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浅变质岩在示踪大别—苏鲁造山带大陆板块俯冲与折返过程中的意义

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摘 要:中国大别—苏鲁造山带为大陆板块俯冲形成的碰撞造山带,该带北缘和内部产有原岩时代为新元古代—晚古生代的浅变质岩。这些浅变质岩对应于扬子板块北缘前寒武变质基底和扬子板块北缘古生代大陆架沉积物,形成过程于印支期扬子板块向北俯冲过程中的刮削作用密切相关,与大洋板块俯冲过程中刮削形成的加积楔具有类似的动力学过程。对大别—苏鲁造山带浅变质岩的深入研究,不仅有助于揭示大陆板块俯冲过程中高压—超高压岩石形成与折返过程,而且确定了扬子板块与华北板块之间的缝合线位置位于大别造山带北淮阳带的北部和苏鲁造山带的五莲—蓬莱群的北侧。

关 键 词:加积楔;大陆板块;浅变质岩;高压变质岩;大别—苏鲁造山带
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0 引 言

Accretionary wedge按《英汉地质词典》(地质出版社,1993,P6)应译为加积楔,是指板块俯冲过程中被刮削下来的构造岩石组合单元(又称增生楔)。这在美国西部Franciscan造山带[1]、苏格兰Southern Uplands造山带[2,3]、南蒙古构造带[4]和俄罗斯南乌拉尔造山带[5]及日本列岛[6~10]等典型的板块俯冲带均有产出。由于加积楔作为板块俯冲过程中特征性产物,对深入探讨和确定板块俯冲时代、俯冲带和缝合带位置、板块俯冲与折返的动力学机制、俯冲板块的角度、板块俯冲的连续性及间断性等具有重要意义[11~14]。前人已对世界各地不同大洋板块俯冲加积楔的形成大地构造背景、构造—岩石组合特征、组成岩石属性、变质变形、流体活动及形成模式等进行了大量研究[1~14]。文献调研表明[15],加积楔作为大洋板块俯冲过程中形成的特征性构造岩石组合,具有如下特征:① 主体形成于板块俯冲带与缝合带之间,以发育特征性构造组合(构造混杂岩—叠瓦状冲断层—同斜褶皱)为代表;② 组成物质以俯冲板块上部岩石组合为主(相当于大洋板块上部5 km组成岩石),经过前锋刮削作用而构造混杂叠置而成;③ 组成加积楔的主体岩石被俯冲板块带入地下的深度较小(俯冲深度小于10 km,温度低于400℃),以绿片岩相为代表,这与被带入地幔深部、形成以蓝片岩和榴辉岩相变质的俯冲板块主体岩石相比在温压条件上存在明显差异;④ 强烈的动力变质作用改造,由于加积楔岩石就位于板块俯冲带前缘,强烈挤压构造应力常造成这些岩石具有强烈褶皱变形改造的特征,并以发育动力变质岩为主;⑤ 具有强烈的流体作用特征,流体来源主要为浅部流体,包括海水和浅部岩石经过埋藏、压实作用产生的空隙水。同时,加积楔体位于流体通道——板块俯冲带附近,深部俯冲带流体可以沿拆离带呈沟道式

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向上流动并与加积楔岩石发生化学反应。强烈的流体作用是其区别于其他构造单元的特征之一。上述地质特征可作为加积楔区别于其他地质单元的主要标志。

加积楔这一构造单元在大洋板块俯冲形成的造山带广泛产出,但在大陆板块俯冲过程中是否存在类似的构造单元尚未见报道。我们在大别—苏鲁造山带浅变质岩研究的基础上,将大洋板块俯冲加积楔的有关理论纳入到大陆板块俯冲的过程中,综合研究板块俯冲、超高压变质岩及浅变质岩形成的时空耦合关系,确定了扬子大陆板块俯冲加积楔存在的可能性及具体特点,并探讨了加积楔在大陆板块俯冲与折返过程中的地球动力学的意义。这一研究成果不仅有助于认识大陆板块的俯冲和折返过程,而且对大别—苏鲁造山带的重要基础地质问题的解决提供了新的研究思路。

