishan orogenic collage, Northwest China. Journal of Asian Earth Sciences, 113 (SI): 369~390.

Degtyarev K E, Kovach V P, Tret'yakov A A, Kotov A B, Wang Kuolun. 2015. Age and sources of Precambrian zircon—rutile deposits in the Kokchetav sialic massif (northern Kazakhstan). Doklady Earth Sciences, 464(2): 1005~1009.

Demoux A, Kröner A, Badarch G, Jian Ping, Tomurhuu D, Wingate M T D. 2009. Zircon ages from the Baydrag block and the Bayankhongor ophiolite zone: Time constraints on late Neoproterozoic to Cambrian subduction- and accretion-related magmatism in central Mongolia. Journal of Geology, 117(4): 377~397.

Draut A E, Clift P D. 2001. Geochemical evolution of arc magmatism during arc—continent collision, South Mayo, Ireland. Geology, 29 (6): 543~546.

Draut A E, Clift P D. 2013. Differential preservation in the geologic record of intraoceanic arc sedimentary and tectonic processes. Earth-Science Reviews, 116: 57~84.

Eizenhofer P R, Zhao Guochun, Zhang Jian, Sun Min. 2014. Final closure of the Paleo-Asian Ocean along the Solonker Suture Zone: Constraints from geochronological and geochemical data of Permian volcanic and sedimentary rocks. Tectonics, 33(4): 441~463.

Eizenhofer P R, Zhao Guochun. 2018. Solonker Suture in East Asia and its bearing on the final closure of the eastern segment of the Palaeo-Asian Ocean. Earth-Science Reviews, 186: 153~172.

Faure M, Natal'In B A. 1992. The geodynamic evolution of the eastern Eurasian margin in Mesozoic times. Tectonophysics, 208(4): 397 ~411.

Gao Jun, Li Maosong, Xiao Xuchang, Tang Yaoqing, He Guoqi. 1998. Paleozoic tectonic evolution of the Tianshan Orogen, Northwestern China. Tectonophysics, 287(1~4): 213~231.

Gao Jun, Klemd R. 2003. Formation of HP—LT rocks and their tectonic implications in the western Tianshan Orogen, NW China: geochemical and age constraints. Lithos, 66(1~2): 1~22.

Gao Jun, Long Lingli, Qian Qing, Huang Dezhi, Su Wen, Klemd R. 2006&. South Tianshan: a Late Paleozoic or a Triassic orogen? Acta Petrologica Sinica, 22(5): 1049~1061.

Gao Jun, Long Lingli, Klemd R, Qian Qing, Liu Dunyi, Xiong Xianming, Su Wen, Liu Wei, Wang Yitian, Yang Fuqun. 2008. Tectonic evolution of the South Tianshan orogen and adjacent regions, NW China: geochemical and age constraints of granitoid rocks. International Journal of Earth Sciences, 98(6): 1221~1238.

Gao Jun, Qian Qing, Long Lingli, Zhang Xi, Li Jilei, Su Wen. 2009&. Accretionary orogenic process of Western Tianshan, China. Geological Bulletin of China, 28(12): 1804~1816.

Gao Jun, Klemd R, Qian Qing, Zhang Xi, Li Jilei, Jiang Tuo, Yang Yongqiang. 2011. The collision between the Yili and Tarim blocks of the Southwestern Altaids: Geochemical and age constraints of a leucogranite dike crosscutting the HP—LT metamorphic belt in the Chinese Tianshan Orogen. Tectonophysics, 499(1~4): 118~131.

Gong Quansheng, Liu Mingqiang, Li Hailin, Liang Minghong, Dai Wenjun. 2002&. The type and basic characteristics of Beishan orogenic belt, Gansu. Northwestern Geology, 35(3): 28~34.

Guo Qianqian, Xiao Wenjiao, Hou Quanlin, Windley B F, Han Chunming, Tian Zhonghua, Song Dongfang. 2014. Construction of Late Devonian Dundunshan arc in the Beishan orogen and its implication for tectonics of southern Central Asian Orogenic Belt. Lithos, 184: 361~378.

Han Baofu, He Guoqi, Wang Xuechao, Guo Zhaojie. 2011. Late Carboniferous collision between the Tarim and Kazakhstan—Yili terranes in the western segment of the South Tian Shan Orogen, Central Asia, and implications for the Northern Xinjiang, Western China. Earth-Science Reviews, 109(3~4): 74~93.

Han Jie, Zhou Jianbo, Li Long, Song Mingchun. 2017a. Mesoproterozoic (~1.4 Ga) A-type gneissic granites in the Xilinhot terrane, NE China: First evidence for the break-up of Columbia in the eastern CAOB. Precambrian Research, 296: 20~38.

Han Jie, Zhou Jianbo, Wilde S A, Song Minchun. 2017b. Provenance analysis of the Late Paleozoic sedimentary rocks in the Xilinhot Terrane, NE China, and their tectonic implications. Journal of Asian Earth Sciences, 144: 69~81.

Han Yigui, Zhao Guochun, Sun Min, Eizenhöfer P R, Hou Wenzhu, Zhang Xiaoran, Liu Qian, Wang Bo, Liu Dongxing, Xu Bing. 2016. Late Paleozoic subduction and collision processes during the amalgamation of the Central Asian Orogenic Belt along the South Tianshan suture zone. Lithos, 246: 1~12.

He Shiping, Ren Bingchen, Yao Wenguang, Fu Lipu. 2002&. The division of tectonic units of Beishan area, Gansu—Inner Mongolia. Northwestern Geology, 35(4): 30~40.

Hong Dawei, Huang Huaizeng, Xiao Yijun, Xu Haiming, Jin Manyuan. 1995. Permian Alkaline Granites in Central Inner Mongolia and Their Geodynamic Significance. Acta Geologica Sinica (English Edition), 1: 27~39.

Huang Zengbao, Jin Xia. 2006a&. Tectonic environment of basic volcanic rocks in the Hongshishan ophiolite mélange zone, Beishan Mountains, Gansu. Geology in China, 35(5): 1030~1037.

Huang Zengbao, Jin Xia. 2006b&. Geological characteristics and its

setting for volcanic rocks of baishan formation in Hongshishan area of Gansu province. Gansu Geology, 15(1): 19~24.

Hui Jie, Zhang Kaijun, Zhang Jin, Qu Junfeng, Zhang Beihang, Zhao Heng, Niu Pengfei. 2021. Middle—late Permian high-K adakitic granitoids in the NE Alxa block, northern China: Orogenic record following the closure of a Paleo-Asian oceanic branch? Lithos, 400~401.

Jahn B M, Wu Fuyuan, Chen B. 2000. Massive granitoid generation in Central Asia; Nd isotope evidence and implication for continental growth in the Phanerozoic. Episodes, 23(2): 82~92.

Jian Ping, Liu Dunyi, Kröner A, Windley B F, Shi Yuruo, Zhang Fuqin, Shi Guanghai, Miao Laicheng, Zhang Wei, Zhang Qi. 2008. Time scale of an early to mid-Paleozoic orogenic cycle of the long-lived Central Asian Orogenic Belt, Inner Mongolia of China; implications for continental growth. Lithos, 101(3~4): 233~259.

