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IBM型洋内弧的形成机制:以祁秦增生杂岩带为例

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摘　要: 岛弧的形成和演化对于理解板块构造和大陆生长有重要意义.祁连山－西秦岭一带发育两条不同类型的弧岩浆岩带,其北侧为北祁连增生杂岩带,由蛇绿岩、高压变质岩和大陆型弧岩浆岩带组成,形成时代为520～440 Ma.岩浆岩以中酸性火山岩－侵入岩为主,部分地区发育典型双峰式火山岩.南侧为祁秦增生杂岩带,由寒武纪蛇绿岩(525～490 Ma)和奥陶纪IBM型洋内弧岩浆岩(470～440 Ma)组成,蛇绿岩以拉脊山－永靖洋底高原型蛇绿岩为代表,蛇绿岩的上部熔岩部分由夏威夷型苦橄岩、板内碱性玄武岩和板内拉斑玄武岩组成,为大洋板块内部地幔柱活动产物.洋内弧岩浆岩以高镁玄武岩、玄武安山岩、高铝安山岩、玻安岩为主,局部发育赞岐岩.祁秦增生杂岩带的蛇绿岩和弧火山岩组合很好地说明洋底高原与海沟碰撞和俯冲带阻塞是造成俯冲带起始和新的洋内弧形成和发展主要因素.

关键词: 寒武纪洋底高原型;奥陶纪洋内弧;祁秦增生杂岩带;岩石学.

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Formation of the IBM-Type Intra-Oceanic Arc: An Example from the Qi-Qin Accretionary Belt, China

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Abstract: Formation and evolution of the island/continental arcs are keys to understanding the plate tectonics and continent growth. In the Qilian and West Qinling, NW China, two different types of arc magmatic belts have been recognized. One is the North Qilian accretionary belt in the north, which consists of ophiolites, high-pressure metamorphic complex, and continental-type arc magmatic belt with ages of 520－440 Ma. The magmas are mainly intermediate to acid volcanics and intrusions. In the south is the Qi-Qin accretionary belt, which consists of Cambrian ophiolites (525－490 Ma) and Izu-Bonin-Mariana (IBM)-type intra-oceanic arc volcanic complexes (470－440 Ma). The Cambrian ophiolites are meanly composed of (1) the Hawaii-type picrite, (2) the within-plate alkaline basalt with intra-plate ocean-island-basalt (OIB) compositions, and (3) the within-plate tholeiitic basalt with enriched mid-ocean-ridge-basalt (E-MORB) compositions. The rock assemblage is best interpreted as an oceanic plateau of mantle plume within the Proto-Tethys ocean plate, obducted as ophiolitic fragments in the QQAB. The intraoceanic arc volcanic complexes are composed of high-Mg basalts, basaltic andesite, high-Al andesite, boninite and sanukite. Therefore, trench jam and subduction cessation caused by the arrival of an oceanic plateau are the primitive trigger for initiation of a new subduction zone with the development of younger volcanic sequence (～460－440 Ma).

Key words: Cambrian oceanic plateau; Ordovician intra-oceanic arc; Qi-Qin accretionary belt; petrology.

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0 引言

全球大洋俯冲带有关的岩浆弧可以划分为两种:(1)大陆弧或活动大陆边缘,(2)大洋弧或洋内弧,二者在俯冲带结构和岩浆作用特征等方面都存在明显差别.大陆弧以太平洋东岸的美洲活动大陆边缘为特征,与俯冲带相关的岩浆作用所产生的岩石组合以中酸性火山岩和花岗质侵入体为主,是地幔楔产生岩浆与上覆大陆地壳岩浆相互作用的结果;洋内弧以太平洋西岸的伊豆－小笠原－马里亚纳(IBM)岛弧为典型,与其后方的弧后盆地构成沟－弧－盆俯冲带结构体系,其岩石组合以中基性火山岩为主,在小笠原地区,最早出现的是亏损的、类似N-型洋中脊玄武岩,然后是玻安岩、高镁安山岩和正常的岛弧火山岩,并以具有特征的、高场强元素和重稀土极度亏损的玻安岩与大陆弧相区分(Gill,1981).洋内弧的形成和演化过程研究对于理解俯冲带起始、后撤及弧后盆地形成等动力学过程及大陆地壳增生等方面有重要意义.