1　大别—苏鲁造山带浅变质岩的区域分布特征

大别—苏鲁造山带为典型的由大陆板块俯冲形成的碰撞造山带,围绕该造山带的高压—超高压变质岩前人进行了大量的地质工作,取得了举世瞩目的研究成果。大别—苏鲁超高压变质带内部和北缘分别产出一系列浅变质岩,已引起地质学家们的广泛关注和讨论[16~25],我们通过详细的野外地质调查[23~25],发现大别—苏鲁造山带浅变质岩可分为超高压带北缘浅变质岩带和超高压带内部浅变质岩两部分。其中造山带北缘分布有东西向带状延伸的绿片岩相变质岩带,出露在大别造山带北缘的浅变质岩称为北淮阳带,由早古生代佛子岭群变质复理石岩系和卢镇关杂岩(新元古代岩浆杂岩为主)构成;该带向东对应于苏鲁造山带北缘的五莲杂岩带,主要由前寒武纪变质碎屑岩—大理岩组合和混杂于其中的新元古代片麻状花岗岩—中基性岩组成。同时,大别—苏鲁高压变质带内部也产出特征性浅变质岩,在大别地区目前已发现分别产出在北大别混合岩杂带中的沈桥(GPS:31°07′25″N,116°29′07″E)、超高压变质带碧溪岭附近的港河(30°41′17″N,116°14′54″E)和高压榴辉岩带中的杨家(33°32′12″N,116°08′21″E)等地;在苏鲁地区超高压带内部目前发现在胶南石灰窑(36°14′50″N,119°40′47″E)、日照坪上(35°07′33″N,119°03′56″E)和赣榆石桥(35°02′32″N,119°10′32″E)等,这些浅变质岩绝大部分浅变质岩原岩结构特征保存清楚,主要为互层状变质碎屑岩(变质砂砾岩、板岩、千枚岩、石英岩、变质火山碎屑岩)类及大理岩类,原岩结构清楚[16~21,23~25],另有部分浅变质岩遭受强烈的褶皱及韧性剪切作用改造的岩石,形成各种构造片岩及糜棱岩。

目前针对这些浅变质岩的一部分(如港河浅变质岩)的原岩性质、是否经历过超高压作用及其与超高压变质围岩的关系尚存在不同的认识[16~25],总体上有“外来”、“原地”2 种观点。一方面,根据其浅变质地特点和原生火山岩结构和层序的保存,认为没有经过超高压变质[16,17,22,23],因此是没有俯冲下去的构造单元[24,25]。另一方面,这些浅变质岩中发现有穿插在其中的含柯石英榴辉岩墙(脉)[18],从而认为这些火山岩与其周围的超高压变质岩一样也俯冲到了地幔深度,只是浅变质岩与其中的岩墙(脉)的变质程度不同而已[19,20]。但是,如果这些火山岩与其中穿插的基性岩墙一起随大陆板块俯冲进入地幔深度,在经受了 700~900℃和 >3.2 GPa 条件的超高压变质作用以后,基性岩墙已经变成为含柯石英榴辉岩,而火山岩只是发生绿片岩相变质,并保留完整的原生火山岩结构和层序,这几乎不可能。因为相对于结晶的岩墙(脉)而言,火山岩为隐晶质,因其颗粒细小更容易重结晶。同时,经过详细的地质观察发现,这些“脉状”榴辉岩与围岩之间并非侵入接触关系,榴辉岩外围的浅变质火山角砾岩已经明显的糜棱岩化,榴辉岩本身也以构造透镜体状产出,因此两者之间实际上为构造接触关系。因此我们认为,港河浅变质岩与石桥等地的浅变质岩一样为没有被俯冲下去的岩石单元,其与周围的超高压变质岩之间以构造片岩或糜棱岩等构造带相分割,而穿插在浅变质岩中的含柯石英榴辉岩体则可能是超高压变质岩折返到地下一定深度时,与浅变质岩构造混杂的产物。