Jian Ping, Liu Dunyi, Kröner A, Windley B F, Shi Yuruo, Zhang Wei, Zhang Fuqin, Miao Laicheng, Zhang Liqao, Tomurhuu D. 2010. Evolution of a Permian intraoceanic arc—trench system in the Solonker suture zone, Central Asian Orogenic Belt, China and Mongolia. Lithos, 118(1~2): 169~190.

Jian Ping, Kröner A, Jahn B M, Liu Dunyi, Zhang Wei, Shi Yuruo, Ma Huadong. 2013. Zircon ages of metamorphic and magmatic rocks within peridotite-bearing mélanges; Crucial time constraints on early Carboniferous extensional tectonics in the Chinese Tianshan. Lithos, 172: 243~266.

Jiang Changyi, Cheng Songlin, Ye Shufeng, Xia Mingzhe, Jiang Hanbing, Dai Yucai. 2006&. Lithogeochemistry and petrogenesis of Zhongposhanbei maric rock body, at Beishan region, Xinjiang. Acta Petrologica Sinica, 22(1): 115~126.

Jiang Tuo, Gao Jun, Klemd R, Qian Qing, Zhang Xi, Xiong Xianming, Wang Xinshui, Tan Zhou, Chen Bangxue. 2014. Paleozoic ophiolitic mélanges from the South Tianshan Orogen, NW China; geological, geochemical and geochronological implications for the geodynamic setting. Tectonophysics, 612: 106~127.

Jong K D, Wang Bo, Faure M, Shu Liangshu, Cluzel D, Charvet J, Ruffet G, Chen Yan. 2008. New $^{40}Ar/^{39}Ar$ age constraints on the Late Palaeozoic tectonic evolution of the western Tianshan(Xinjiang, northwestern China), with emphasis on Permian fluid ingress. International Journal of Earth Sciences, 98(6): 1239~1258.

John T, Klemd R, Gao Jun, Garbe-Schönberg C D. 2008. Trace-element mobilization in slabs due to non steady-state fluid—rock interaction; constraints from an eclogite-facies transport vein in blueschist(Tianshan, China). Lithos, 103(1~2): 1~24.

Khain E V, Bibikova E V, Kröner A, Zhuravlev D Z, Sklyarov E V, Fedotova A A, Kravchenko-Berezhnoy I R. 2002. The most ancient ophiolite of the Central Asian fold belt; U-Pb and Pb-Pb zircon ages for the Dunzhugur Complex, Eastern Sayan, Siberia, and geodynamic implications. Earth and Planetary Science Letters, 199(3~4): 311~325.

Khain E V, Bibikova E V, Salnikova E B, Kröner A, Gibsher A S, Didenko A N, Degtyarev K E, Fedotova A A. 2003. The Palaeo-Asian ocean in the Neoproterozoic and early Palaeozoic; new geochronologic data and palaeotectonic reconstructions. Precambrian Research, 122(1~4): 329~358.

Klemd R, Bröcker M, Hacker B R, Gao J, Gans P, Wemmer K. 2005. New Age Constraints on the Metamorphic Evolution of the High - Pressure/Low - Temperature Belt in the Western Tianshan Mountains, NW China. Journal of Geology, 113(2): 157~168.

Klemd R, John T, Scherer E E, Rondenay S, Gao J. 2011. Changes in dip of subducted slabs at depth: Petrological and geochronological evidence from HP—UHP rocks (Tianshan, NW-China). Earth and Planetary Science Letters, 310(1): 9~20.

Kravchinsky V A, Cogne J P, Harbert W P, Kuzmin M I. 2002. Evolution of the Mongol—Okhotsk Ocean as constrained by new palaeomagnetic data from the Mongol—Okhotsk suture zone, Siberia. Geophysical Journal International, 148(1): 34~57.

Kröner A, Windley B F, Badarch G, Tomurtogoo O, Hegner E, Jahn B M, Gruschka S, Khain E V, Demoux A, Wingate M T D. 2007. Accretionary growth and crust formation in the Central Asian Orogenic Belt and comparison with the Arabian—Nubian shield. Memoirs——Geological Society of America, 200: 181~209.

Kröner A, Alexeiev D V, Rojas-Agramonte Y, Hegner E, Wong J, Xia X, Belousova E, Mikolaichuk A V, Seltmann R, Liu D. 2013. Mesoproterozoic (Grenville-age) terranes in the Kyrgyz North Tianshan; zircon ages and Nd—Hf isotopic constraints on the origin and evolution of basement blocks in the southern Central Asian Orogen. Gondwana Research, 23(1): 272~295.

Kröner A, Kovach V, Belousova E, Hegner E, Armstrong R, Dolgopolova A, Seltmann R, Alexeiev D V, Hoffmann J E, Wong J, Sun M, Cai K, Wang T, Tong Y, Wilde S A, Degtyarev K E, Rytsk E. 2014. Reassessment of continental growth during the accretionary history of the Central Asian Orogenic Belt. Gondwana Research, 25(1): 103~125.

Li Chao, Xiao Wenjiao, Han Chunming, Zhou Kefa, Zhang Ji'en, Zhang Zhixin. 2015. Late Devonian—Early Permian accretionary orogenesis along the North Tianshan in the southern Central Asian orogenic belt. International Geology Review, 57(5~8): 1023~1050.

Li Chengdong, Zhang Fuqin, Miao Laicheng, Jie Hangqiang, Xu Yawen. 2007&. Zircon SHRIMP geochronology and geochemistry of Late Permian high-Mg andesites in Seluohe area, Jilin province, China. Acta Petrologica Sinica, 23(4): 767~776.

Li Chunyu, Wang Quan, Zhang Zhimeng, Liu Xueya. 1980&. The contours of Chinese plate tectonics, Acta Geoscientica Sinica, 2(1): 11~22.

Li Huaqin, Chen Fuwen, Mei Yuping, Wu Hua, Cheng Songlin, Yang Jiaquan, Dai Yucai. 2006&. Isotopic ages of No. 1 intrusive body in Pobei mafic—ultramafic belt of Xinjiang and their geological significance. Mineral Deposits, 25(4): 463~469.

Li Jiliang. 2004&. Basic characteristics of accretion-type orogens. Geological Bulletin of China, 23(9): 947~951.

Li Jinyi. 2006. Permian geodynamic setting of Northeast China and adjacent regions: Closure of the Paleo-Asian Ocean and subduction of the Paleo-Pacific Plate. Journal of Asian Earth Sciences, 26(3~4): 207~224.

Li Jinyi, Wang Kezhuo, Li Yaping, Sun Guihua, Chu Chunhua, Li Liqun, Zhu Zhixin. 2006&. Geomorphological features, crustal composition and geological evolution of the Tianshan Mountains. Geological Bulletin of China, 25(8): 895~909.