1 祁秦增生杂岩带的分布和岩石组合

如图1所示,祁连造山带和东昆仑造山带位于柴达木地块的两侧,二者向东收敛与秦岭造山带汇合.祁连山－西秦岭一带发育两条不同类型的弧岩浆岩带,其北侧为北祁连增生杂岩带,发育有祁连－白银大陆弧岩浆岩带,其发育时代为520～440 Ma,以中酸性火山岩－侵入岩为主,部分地区发育典型双峰式火山岩(Song *et al.*,2013).近年来,通过西秦岭和南祁连的蛇绿岩和弧岩浆岩研究,我们建立了连接祁连和秦岭的“祁秦俯冲增生杂岩带”(Song *et al.*,2017).自西向东,该杂岩带从肃北党河南山－盐池湾开始,经青海湖北侧的刚察和海晏,拉脊山、永靖、西秦岭武山－天水,延伸到东秦岭,长度约2 000 km(图1).

祁秦增生杂岩带呈断续分布的地体沿NW-SE方向展布.在祁连山地区,该杂岩带展布于任纪舜等(1980)划分的中祁连地块与南祁连冒地槽褶皱带之间的分界线上,我们称之为“南祁连增生杂岩带”,包括最西端的党河南山－盐池湾地体、木里地体、刚察地体和拉脊山－永靖地体.而南祁连早古生代沉积岩地层是被动陆缘和俯冲带之间的沉积盆地(Song *et al.*,2013).向东延伸至西秦岭造山带天水－武山地体(董云鹏等,2007;Song *et al.*,2017;Yang *et al.*,2018),并与东秦岭地区商丹杂岩带(Li *et al.*,2015)相连.

祁秦增生杂岩带主要由寒武纪(>490 Ma)蛇绿岩和奥陶纪洋内弧火山岩＋弧前蛇绿岩组成.早期蛇绿岩形成于535～490 Ma,为俯冲带无关的蛇绿岩组合,形成于洋底高原和洋中脊(付长垒等,

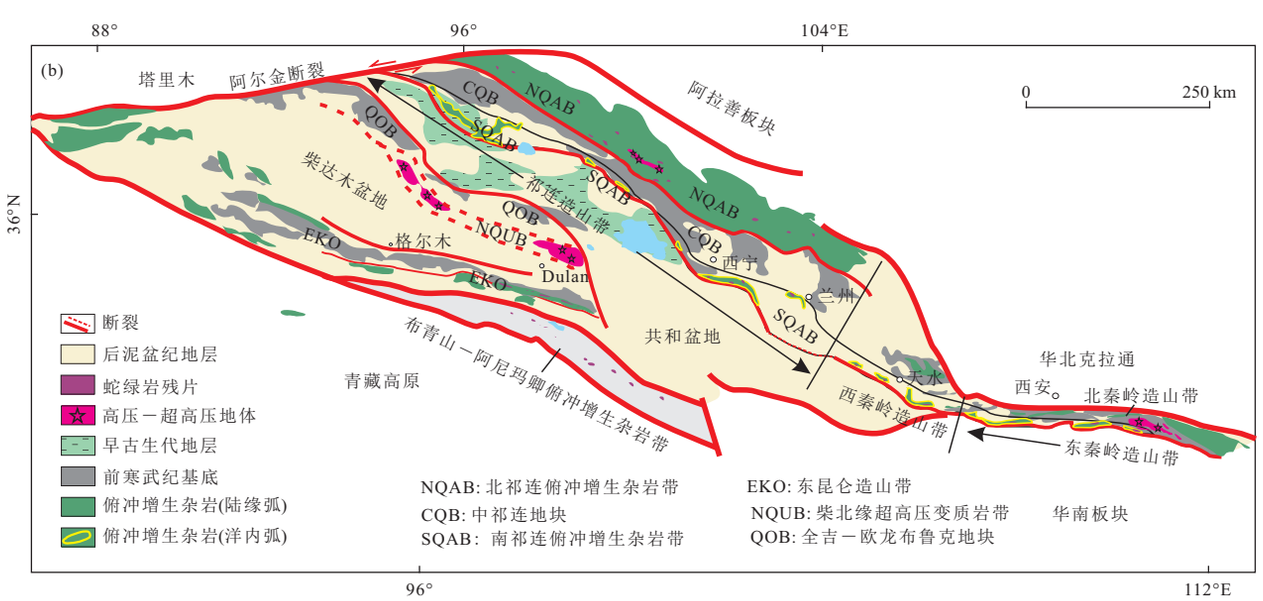

图1 祁连－秦岭地质简图及祁秦增生杂岩带的分布

Fig.1 Skeleton geological map of the Qilian-Qinling orogens and distribution of the Qi-Qin accretionary complex belt

据 Song *et al.*(2017)

2014;Song *et al.*,2017;Zhang *et al.*,2017;Yang *et al.*,2019a).晚期蛇绿岩470～440 Ma,形成于俯冲带环境,为弧前伸展的SSZ型蛇绿岩.