2　大别—苏鲁造山带浅变质岩的典型地质—地球化学特征

结合前人的研究[16~35]及其他相关领域的大量研究成果[36~48],我们[23~25]的研究显示,大别—苏鲁造山带部分浅变质岩具有以下地质特征:

(1) 以绿片岩相变质为特征,典型的变质矿物组合为变质砂岩(绿泥石 + 绢云母 + 石英),千枚岩(绿泥石 + 绢云母 + 石英 + 纳长石),变质火山碎屑岩(绿帘石 + 绢云母 + 石英 + 纳长石)等,以绿片岩相变质(P = 200~300 MPa,T = 300~400℃)为

主,为明显有别于高压—超高压变质岩和前陆褶冲带中未变质岩石的特征性构造—岩石组合;同时,浅变质岩本身以低绿片岩相变质为主遭受不同程度的韧性剪切变形和动力变质作用的改造,局部存在高绿片岩相及未变质岩石,且变质与变形具有正相关性,具动力变质岩的特征。

(2) 浅变质岩可分为2个组成部分,其一为前寒武纪变质杂岩组合,包括大别—苏鲁超高压带内部的浅变质岩以及卢镇关杂岩和五莲杂岩,其中部分浅变质岩中产出有代表扬子板块北缘浅海相的震旦纪藻类化石,代表了扬子板块北缘前寒武纪变质基底;其二为产出在造山带北缘古生代变质复理石系,其中杨山群底部地层中产出的珊瑚化石(Heliofltes cf anhuicnsis Dong)为扬子板块的标型生物,五莲—蓬莱杂岩中发育石英岩—碳质板岩—千枚岩—大理岩组合,该组合岩石以低绿片岩相变质为主,为典型的浅变质沉积岩系。山东地矿局和赵达等[29]曾对五莲地区进行微古植物化石的采样和鉴定,发现大量的藻类化石,如Cerarophyton Vernicosum(光亮角形藻)、Teophipolia Lacelata(撕裂杰菲波藻)、Lophosphaeridium sp(瘤面球藻,未定种)及Preasolenopore sp(前管扎藻,未定种)等,这些微古植物化石代表这些岩石形成于震旦—早寒武纪,与扬子板块北缘震旦纪陡山陀组化石可以对比,代表了扬子板块北缘的震旦纪前后浅海相稳定环境下的沉积。同时,五莲杂岩带北侧黄华店莱阳群灰岩砾石中采集到扬子型石炭—二叠系䗴类及有孔虫类化石(Schubertella lata Lee et Chen., Palaeotextularia sp., Climacammina sp., Tetrataxis sp., Eotuberitina sp.),这些砾石的母岩明显来源于五莲杂岩。也显示五莲杂岩具有扬子板块的构造岩石组合特征,这与大别—苏鲁超高压带内部和北淮阳构造带内的浅变质岩一致[23,24]。因此这些浅变质岩不是华北板块仰冲到超高压带上的构造岩片,而是受强烈韧性剪切作用的扬子板块北缘的古生代沉积物及其下覆的前寒武纪变质基底。

(3) 造山带北缘浅变质岩以发育东西向紧闭同斜褶皱—叠瓦状逆冲断层—构造混杂岩为主;造山带内部浅变质岩多发生不同程度的韧性变形改造,并可见浅变质岩中混杂有三叠纪超高压花岗片麻岩甚至榴辉岩透镜体,整体以构造混杂岩的形式出露。区域上发育逆冲型韧性剪切带区域上呈同斜褶皱—叠瓦状冲断层—构造混杂岩等特征性构造岩石组合,这种构造岩石组合应形成与强烈的挤压构造环境,这与大洋板块俯冲加积楔的特征性构造组合形式类似。