Li Qiuli, Lin Wei, Su Wen, Li Xianhua, Shi Yonghong, Liu Yu, Tang Guoqiang. 2011. SIMS U-Pb rutile age of low-temperature eclogites from southwestern Chinese Tianshan, NW China. Lithos, 122(1), 76~86.

Li Shan, Wilde S A, He Zhengjun, Jiang Xiaojun, Liu Renyan, Zhao Lei. 2014. Triassic sedimentation and postaccretionary crustal evolution along the Solonker suture zone in Inner Mongolia, China. Tectonics, 33(6): 960~981.

Li Shan, Chung S, Wilde S A, Jahn B M, Xiao Wenjiao, Wang Tao, Guo Qianqian. 2017. Early—Middle Triassic high Sr/Y granitoids in the southern Central Asian Orogenic Belt; Implications for ocean

closure in accretionary orogens. Journal of Geophysical Research, 122(3): 2291~2309.

Li Xiangdong, Wang Kezhuo. 2000&. On orogenic to basinal tectonic transfer along the southern margin of West Tianshan mountains, China. Xinjiang Geology, 18(3): 211~219.

Li Xiangmin, Yu Jiyuan, Wang Guoqiang, Wu Peng. 2012&. Geochronology of Jijitaizi ophiolite in Beishan area, Gansu Province, and its geological significance. Geological Bulletin of China, 31(12): 2025~2031.

Li Xuping, Zhang L, Wei C, Ai Y, Chen J. 2007. Petrology of rodingite derived from eclogite in western Tianshan, China. Journal of Metamorphic Geology, 25(3): 363~382.

Li Yuejun, Wang Zhaoming, Mai Guangrong, Wu Haoruo, Huang Zhibin, Tan Zejin. 2002&. New discovery of radiolarian fossils from Aiktik Group at in Tarim Basin and its significance. Xinjiang Petroleum Geology, 23(6): 496~500.

Li Yilong, Zhou Hanwen, Zhong Zengqiu, Zhang Xionghua, Liao Qun'an, Ge Mengchun. 2009&. Collision processes of North China and Siberian Plates: Evidence from LA-ICP-MS zircon U-Pb age on deformed granite in Xar Moron suture zone. Earth Science (Journal of China University of Geosciences), 34(6): 931~938.

Li Zhi, Zhu Wenbin, Wu Hailin. 2019&. Structural characteristics and chronological constraints on the Yemaquan—Lebaquan ductile shear zone in Mazongshan Area, Beishan. Geological Journal of China Universities, 25(6): 932~942.

Lin Wei, Chu Yang, Ji Wenbin, Zhang Zhongpei, Shi Yonghong, Wang Zhenyuan, Li Zhong, Wang Qingchen. 2013. Geochronological and geochemical constraints for a middle Paleozoic continental arc on the northern margin of the Tarim block; Implications for the Paleozoic tectonic evolution of the South Chinese Tianshan. Lithosphere, 5(4): 355~381.

Liu Chang, Zhao Zehui, Guo Zhaojie. 2006&. Chronology and geochemistry of lamprophyre dykes from Beishan area, Gansu province and implications for the crust—mantle interaction. Acta Petrologica Sinica, 22(5): 1294~1306.

Liu Changfeng, Zhou Zhiguang, Zhang Huafeng, Liu Wencan, Zhang Lei. 2011&. Petrochemical characteristics and timing of Wuertagaolemiao granitoids, Siziwangqi, Inner Mongolia. Journal of Mineralogy and Petrology, 31(4): 34~43.

Liu Jinyu, Xi Aihua, Ge Yuhui, Sun Hongtao, Gong Penghui. 2010&. Mineralization age of the No. 3 ore-bearing intrusion and its petrological significance in Hongqiling Cu—Ni sulfide deposits, Jilin Province. Journal of Jilin University (Earth Science Edition), 40(2): 321~326.

Liu Qian, Zhao Guochun, Sun Min, Eizenhöfer P R, Han Yigui, Hou Wenzhu, Zhang Xiaoran, Wang Bo, Liu Dongxing, Xu Bing. 2015. Ages and tectonic implications of Neoproterozoic ortho- and paragneisses in the Beishan Orogenic Belt, China. Precambrian Research, 266: 551~578.

Liu Xueya, Wang Quan. 1995&. Tectonics of orogenic belts in Beishan Mountains, Western China and their evolution. Collected works of Institute of geology, Chinese Academy of Geological Sciences(28), 37~48.

Liu Zhihong, Wang Chao, Song Jian, Gao Xiang, Sun Linan. 2016&. ^{40}Ar-^{39}Ar dating and its tectonic significance of the Hulan Group at the northern margin of the North China Plate. Acta Petrologica Sinica, 32(9): 2757~2764.

Lu Huafu, Jia Chengzao, Jia Dong, Chen Chuming, Liu Zhihong, Wang Guoqiang, Wang Shengli. 2001&. Features of the thrust wedge of deformation belt in Kuqa Rejuvenation Foreland Basin. Geological Journal of China Universitiesf, 7(3): 257~271.

Lu Linsu, Mao Jingwen, Li Hongbo, Pirajno F, Zhang Zuoheng, Zhou Zhenhua. 2011. Pyrrhotite Re-Os and shrimp zircon U-Pb dating of the Hongqiling Ni—Cu sulfide deposits in northeast China. Ore Geology Reviews, 43(1): 106~119.

Lü Hongbo, Feng Xuedong, Wang Jun, Zhu Xiaoqing, Dong Xiaopeng, Zhang Haichun, Zhang Yuxu. 2018&. Ophiolitic mélanges found in Mount Langshan——As the crucial evidence of collisional margin between North China Craton and Central Asian Orogenic Belt. Geological Review, 64(4): 777~805.

Lü Zeng, Bucher K, Zhang L, Du J. 2012. The Habutengsu metapelites and metagreywackes in western Tianshan, China: Metamorphic evolution and tectonic implications. Journal of Metamorphic Geology, 30: 907~926.

Mao Qigui, Xiao Wenjiao, Windley B F, Han Chunming, Qu Junfeng, Ao Songjian, Zhang Ji'en, Guo Qianqian. 2011. The Liuyuan complex in the Beishan, NW China; a Carboniferous—Permian ophiolitic fore-arc sliver in the southern Altaids. Geological Magazine, 149(3): 483~506.

Maruyama S. 1997. Pacific - type orogeny revisited; Miyashiro - type orogeny proposed. Island Arc, 6(1): 91~120.

Meng Lingshun, Guan Ye, Qi Li, Gao Rui. 1995&. Gravity field and deep crustal structure in Golmud—Ejinqi geoscience transection and nearby area. Chinese Journal of Geophysics, 38: 36~45.

Miao Laicheng, Fan Weiming, Liu Dunyi, Zhang Fuqin, Shi Yuruo, Guo Feng. 2008. Geochronology and geochemistry of the Hegenshan ophiolitic complex; Implications for late-stage tectonic evolution of the Inner Mongolia—Daxinganling Orogenic Belt, China. Journal of Asian Earth Sciences, 32(5~6): 348~370.