1.1　西秦岭天水-武山地体

天水－武山俯冲增生杂岩带主要是由几个不连续的NW-SE展布的透镜状构造岩片组成,主要包括天水地体和武山地体,位于北部的活动大陆边缘和南部的陆间盆地之间.这些地体主要由两个单元组成:蛇绿混杂岩和岛弧火山岩序列,二者平行展布.

天水－武山地体的蛇绿岩包括关子镇蛇绿岩和武山蛇绿岩,展布于俯冲杂岩体的北侧,岩石组合主要为块状和枕状变玄武岩,变辉长岩和薄层的深海燧石条带,斜长花岗岩和蛇纹岩零星分布.玄武岩具有富集到亏损的大洋中脊玄武岩的地球化学成分特征(董云鹏等,2007;Yang *et al.*,2018),辉长岩中锆石的U-Pb定年确定蛇绿岩的形成时代为537～500 Ma(裴先治等,2007;李王晔,2008;Yang *et al.*,2018),与祁连山蛇绿岩带的形成时间(Song *et al.*,2013)基本一致.地球化学分析显示蛇绿岩中的块状和枕状熔岩均为拉斑玄武岩,并具有N-MORB和E-MORB的微量元素特征,无高场强元素的亏损(Yang *et al.*,2018).

岛弧火山岩的岩石类型主要有岛弧玄武安山岩和玻安岩,不同岩石类型之间未见清晰的界限.玄武安山岩显示深绿色、块状构造和无斑晶结构.玻安岩则为斑状结构,含有粗粒橄榄石和单斜辉石斑晶的假象.

1.2　东秦岭丹凤杂岩

很多学者认为西秦岭的天水－武山杂岩向东可以与丹凤杂岩对比或连接(董云鹏等,2007;裴先治等,2007;Dong *et al.*,2011a,2011b;李源等,2012;Li *et al.*,2015).在东秦岭地区,早古生代丹凤杂岩呈断续出露的构造块体自西向东分布,包括唐藏、岩湾、鹦鸽嘴、丹凤等地.由于后期构造作用的改造,很多蛇绿岩和弧火山岩层序以及完整性被肢解并破坏而难以识别和区分.在岩湾地区,蛇绿岩中玄武岩具有N-和E-型洋中脊玄武岩特征,辉长岩的锆石年龄为517±2.8 Ma(陈隽璐等,2008;Dong *et al.*,2011a).在鹦鸽嘴地区,蛇绿岩中玄武岩也具有N-和E-型洋中脊玄武岩的地球化学特征,形成年龄为524±1 Ma和474±2 Ma,可能分别代表洋中脊和弧后盆地蛇绿岩的形成时代(陈隽璐等,2008;Dong *et al.*,2011a,2011b;李源等,2012).Li *et al.*(2015)通过对丹凤杂岩的地球化学研究,划分出3种类型岩石组合:洋中脊玄武岩类、玻安岩类和岛弧火山岩类.因此,东秦岭的丹凤杂岩也可以大致区分出寒武纪蛇绿岩组合和奥陶纪弧火山岩组合,与上述的西秦岭天水－武山地体可以对比.

1.3　拉脊山-永靖地体

拉脊山－永靖地体主要分布在南祁连增生杂岩带的东侧,也是由蛇绿岩和岛弧火山岩组成.蛇绿岩主要呈北西－南东向展布于地体的北侧,岛弧火山岩展布于增生杂岩地体的南部,二者为断层接触.地体被白垩纪沉积地层不整合覆盖.