(4) 同位素年代学初步研究表明:北淮阳带东段卢镇关岩群变形花岗岩的单颗粒锆石U-Pb年龄测定得到,其岩浆侵位年龄为665±39～744±9 Ma。山东五莲杂岩中桑园片麻状花岗质岩石锆石U-Pb年龄测定得到,其原岩年龄为684±1.6～742±12 Ma,这些岩浆杂岩主要为晋宁期杂岩组合,与大别—苏鲁地区花岗片麻岩的原岩时代一致。各区代表性浅变质岩白云母单矿物Ar-Ar同位素年龄测定结果多为印支期(202～230 Ma),与大别—苏鲁造山带印支期俯冲碰撞时代及该地区超高压变质岩的峰期变质时代一致[40～44],说明这些浅变质岩曾参与了扬子板块俯冲的主要地质过程,并遭受了扬子板块俯冲过程中主要构造热事件的改造。

(5) 氧同位素分析发现,这些浅变质岩 $\delta^{18}O$ 值普遍较低(千枚岩4.4‰～4.6‰,变质火山碎屑岩−0.4‰～8.2‰,长英质糜棱岩0.1‰～1.6‰,云母片岩为2.6‰～2.8‰),锆石单矿物 $\delta^{18}O$ 分析也给出了一致的变化特征(1.54‰～8.42‰),这与大别山超高压榴辉岩和片麻岩的低 $\delta^{18}O$ 值(−5‰～5‰)特点相似[47,48],说明这些浅变质岩与超高压岩石一样,在大陆板块俯冲之前经历过高温大气降水热液蚀变。

(6) 浅变质岩与超高压变质岩的原岩都是扬子板块北缘大陆板块的组成部分,其中前寒武纪变质杂岩在原岩性质、形成时代、变质历史以及稳定同位素组成等方面与超高压变质岩存在一定的可对比性。

3 浅变质岩的形成构造背景分析

大别—苏鲁造山带在印支期曾发生强烈陆—陆俯冲和碰撞作用已被大量的同位素地质年代学研究所证实[40～43,49～51]。如果浅变质岩的上述地质事实得到进一步证实和确定,那么扬子板块作为俯冲盘在印支期前后向华北板块俯冲过程中,大别—苏鲁地区浅变质岩作为扬子俯冲板块北缘的前印支期陆壳岩石和表层沉积物不可避免地参与了这一重大地质过程。同位素年代学和稳定同位素研究表明它们遭受了与大别—苏鲁超高压变质岩相同的加里东—印支期构造热事件的改造,并遭受了与板块俯冲密切相关的流体作用改造,进一步说明这些浅变质岩曾参与了扬子板块俯冲的主要地质过程。同时这些浅变质岩与部分超高压变质岩存在一定的可比性,

但又以明显的绿片岩相变质而与高压—超高压变质岩相区别,说明它们没有被俯冲板块携带下去发生高压—超高压变质;而是被刮削下来以明显的绿片岩相变质、强烈的动力变质作用改造和构造混杂岩—叠瓦状冲断层—同斜褶皱的构造—岩石组合形式被构造叠置于板块俯冲带附近,这些地质特征与大洋板块俯冲过程中形成的加积楔具有一致性。因此大别—苏鲁地区的浅变质岩可能为扬子大陆俯冲过程中被刮削下来的岩石组合,而目前保存下来的浅变质岩应为大规模加积楔的残余部分。