Miao Laicheng, Zhang Fuqin, Fan Weiming, Liu Dunyi. 2007. Phanerozoic evolution of the Inner Mongolia—Daxinganling orogenic belt in North China; constraints from geochronology of ophiolites and associated formations. Geological Society, London, Special Publications, 280(1): 223~237.

Mueller J F, John J W R, Jin Yugan, Wang Huayu, Li Wenguo, John C, Joseph F M. 1991. Late Carboniferous to Permian sedimentation in Inner Mongolia, China, and tectonic relationships between North China and Siberia. Journal of Geology, 99(2): 251~263.

Natalin B A. 1991. Mesozoic accretionary and collision tectonics of the South Far East of the USSR. Tikhookeanskaya Geologiya, 5: 3~23.

Nie Fengjun. 2002&. Metallogenic Regularity and Prospecting Direction of Metal Deposits in Beishan Area. Beijing: Geological Publishing House.

Niu Wenchao, Xin Houtian, Duan Lianfeng, Wang Genhou, Zhao Zelin, Zhang Guozhen, Zheng Yilong. 2019&. The identification and subduction polarity of the Baiheshan ophiolite mélanges belt in the Beishan area, Inner Mongolia——New understanding based on the geological map of Qinghegou Sheet (1∶50000). Geology in China, 46(5): 977~994.

Niu Yazhuo, Lu Jincai, Liu Chiyang, Song Bo, Shi Jizhong, Xu Wei. 2018&. Chronostratigraphy and regional comparison of marine Permian system in the Beishan region, North China. Acta Geologica Sinica, 92(6): 1131~1148.

Nozaka T, Liu Yan. 2002. Petrology of the Hegenshan ophiolite and its implication for the tectonic evolution of northern China. Earth and Planetary Science Letters, 202(1): 89~104.

Pei Shenghui, Zhou Jianbo, Li Long. 2016. U-Pb ages of detrital zircon of the Paleozoic sedimentary rocks; New constraints on the emplacement time of the Hegenshan ophiolite, NE China. Journal of Asian Earth Sciences, 130: 75~87.

Rasmussen B. 2005. Zircon growth in very low grade metasedimentary rocks;evidence for zirconium mobility at ~250°C. Contributions to Mineralogy and Petrology, 150(2): 146~155.

Ren Jishun, Niu Baogui, Liu Zhigang. 1999&. Soft collision, superposition orogeny and polycyclic suturing. Earth Science Frontiers, 6(3): 85~93.

Ren Qiang, Zhang Shihong, Gao Yangjun, Zhao Hanqing, Wu Huaichun, Yang Tianshui, Li Haiyan. 2020. New Middle—Late Permian Paleomagnetic and Geochronological Results From Inner Mongolia and their Paleogeographic Implications. Journal of Geophysical Research;Solid Earth. 125(7): e2019JB019114.

Robinson P T, Zhou Meifu, Hu Xufeng, Reynolds P, Bai Wenji, Yang Jingsui. 1999. Geochemical constraints on the origin of the Hegenshan Ophiolite, Inner Mongolia, China. Journal of Asian Earth ences, 17(4): 423~442.

Şengör A M C, Okurogullari A H. 1991. The role of accretionary wedges in the growth of continents——Asiatic examples from argand to plate-tectonics. Eclogae Geologicae Helvetiae, 84(3): 535~597.

Şengör A M C, Natal´In B A, Burtman V S. 1993. Evolution of the Altaid tectonic collage and Palaeozoic crustal growth in Eurasia. Nature, 364: 299~307.

Şengör A M C. 1996. Paleotectonics of Asia;fragments of a synthesis. The tectonic evolution of Asia, 486~640.

Shang Qinghua. 2004&. The discovery and significance of Permian radiolarians in the northern and middle Inner Mongolia, Northern Orogenic belt. Chinese Science Bulletin, 49(24): 2574~2579.

Shao Ji'an. 1991&. Crustal Evolution in the middle part of the Northern Margin of the Sino—Korean Plate. Beijing: Peking University Press.

Shi Yuruo, Jian Ping, Kroener A, Li Linlin, Liu Cui, Zhang Wei. 2016. Zircon ages and Hf isotopic compositions of Ordovician and Carboniferous granitoids from central Inner Mongolia and their significance for early and late Paleozoic evolution of the Central Asian Orogenic Belt. Journal of Asian Earth Sciences, 117: 153~169.

Shi Yuruo, Zhang Wei, Kröner A, Li Linlin, Jian Ping. 2018. Cambrian ophiolite complexes in the Beishan area, China, southern margin of the Central Asian Orogenic Belt. Journal of Asian Earth Sciences, 153: 193~205.

Shu Liangshu, Wang Bo, Zhu Wenbin. 2007&. Age of radiolarian fossils from the Heiyingshan ophiolitic Mélange, Southern Tianshan belt, NW China, and its tectonic significance. Acta Geologica Sinica, 81(9): 1161~1168.

Song Dongfang, Xiao Wenjiao, Han Chunming, Li Jiliang, Qu Junfeng, Guo Qianqian, Lin Lina, Wang Zhongmei. 2013a. Progressive accretionary tectonics of the Beishan orogenic collage, southern Altaids;insights from zircon U-Pb and Hf isotopic data of high-grade complexes. Precambrian Research, 227: 368~388.

Song Dongfang, Xiao Wenjiao, Han Chunming, Tian Zhonghua, Wang Zhongmei. 2013b. Provenance of metasedimentary rocks from the Beishan orogenic collage, southern Altaids;Constraints from detrital zircon U-Pb and Hf isotopic data. Gondwana Research, 24(3~4): 1127~1151.

Song Dongfang, Xiao Wenjiao, Han Chunming, Tian Zhonghua. 2014. Polyphase deformation of a Paleozoic forearc—arc complex in the Beishan orogen, NW China. Tectonophysics, 632: 224~243.

Song Dongfang, Xiao Wenjiao, Windley B F, Han Chunming, Tian Zhonghua. 2015. A Paleozoic Japan-type subduction—accretion system in the Beishan orogenic collage, southern Central Asian Orogenic Belt. Lithos, 224: 195~213.

Song Dongfang, Xiao Wenjiao, Han Chunming, Tian Zhonghua, Li Yongchen. 2018&. Accretionary processes of the central segment of Beishan: Constraints from structural deformation and ^{40}Ar-^{39}Ar geochronology. Acta Petrologica Sinica, 34(7): 2087~2098.

Song Dongfang, Xiao Wenjiao, Windley B F, Mao Qigui, Ao Songjian, Wang H Y C, Li Rui. 2021. Closure of the Paleo-Asian Ocean in the Middle—Late Triassic (Ladinian—Carnian): Evidence From Provenance Analysis of Retroarc Sediments. Geophysical Research Letters. 48(14): e2021GL094276

Song Shuguang, Wang Mingming, Xu Xin, Wang Chao, Niu Yaoling, Allen M B, Su Li. 2016. Ophiolites in the Xing´an—Inner Mongolia accretionary belt of the CAOB;Implications for two cycles of seafloor spreading and accretionary orogenic events. Tectonics, 34(10): 2221~2248.