拉脊山－永靖蛇绿岩组合的规模较大,岩石新鲜,可以作为南部蛇绿岩带的代表,蛇绿岩下部组合的橄榄岩和堆晶岩相对较少,零星出露,而上部组合的玄武质熔岩占主要成分,局部出现红色硅质岩.地球化学分析显示玄武质熔岩主要有3种类型岩石组成:洋岛拉斑玄武岩、洋岛碱性玄武岩和夏威夷型苦橄岩,为典型的地幔柱型洋底高原岩石组合(Zhang *et al.*,2017),形成年龄为寒武纪(525～491 Ma)(付长垒等,2014;Zhang *et al.*,2017).

岛弧火山岩主要为中基性火山岩,包括高镁苦橄岩(ankaramite)、玻安岩、高镁安山岩、高铝安山岩和赞岐岩,其中玻安岩自西向东延伸约1 500 km,为典型的洋内弧火山岩组合,可以与西太平洋IBM洋内岛弧对比,形成时代为奥陶纪(460～440 Ma)(Yang *et al.*,2019b).

1.4　木里地体

木里地体主要位于南祁连增生杂岩带的中段,面积大约为16×20 km^2.其北侧为寒武纪蛇绿岩残片,南侧为奥陶纪的岛弧火山－沉积岩系组成,然后被三叠纪沉积岩不整合覆盖,并被～470～445 Ma的中酸性岛弧相关深成岩体侵入(Yan *et al.*,2019;Yang *et al.*,2019b).

蛇绿混杂岩主要以几个北西－南东向展布的透镜体岩片形式出露,位于北部的中祁连地块前寒武纪基底和南侧的花岗岩侵入体之间.岩石组合主要包括蛇纹石化橄榄岩、辉石岩、辉长岩和枕状玄武岩.枕状玄武岩具有N-MORB的地球化学特征;辉长岩的锆石年龄为520～492 Ma(青海地调院,未刊资料;Yan *et al.*,2019).