4 浅变质岩在示踪扬子大陆板块俯冲与折返过程中的意义

大陆板块俯冲与大洋板块俯冲加积楔形成的相似性,即两者在形成大地构造背景、组成物质来自于俯冲板块的属性、构造—岩石组合特征、变质—变形、流体作用特征以及加积方式等方面应具有相似特征,大洋板块加积楔的重要意义在大陆板块俯冲加积楔的研究中可以参考。同时大陆板块俯冲与大洋板块俯冲存在重大差别,主要表现在:① 两者的组成物质存在差异。由于加积楔的主要组成物质为俯冲板块的表层岩石,而大洋板块和大陆板块的组成物质存在重大差异,因此刮削下来构成加积楔的物质存在重大差异。就大别—苏鲁造山带而言,加积楔组成物质以前印支期岩石为主,由于这些岩石较洋壳物质密度小、孔隙度大,因此在板块俯冲过程中更容易被刮削下来形成加积楔。② 就位方式的差异性。大陆板块俯冲有其独特的特点,一般遵循规由洋—陆俯冲到陆—陆俯冲的动力学过程。因此大别—苏鲁造山带浅变质岩加积楔研究过程中具有其特殊的地质意义。

⑴ 寻找可能的洋壳物质。加积楔作为板块俯冲过程中特征性产物,板块在俯冲过程的不同阶段均可刮削下来俯冲板块上部岩石。由于加积楔的主要组成物质为俯冲板块的表层岩石,而大洋板块和大陆板块的组成物质存在重大差异,因此刮削下来构成加积楔的物质存在重大差异。可以在加积楔岩石中注意找寻是否存在可能的洋壳物质,如桐柏地区苏家河地区的部分岩石具有洋壳岩石的地球化学特征[52,53]。在此基础上进一步开展工作可能大量发现板块俯冲初期大洋板块俯冲过程中刮削下来的洋壳物质,进而进一步完善大别—苏鲁造山带由洋—陆俯冲到陆—陆俯冲的动力学过程。

⑵ 示踪板块俯冲时代。大别—苏鲁造山带的俯冲碰撞时代一致是大别—苏鲁地区研究的争议问题[40～43,49～51,55],就大别—苏鲁造山带而言,加积楔主要组成物质以以前印支期岩石为主,由于这些岩石较洋壳物质密度小、孔隙度大,因此在板块俯冲过程中更容易被刮削下来形成加积楔,因此加积楔在示踪板块俯冲时代研究中尤其重要。目前在浅变质岩中已发现加里东期构造—岩浆活动记录[28],同时在桐柏地区混杂岩中也有加里东期年龄显示[52,53],这些加积杂岩是否代表大别—苏鲁地区板块俯冲从加里东期已经开始值得深入研究。

⑶ 示踪板块俯冲的俯冲带和缝合带位置。大别—苏鲁造山带的俯冲带和缝合带位置一致是大别—苏鲁地区研究的争议问题[25～27,54～59]。板块俯冲过程中,俯冲板块上部岩石被刮削下来构造混杂堆积于缝合带附近,伴随加积杂岩的逐渐堆积板块俯冲带逐渐后移,因此加积楔均发育在俯冲带与缝合带之间的楔型区域,其与蛇绿岩在确定板块俯冲带与缝合带位置具有相同重要的指示意义。就大别造山带而言,目前已查明浅变质岩分布的北界为信阳—舒城断裂,分布的南界为下扬子前陆褶皱冲断带北侧的襄樊—广济断裂,按扬子板块俯冲向北俯冲的模式,可以大致确定大别地区的缝合带位置为信阳—舒城断裂,俯冲带位置为襄樊—广济断裂。而针对苏鲁造山带,俯冲带位置为浅变质岩和超高压变质岩出露区的南部,于传统划分的嘉山—响水断裂相当;缝合线位置则位于五莲杂岩—蓬莱群浅变质岩带出露区的北侧[25]。