Su Wen, Gao Jun, Klemd R, Li Jilei, Zhang Xi, Li Xianhua, Chen Nengsong, Zhang Lu. 2010. U-Pb zircon geochronology of Tianshan eclogites in NWChina: implication for the collision between the Yili and Tarim blocks of the southwestern Altaids. European Journal of Mineralogy, 22(4), 473—478.

Sun Lixin, Zhang Jiahui, Ren Bangfang, Niu Wenchao, Ren Yunwei, Zhang Kuo. 2017&. Geochemical characteristics and U-Pb age of Baiyunshan ophiolite mélange in the Beishan orogenic belt and their geological implications. Acta Petrologica et Mineralogica, 36(2): 131~147.

Sun Yuewu, Shi Xiao, Li Xiang, Lang Jiabin, Zheng Yuejuan, Zhang Dejun, Zhang Yan. 2018&. Permian flora of the Northeast China and its geological significance. Abstract Volume of Joint Meetings on the 12th National Congress of the Palaeontological Society of China (PSC) and the 29th Annual Conference of PSC.

Tang Kedong. 1990. Tectonic development of Paleozoic foldbelts at the north margin of the Sino - Korean Craton. Tectonics, 9(2): 249~260.

Tang Kedong, Wang Ying, He Guoqi, Shao Ji'an. 1995&. Continental-margin structure of northeast China and its Adjacent areas. Acta Geologica Sinica, 1: 16~30.

Tian Dexin, Yang Hao, Ge Wenchun, Zhang Yanlong, Chen Jingsheng, Chen Huijun, Yun Xiuyu. 2018. Petrogenesis and tectonic implications of Late Carboniferous continental arc high-K granites in the Dongwuqi area, central Inner Mongolia, North China. Journal of Asian Earth Sciences, 167: 82~102.

Tian Zhonghua, Xiao Wenjiao, Windley B F, Lin Li´na, Han Chunming, Zhang Ji´en, Wan Bo, Ao Songjian, Song Dongfang, Feng Jianyun. 2014. Structure, age, and tectonic development of the Huoshishan—Niujuanzi ophiolitic melange, Beishan, southernmost Altaids. Gondwana Research. 25(2): 820~841.

Wang Baoyu, Lang Zhijun, Li Xiangdong. 1994&. Study on the Geological Sections Across the Western Segment of Tianshan Mountains, China. Beijing: Science Press.

Wang Bin, Zhou Jianbo, Wilde S A, Zhang Xingzhou, Ren Shoumai. 2016a. The timing of final closure along the Changchun—Yanji suture zone; Constraints from detrital zircon U-Pb dating of the Triassic Dajianggang Formation, NE China. Lithos, 261: 216~231.

Wang Bo, Chen Yan, Zhan Sheng, Shu Liangshu, Faure M, Cluzel D, Charvet J, Laurent-Charvet S. 2007. Primary Carboniferous and Permian paleomagnetic results from the Yili Block (NW China) and their implications on the geodynamic evolution of Chinese Tianshan Belt. Earth and Planetary Science Letters, 263(3~4): 288~308.

Wang Bo, Shu Liangshu, Faure M, Jahn B M, Cluzel D, Charvet J, Chung S, Meffre S. 2011. Paleozoic tectonics of the southern

Chinese Tianshan; Insights from structural, chronological and geochemical studies of the Heiyingshan ophiolitic mélange (NW China). Tectonophysics, 497(1~4): 85~104.

Wang Guoqiang, Li Xiangmin, Xu Xueyi, Yu Jiyuan, Wu Peng. 2021&. Research status and progress of Paleozoic ophiolites in Beishan orogenic belt. Geological Bulletin of China. 40(1): 71~81.

Wang Jingfan, Wang Jichun, Zhou Lulu, Zhao Xin, Qin Jiangdong, Guo Wenjun, Han Hongyu, Zhang Xiaoxin, Liu Yang. 2021&. The first recognition of Paleozoic ophiolitic melanges in Wenduermiao area, Inner Mongolia. Geological Review, 67(z1): 1163~1166.

Wang Quan, Liu Xueya. 1986. Paleoplate tectonics between Cathaysia and Angaraland in inner Mongolia of China. Tectonics, 5(7): 1073~1088.

Wang Yanyang, Xu Bei, Cheng Shengdong, Liao Wen, Shao Jun, Wang Yan. 2014&. Zircon U-Pb dating of the mafic lava from Wudaoshimen, Hexigten, Inner Mongolia and its geological significance. Acta Petrologica Sinica, 30(7): 2055~2062.

Wang Yu, Luo Zhaohua, Santosh M, Wang Shuzhi, Wang Na. 2016b. The Liuyuan Volcanic Belt in NW China revisited; evidence for Permian rifting associated with the assembly of continental blocks in the Central Asian Orogenic Belt. Geological Magazine, 154(2): 265~285.

Wang Yujing, Fan Zhiyong. 1997&. Discovery of Permian radiolarians in ophiolite belt on northern side of Xar Moron river, Nei Monggol, and its geological significance. Acta Palaeontologica Sinica, 1: 60~71.

Wang Yuanlong, Cheng Shoude. 2001&. Crust evolution and mineralization of Xinjiang uygur autonomous region. Chinese Journal of Geology, 36(2): 129~143.

Wang Zuoxun, Wu Jiyi, Lv Xichao, Liu Chengde, Zhang Jingguo. 1990&. Polycyclic Tectonic Evolution and Metallogeny of the Tianshan Mountains. Beijing: Science Press.

Wei Ruihua, Gao Yongfeng, Xu Shengchuan, Santosh M, Xin Houtian, Zhang Zhenmin, Li Weilong, Liu Yafang. 2018. Carboniferous continental arc in the Hegenshan accretionary belt; Constrains from plutonic complex in central Inner Mongolia. Lithos, 308: 242~261.

Wei Zhijun, Huang Zengbao, Jin Xia, Sun Yongjun, Huo Junchang. 2004&. Geological characteristics of ophiolite migmatitic complex of Hongshishan region, Gansu. Northwestern Geology, 37(2): 13~18.

Wilde S A. 2003. Late Pan-African magmatism in Northeastern China; SHRIMP U-Pb zircon evidence for igneous ages from the Mashan Complex. Precambrian Research, 122: 311~327.

Wilde S A, Wu Fuyuan, Zhang Xingzhou. 2003. Late Pan-African magmatism in northeastern China; SHRIMP U-Pb zircon evidence from granitoids in the Jiamusi Massif. Precambrian Research, 122(1~4): 311~327.

Windley B F, Allen M B, Zhang C, Zhao Z Y, Wang G R. 1990. Paleozoic accretion and Cenozoic redeformation of the Chinese Tien Shan Range, central Asia. Geology. 18(2): 128~131.

Windley B F, Alexeiev D, Xiao Wenjiao, Kroener A, Badarch G. 2007. Tectonic models for accretion of the Central Asian Orogenic Belt. Journal of the Geological Society, 164(1): 31~47.