木里岛弧火山－沉积岩系主要由火山碎屑岩、火山角砾岩和少量块状火山岩组成,厚度超过

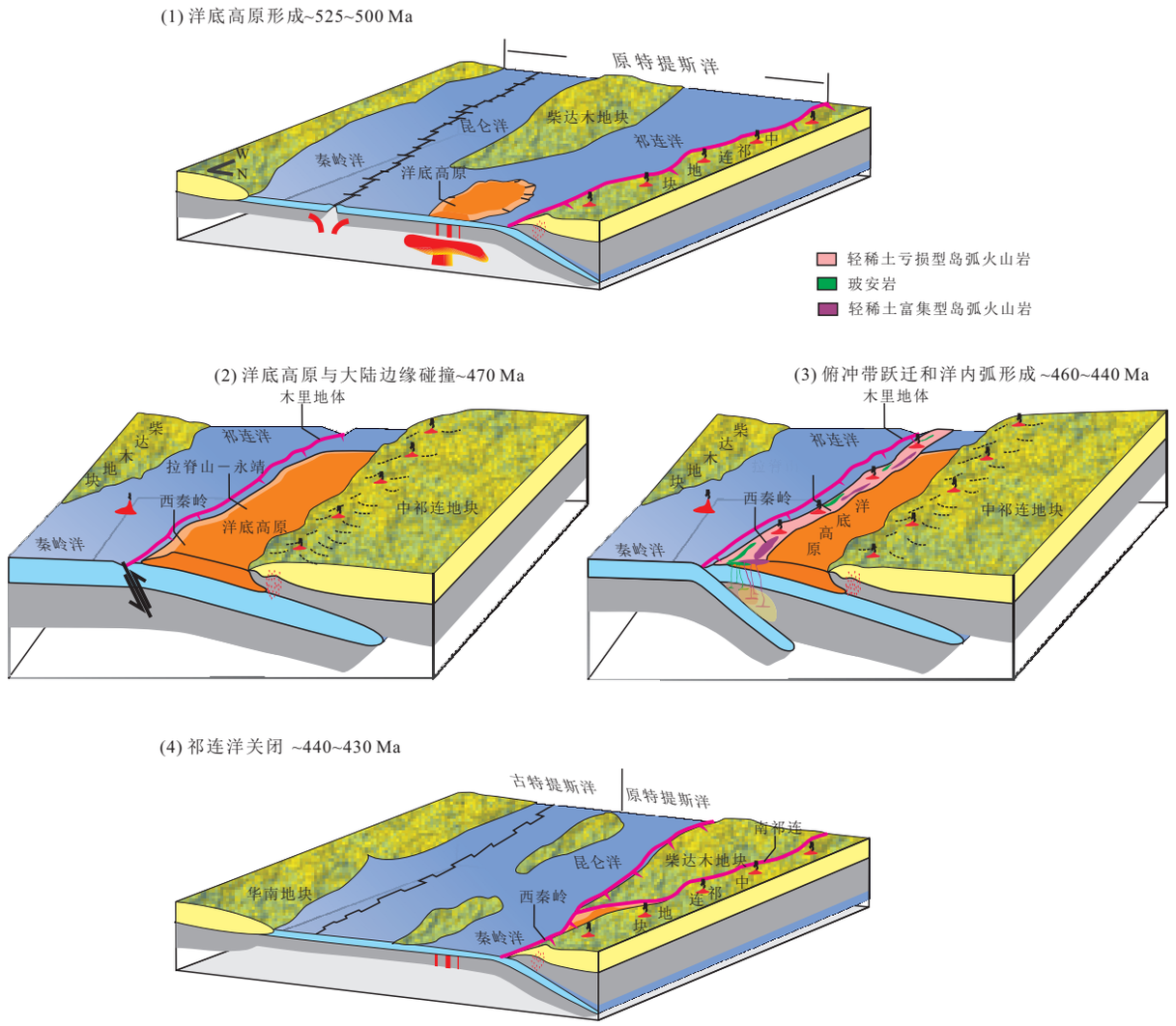

图 2 祁－秦俯冲增生杂岩带及特提斯洋(包括昆仑洋)构造－岩浆演化模式

Fig.2 Schematic model for the tectonic-magmatic evolution of the Qi-Qin accretionary complex belt and the Proto-Tethys ocean (including Kunlun ocean)

据 Yang *et al.*(2018)

2.5 km,主要岩石为块状安山质－英安质火山岩,并有基性火山岩包体.早古生代复理石沉积建造发育,自下而上由浅海浊流相复理石建造和陆源碎屑岩相磨拉石建造组成.地球化学特征为钠质的类埃达克岩,锆石年龄~445 Ma,形成于地幔源区产生的基性岩浆和俯冲板片熔融产生的熔体的混合作用(Yang *et al.*,2019b).

1.5 党河南山－盐池湾地体

党河南山－盐池湾地体位于祁秦增生杂岩带的最西端,由于地理条件限制,其研究程度相对较差.沿党河南山主要为奥陶纪岛弧火山岩(玄武安山岩和玻安岩;宋述光等,未刊资料)和 465~440 Ma 花岗质岩石(Wang *et al.*,2017).黄增保等(2016)在大道尔吉蛇绿岩中的镁铁－超镁铁质堆晶岩中获得 Sm-Nd 等时线的年龄为 441±58 Ma,并认为大道尔吉蛇绿岩属于 SSZ 型蛇绿岩,形成于弧后盆地环境.

2 祁秦增生杂岩带中洋内弧的形成模式

南祁连拉脊山－永靖地区寒武纪(525~500 Ma)洋底高原型蛇绿岩的确定,证明了寒武纪原特提斯洋板内地幔柱活动和大火成岩省的存在(Song *et al.*,2017;Zhang *et al.*,2017);同时,奥陶纪(460~440 Ma)洋内岛弧火山岩的研究揭示了该区

域岛弧火山岩的成因,并有助于理解洋内岛弧的性质、形成和演化过程(Yang *et al.*,2019a).

我们认为祁秦俯冲增生杂岩带主要形成于原特提斯洋寒武纪洋底高原大洋俯冲过程中在俯冲带形成阻塞,增生到活动陆缘,并在其后侧发生俯冲带后撤,形成新的奥陶纪IBM型洋内岛弧(Song *et al.*,2017;Yang *et al.*,2018,2019).祁秦增生杂岩带的蛇绿岩和弧火山岩组合注明洋底高原与海沟碰撞是造成俯冲带起始和新的IBM型洋内弧形成和发展主要因素.图2显示了祁秦增生杂岩带和洋内弧的形成过程,该增生模式在地球历史的大陆增生过程中起重要的作用(Condie 2001;Niu *et al.*,2003).祁秦增生杂岩带的建立不仅确定了祁连造山带与秦岭造山带的构造关系,而且对于理解西太平洋型洋内弧的形成、俯冲带的形成和结构的变迁以及大陆边缘增生有重要意义.

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