⑷ 示踪浅变质岩—超高压变质岩的时空耦合关系。大陆板块俯冲一般遵循着由洋—陆俯冲到陆—陆俯冲的机制,并存在超高压岩石的折返过程,造成刮削下来(加积楔)的浅变质岩与被带入地幔深度并折返地表的超高压变质岩石构造叠置在一起,并改变了加积楔岩石的赋存和出露状态。这既是前人研究大洋板块俯冲加积楔所未曾遇到的问题,同时也为我们探索大陆板块俯冲加积楔提供了更为有利的可对比条件。可以通过浅变质岩与超高压岩石原岩的地质—地球化学研究证明两者的亲缘关系,同时通过 P-t-D 路径差异结合同位素年代学研究,确定两者在板块俯冲不同阶段的时空耦合关系。

⑸ 示踪板块俯冲的角度、俯冲过程的连续性和间断性。大量的研究显示[1～14],加积楔的发育特征及其有无与板块俯冲的角度、俯冲过程的连续性和间断性密切相关。在高角度板块俯冲边界往往不发育加积楔,在俯冲过程不连续存在俯冲间断的地

区,早期发育的加积楔往往遭受破坏和后期改造,因此保留的加积楔杂岩往往缺少早期刮削岩石的记录。大别—苏鲁地区广泛发育浅变质岩加积楔反映了该区扬子板块俯冲角度较小(<30°)的特点,同时根据大别—苏鲁地区广泛不发育洋壳物质的特点,说明该区在大洋板块向大陆板块俯冲转换过程中可能存在俯冲间断。

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TECTONIC IMPLICATIONS OF THE LOW-GRADE METAMORPHIC ROCKS FOR THE SUBDUCTION OF A CPMTOMEMTAL PLATE IN THE DABIE-SULU OROGEN

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Abstract: In the margin area of subduction of oceanic plate, a great deal of marine sediments and underlying rocks were scraped off from the subducting oceanic plate to accumulate as wedge-shaped mass. It is called the accretionary wedge and uniquely develops at the boundary of convergent plates. This tectonic unit frequently occurs in orogenic belts, which were formed by subduction of oceanic plate, but it is unclear whether it also occurs in orogenic belts due to subduction of continental plate. The Dabie-Sulu Orogen in East-central China is a typical continent-continent collision orogen due to subduction of the Yangtze craton beneath the Sino-Korean craton at Triassic. Ultrahigh-pressure (UHP) metamorphism has been recognized by occurrence of micro-diamond and coesite-bearing eclogites and gneisses within this orogen. There are a great deal of low-grade metasedimetary and metaigneous rocks to occur not only in the northern margin of the UHP metamorphic belt but also in its interior. They consist of two parts: (1) large masses in the northern margin of the belt which are composed of slates, schists, phyllites, metasandsones and marble as well as intrusions; (2) sparotic outcrops in the interior of the belt which are composed of metaclastics, phyllite, and marbles. All of the rocks suffered strong deformation and dynamic metamorphism mostly at greenschist facies. Palaeotological, petrologic and geochronological investigations show that the metasedimentary rocks were deposited in the northern passive continental margin of the Yangtze plate as a flysch facies prior to Triassic, and that the intrusions are of Neoproterozoic ages and thus the product of rift magmatism in the northern margin of the Yangtze craton at Late Precambrian. Both Middle Paleozoic and Triassic events were dated for the low-grade rocks, being concordant with tectonic events experienced by the ultrahigh-pressure rocks in the Dabie-Sulu orogen. Apparently, the low-grade metamorphic rocks were scraped off from the subducting Yangtze plate at Triassic and thus correspond to a part of the accretionary complexes of the continental plate subduction. Within the framework of the accretionary wedge of continental plate subduction, the low-grade metamorphic rocks in the northern margin and the interior and of the Dabie-Sulu orogenic belt can be unified as a whole in comparison with the UHP metamorphic rocks. Relationship in time and space between the low-grade and the UHP metamorphic rocks is studied in order to understand the geodynamics of the Yangtze plate subduction.

Key words: Accretionary wedge; Continental plate; Low-grade rocks; Ultrahigh pressure; Dabie-Sulu orogen.