Wu Didi, Li Shan, Chew D, Liu Tieyi, Guo Donghai. 2021&. Permian—Triassic magmatic evolution of granitoids from the southeastern Central Asian Orogenic Belt: Implications for accretion leading to collision. Science China Earth Sciences, 51(6): 906~926.

Wu Fuyuan, Sun Deyou, Li Huimin, Jahn B M, Wilde S A. 2002. A-type granites in northeastern China; age and geochemical constraints on their petrogenesis. Chemical Geology, 187(1~2): 143~173.

Wu Fuyuan, Zhao Guochun, Sun Deyou, Wilde S A, Yang Jinhui. 2007. The Hulan Group; Its role in the evolution of the Central Asian Orogenic Belt of NE China. Journal of Asian Earth Sciences, 30(3~4): 542~556.

Wu Fuyuan, Sun Deyou, Ge Wenchun, Zhang Yanbin, Grant M L, Wilde S A, Jahn B M. 2011a. Geochronology of the Phanerozoic granitoids in northeastern China. Journal of Asian Earth Sciences, 41(1): 1~30.

Wu Tairan, Zheng Rongguo, Zhang Wen. 2011b. Tectonic framework of Beishan Mountain—Northern Alxa Area and the time constraints for the closing of the Paleo-Asian Ocean. Proceedings of the Fifth Workshop on 1;5M International Geological Map of Asia, 95~98.

Xi Aihua, Ren Hongmao, Zhang Baofu, Wang Yongxiang, Shi Shubao, Zhi Xuejun. 2003&. Isotopic chronology of the Hulan Group and its geological significance in the central Jilin Province. Journal of Jilin University (Earth Science Edition), 33(1): 15~18.

Xia Linqi, Xu Xueyi, Xia Zuchun, Li Xiangmin, Ma Zhongpin, Wang Lishe. 2003. Carboniferous Post-collisional Rift Volcanism of the Tianshan Mountains, Northwestern China. Acta Geologica Sinica (English Edition), 3: 338~360.

Xia Linqi, Xu Xueyi, Xia Zuchun, Li Xiangmin, Ma Zhongpin, Wang Lishe. 2004. Petrogenesis of Carboniferous rift-related volcanic rocks in the Tianshan, northwestern China. Geological Society of America Bulletin, 116(3~4): 419~433.

Xia Linqi, Li Xiangmin, Xu Xueyi, Xia Zuchun, Ma Zhongpin, Wang Lishe. 2005. Petrogenetic Evolution of the Bayan Gol Ophiolite——Geological Record of an Early Carboniferous "Red Sea Type" Ocean Basin in the Tianshan Mountains, Northwestern China. Acta Geologica Sinica - English Edition, 79(2): 174~192.

Xia Linqi, Xia Zuchun, Xu Xueyi, Li Xiangmin, Ma Zhongpin. 2008. Relative contributions of crust and mantle to the generation of the Tianshan Carboniferous rift-related basic lavas, northwestern China. Journal of Asian Earth Sciences, 31(4~6): 357~378.

Xiao Wenjiao, Windley B F, Hao Jie, Zhai Mingguo. 2003. Accretion leading to collision and the Permian Solonker suture, Inner Mongolia, China: Termination of the central Asian orogenic belt. Tectonics, 22(6): 1~20.

Xiao Wenjiao, Han Chunming, Yuan Chao, Sun Min, Lin Shoufa, Chen Hanlin, Li Zilong, Li Jiliang, Sun Shu. 2008. Middle Cambrian to Permian subduction-related accretionary orogenesis of Northern Xinjiang, NW China; implications for the tectonic evolution of central Asia. Journal of Asian Earth Sciences, 32(2~4): 102~117.

Xiao Wenjiao, Mao Qigui, Windley B F, Han Chunming, Qu Junfeng, Zhang Ji'en, Ao Songjian, Guo Qianqian, Cleven N R, Lin Shoufa, Shan Y H, Li Jiliang. 2010a. Paleozoic multiple accretionary and collisional processes of the Beishan orogenic collage. American Journal of Science, 310(10): 1553~1594.

Xiao Wenjiao, Huang Baochun, Han Chunming, Sun Shu, Li Jiliang. 2010b. A review of the western part of the Altaids; a key to understanding the architecture of accretionary orogens. Gondwana Research, 18(2~3): 253~273.

Xiao Wenjiao, Windley B F, Allen M B, Han Chunming. 2013. Paleozoic multiple accretionary and collisional tectonics of the Chinese Tianshan orogenic collage. Gondwana Research, 23(4): 1316~1341.

Xiao Wenjiao, Windley B F, Sun Shu, Li Jiliang, Huang Baochun, Han

Chunming, Yuan Chao, Sun Min, Chen Hanlin. 2015. A Tale of Amalgamation of Three Permo—Triassic Collage Systems in Central Asia; Oroclines, Sutures, and Terminal Accretion. Annual Review of Earth and Planetary Sciences, 43(1): 477~507.

Xiao Wenjiao, Windley B F, Han Chunming, Liu Wei, Wan Bo, Zhang Ji'en, Ao Songjian, Zhang Zhiyong, Song Dongfang. 2018. Late Paleozoic to early Triassic multiple roll-back and oroclinal bending of the Mongolia collage in Central Asia. Earth-Science Reviews, 186: 94~128.

Xiao Wenjiao, Li Jiliang, Song Dongfang, Han Chunming, Wan Bo, Zhang Ji'en, Ao Songjian, Zhang Zhiyong. 2019&. Structural Analyses and Spatio—Temporal constraints of accretionary orogens. Earth Science (Journal of China University of Geosciences), 44(5): 1661~1687.

Xie Li, Yin Haiquan, Zhou Hongrui, Zhang Weijie. 2014&. Permian radiolarians from the Engeerwusu suture zone in Alxa area of Inner Mongolia and its geological significance. Geological Bulletin of China, 5: 691~697.

Xin Houtian, Niu Wenchao, Tian Jian, Teng Xuejian, Duan Xiaolong. 2020&. Spatio—temporal structure of Beishan orogenic belt and evolution of Paleo-Asian Ocean, Inner Mongolia. Geological Bulletin of China, 39(9): 1297~1316.

Xin Yulian, Ren Junli, Peng Yujing, Sun Xiqing. 2011&. Ending of the mountain-building movement of Xing'an—Mongolian—Ji—Hei Orogenic Belt in Northeast China: evidence from Late Triassic molasse (geotectoinc phase). Geology and Resources, 20(6): 413~419.

Xu Bei, Chen Bin. 1997&. Structure and evolution of Mesozoic Paleozoic orogenic belt between North China plate and Siberian plate in northern Inner Mongolia. Science in China, Ser. D, 3: 227~232.

Xu Xueyi, Xia Linqi, Ma Zhongping, Wang Yanbin, Xia Zuchun, Li Xiangmin, Wang Lishe. 2006&. SHRIMP zircon U-Pb geochronology of the plagiogranites from Bayingou ophiolite in North Tianshan Mountains and the petrogenesis of the ophiolite. Acta Petrologica Sinica, 22(1): 83~94.

Xu Xueyi, Wang Hongliang, Li Ping, Chen Junlu, Ma Zhongping, Zhu Tao, Wang Ning, Dong Yunpeng. 2013. Geochemistry and geochronology of Paleozoic intrusions in the Nalati (Narati) area in western Tianshan, Xinjiang, China; Implications for Paleozoic tectonic evolution. Journal of Asian Earth Sciences, 72: 33~62.

Yakubchuk A. 2004. Architecture and mineral deposit settings of the Altaid orogenic collage; a revised model. Journal of Asian Earth Sciences, 23(5): 761~779.

Yang Gaoxue, Li Yongjun, Si Guohao, Li Hai, Tong Lili, Wang Zuopeng. 2021&. Discussion on time and mechanism of subduction initiation in the western Central Asian Orogenic Belt. Journal of Earch Sciences and Environment, 43(2): 244~261.

Yang Hequn, Li Ying, Li Wenming, Yang Jianguo, Zhao Guobin, Sun Nanyi, Wang Xiaohong, Tan Wenjuan. 2008&. General discussion on metallogenitic tectonic setting of Beishan mountain, Northwestern China. Northwestern Geology, 41(1): 22~28.

Yang Hequn, Li Ying, Zhao Guobin, Li Wenyuan, Wang Xiaohong, Jiang Hanbing, Tan Wenjuan, Sun Nanyi. 2010&. Character and structural attribute of the Beishan ophiolite. Northwestern Geology, 43(1): 26~36.

Yang Jinhui, Wu Fuyuan, Wilde S A, Belousova E, Griffin W L. 2008. Mesozoic decratonization of the North China block. Geology, 36(6): 467~470.

Yu Qinfan, Lou Hai, Hu Zhongdong. 1995&. Magnetic data interpretation of the crustal structure of the geoscience transection from Golmud to Ejinqi. Chinese Journal of Geophysics, 38(A02): 58~70.

Yuan Lingling, Zhang Xiaohui, Xue Fuhong, Liu Fulin. 2016. Juvenile crustal recycling in an accretionary orogen; Insights from contrasting Early Permian granites from central Inner Mongolia, North China. Lithos, 264: 524~539.

Zhang Chunyan, Zhang Xingzhou, Xia Qinghe. 2009&. Zircon U-Pb age of siliceous rock from the central Jilin and its geological significance. Geoscience, 23(2): 256~261.

Zhang Lifei, Song Shuguang, Liou J G, Ai Yongliang, Li Xuping. 2005. Relict coesite exsolution in omphacite from Western Tianshan eclogites, China. American Mineralogist, 90(1): 181~186.

Zhang Lifei, Ai Yongliang, Li Qiang, Li Xuping, Song Shuguang, Wei Chunjing. 2005&. The formation and tectonic evolution of UHP metamorphic belt in southwestern Tianshan, Xinjiang. Acta Petrologica Sinica, 21(4): 1029~1038.

Zhang Lifei, Ai Yongliang, Li Xuping, Rubatto D, Song Biao, Williams S, Song Shuguang, Ellis D, Liou J G. 2007. Triassic collision of western Tianshan orogenic belt, China; Evidence from SHRIMP U-Pb dating of zircon from HP/UHP eclogitic rocks. Lithos, 96(1~2): 266~280.

Zhang Lifei, Du Jinxue, Lu Zeng, Yang Xin, Gou Longlong, Xia Bin, Chen Zhenyu, Wei Chunjing, Song Shuguang. 2013&. A huge oceanic-type UHP metamorphic belt in southwestern Tianshan, China; Peak metamorphic age and P—T path. Chinese Science Bulletin, 58(35): 4378~4383.

Zhang Shuanhong, Zhao Yue, Kroener A, Liu Xiaoming, Xie Liewen, Chen Fukun. 2009a. 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. International Journal of Earth Sciences, 98(6): 1441~1467.

Zhang Shuanhong, Zhao Yue, Davis G A, Ye Hao, Wu Fei. 2014. Temporal and spatial variations of Mesozoic magmatism and deformation in the North China Craton; Implications for lithospheric thinning and decratonization. Earth-Science Reviews, 131: 49~87.

Zhang Shuanhong, Zhao Yue, Liu Jianmin, Hu Jianmin, Song Biao, Liu Jian, Wu Hai. 2010&. Geochronology, geochemistry and tectonic setting of the Late Paleozoic—Early Mesozoic magmatism in the northern margin of the North China Block: A preliminary review. Acta Petrologica Et Mineralogica, 29(6): 824~842.

Zhang Xiaohui, Wilde S A, Zhang Hongfu, Tang Yanjie, Zhai Mingguo. 2009b. Geochemistry of hornblende gabbros from Sonidzuoqi, Inner Mongolia, North China; implications for magmatism during the final stage of suprasubduction - zone ophiolite formation. International Geology Review, 51(4): 345~373.

Zhang Yanbin, Wu Fuyuan, Wilde S A, Zhai Mingguo, Lu Xiaoping, Zhang Huafeng. 2008. Geochronology and tectonic implications of the "Proterozoic" Seluohe Group at the northern margin of the North China Craton. International Geology Review, 50(2): 135~153.

Zhang Yuanyuan, Dostal J, Zhao Zehui, Liu Chang, Guo Zhaojie. 2011. Geochronology, geochemistry and petrogenesis of mafic and ultramafic rocks from Southern Beishan area, NW China; Implications for crust—mantle interaction. Gondwana Research, 20(4): 816~830.

Zhang Yunping, Tang Kedong. 1989. Pre-Jurassic tectonic evolution of intercontinental region and the suture zone between the North China and Siberian platforms. Journal of Southeast Asian Earth Sciences, 3(1~4): 47~55.

Zhao Yingli, Li Weimin, Wen Quanbo, Liang Chenyue, Feng Zhiqiang,

Zhou Jianping, Shen Liang. 2016&. Late Paleozoic tectonic framework of eastern Inner Mongolia: Evidence from the detrital zircon U-Pb ages of the Mid—Late Permian to Early Triassic sandstones. Acta Petrologica Sinica, 32(9): 2807~2822.

Zheng Rongguo, Wu Tairan, Zhang Wen, Xu Cao, Meng Qingpeng, Zhang Zhaoyu. 2014. Late Paleozoic subduction system in the northern margin of the Alxa block, Altaids: Geochronological and geochemical evidences from ophiolites. Gondwana Research. 25(2), 842~858.

Zhou Jianbo, Wilde S A. 2013. The crustal accretion history and tectonic evolution of the NE China segment of the Central Asian Orogenic Belt. Gondwana Research, 23(4): 1365~1377.

Zhou Jianbo, Wilde S A, Zhang Xingzhou, Zhao Guochun, Zheng Changqing, Wang Yuejun, Zhang Xiaohui. 2009. The onset of Pacific margin accretion in NE China: evidence from the Heilongjiang high-pressure metamorphic belt. Tectonophysics, 478(3~4): 230~246.

Zhou Jianbo, Wilde S A, Zhao Guochun, Zhang Xingzhou, Wang Hu, Zeng Weishun. 2010a. Was the easternmost segment of the Central Asian Orogenic Belt derived from Gondwana or Siberia: an intriguing dilemma? Journal of Geodynamics, 50(3~4): 300~317.

Zhou Jianbo, Wilde S A, Zhao Guochun, Zhang Xingzhou, Zheng Changqing, Wang Hu. 2010b. New SHRIMP U-Pb zircon ages from the Heilongjiang High-Pressure Belt: Constraints on the Mesozoic evolution of NE China. American Journal of Science, 310(9): 1024~1053.

Zhou Jianbo, Wilde S A, Zhao Guochun, Zhang Xingzhou, Zheng Changqing, Wang Hu, Zeng Weishun. 2010c. Pan-African metamorphic and magmatic rocks of the Khanka Massif, NE China: further evidence regarding their affinity. Geological Magazine, 147(5): 737~749.

Zhou Jianbo, Zeng Weishun, Cao Jialin, Han Jie, Guo Xiaodan. 2012&. The tectonic framework and evolution of the NE China: from ~500 Ma to ~180 Ma. Journal of Jilin University (Earth Science Edition), 42(5): 1298~1316.

Zhou Jianbo, Han Jie, Wilde S A, Guo Xiaodan, Zeng Weishun, Cao Jialin. 2013&. A primary study of the Jilin—Heilongjiang high-pressure metamorphic belt: Evidence and tectonic implications. Acta Petrologica Sinica, 29(2): 386~398.

Zhou Jianbo, Cao Jialin, Wilde S A, Zhao Guochun, Zhang Jinjiang, Wang Bin. 2014. Paleo - Pacific subduction - accretion: Evidence from Geochemical and U - Pb zircon dating of the Nadanhada accretionary complex, NE China. Tectonics, 33(12): 2444~2466.

Zhou Jianbo, Han Jie, Zhao Guochun, Zhang Xingzhou, Cao Jialin, Wang Bin, Pei Shenghui. 2015. The emplacement time of the Hegenshan ophiolite; Constraints from the unconformably overlying Paleozoic strata. Tectonophysics, 662: 398~415.

Zhou Jianbo, Li Long. 2017. The Mesozoic accretionary complex in Northeast China; evidence for the accretion history of Paleo-Pacific subduction. Journal of Asian Earth Sciences, 145: 91~100.

Zhou Jianbo, Wilde S A, Zhao Guochun, Han Jie. 2018. Nature and assembly of microcontinental blocks within the Paleo-Asian Ocean. Earth-Science Reviews, 186: 76~93.

Zhou Jianbo, Cao Jialin, Han Wei, Li Gongyu. 2020&. The Changchun—Yanji suture zone: Nature and tectonic implications. Acta Petrologica Sinica, 36(3): 635~643.

Zhu Junbin. 2015&. The Upper Carboniferous—Lower Triassic Sedimentary Environment And Tectonic Setting of Southeast Inner Mongolia. Tutor: Ren Jishun. Beijing: Doctoral Dissertation of China University of Geosciences: 1~122.

Zhu Junbin, He Zhengjun. 2017&. Detrital zircon records of Upper Permian—Middle Triassic sedimentary sequence in the Linxi area, Inner Mongolia and constraints on timing of final closure of the Paleo-Asian Ocean (eastern segment). Acta Geologica Sinica, 91(1): 232~248.

Zorin Y A. 1999. Geodynamics of the western part of the Mongolia—Okhotsk collisional belt, Trans-Baikal region (Russia) and Mongolia. Tectonophysics, 306(1): 33~56.

Zuo Guochao, Zhang Shuling, He Guoqi, Zhang Yang. 1990&. Early Paleozoic plate tectonics in Beishan area. Chinese Journal of Geology, 25(4): 305~314.

Zuo Guochao, Zhang Zuoheng, Wang Zhiliang, Liu Min, Wang Longsheng. 2008&. Tectonic division, stratigraphical system and the evolution of western Tianshan mountains, Xinjiang. Geological Review, 54(6): 748~767.

Nature and evolution of the South Tianshan Mountains—Beishan Mountains—Solonker—Changchun Suture

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Abstract: The formation and evolution of the South Tianshan Mountains—Beishan Mountains—Solonker—Changchun Suture, as the final closure position of the Paleo-Asian Ocean, has been the focus of research of the Central Asian Orogenic Belt. Studies on the formation age and subduction polarity of this suture zone can help us to reveal the accretionary and evolutionary history of the Central Asian Orogenic Belt and provide theoretical support for the establishment of a tectonic evolutionary model of the Paleo-Asian Ocean. In this paper, the South Tianshan Mountains —Beishan Mountains —Solonker—Changchun Suture is divided into four segments based on the differences in geotectonic setting, rock composition, closure mode and closure era, and they are, from west to east:

the South Tianshan Suture, the Beishan Suture, the Solonker—Changchun Suture, and the Changchun—Yanji Suture. The South Tianshan Suture is located in the western section of this suture zone and is a result of the northward subduction of the Tarim block, which collapsed with the Kazakhstan—Yili block, and it was formed in the Late Carboniferous based on the evidences of high-pressure metamorphic age, intrusive dike and unconformity cover, etc. The Beishan Suture is located in the middle section, formed during the northward subduction of Dunhuang and Alxa blocks, which collapsed with the Tuva—Mongolia block, and it was formed in the Early—Middle Permian based on the chronological evidences of the ophiolites. The two ophiolite belts at the northern margin of the Alxa block, as the connecting belt between the Beishan Suture and the Solonker—Changchun Suture, represent the suture zone and the post-arc basin formed during the closure process of the Paleo-Asian Ocean, and they were formed in the middle Permian—early Late Permian. The Solonker—Changchun Suture is located in the middle—eastern section, where the Paleo-Asian Ocean underwent simultaneous southward and northward subduction in both directions, and the amalgamation of two sides was completed in the Middle Permian—Early Triassic. The Changchun—Yanji Suture was formed during the amalgamation between the North China Craton and the Jiamusi—Khanka block around the Middle Triassic, and is 20 ~ 30 Ma later than the formation age of the Solonker—Changchun Suture (270 ~ 250 Ma), Therefore, these two sutures have significantly different formation age and tectonic setting, and the Changchun—Yanji Suture is not part of the eastern extension of the Solonker—Changchun Suture. The Paleo-Asian Ocean evolved in four stages along the South Tianshan Mountains —Beishan Mountains —Solonker—Changchun suture, and the closure age gradually become younger from west to east, and the whole process lasted from the Late Carboniferous to Triassic, in which the Changchun—Yanji suture recorded the geological process of superposition and transformation between the Paleo-Asian Ocean tectonic domain and the Paleo-Pacific Ocean tectonic domain.

Keywords: Central Asian orogenic belt; South Tianshan Mountains —Beishan Mountains —Solonker—Changchun suture; segmental evolution; subduction polarity; tectonic domain conversion

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