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大别山北淮阳带东段石榴斜长角闪岩石炭纪变质作用的测定

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摘 要: 北淮阳带位于大别碰撞造山带北部,相对于南部三叠纪超高压变质带来说,通常被认为是一个相对低级变质的构造岩石单位.以商(城)-麻(城)为界,分为西段和东段.其中,东段未发现与西段相对应的古生代大洋俯冲记录,也缺乏相关的古生代岩浆作用和变质作用方面报道.因而严重地阻碍了对大别造山带形成和演化的深刻理解和准确认识.北淮阳带东段岩石类型丰富,主要包括3类(套)岩石:(1)变质岩,如变质花岗岩(花岗片麻岩)、(石榴)斜长角闪岩、大理岩、云母石英片岩和变质复理石等;(2)岩浆岩,主要为中生代花岗岩、正长岩和火山岩等;(3)盆地沉积岩,主要为中新生代沉积及少量石炭纪沉积.然而,该区一直未发现古生代变质作用的岩石学记录.为此,对北淮阳带东段金寨县铁冲一带与大理岩相共生的石榴斜长角闪岩开展了锆石SHRIMP U-Pb定年和初步的岩石学研究.结果表明,该区石榴斜长角闪岩经历了355±5 Ma变质作用,因而首次发现研究区经历了石炭纪变质作用,为秦岭-桐柏造山带的东延以及大别山碰撞造山带的古生代构造演化过程提供了新的制约.

关键词: 锆石;SHRIMP U-Pb定年;石榴斜长角闪岩;石炭纪变质作用;北淮阳带东段;大别造山带;地球化学.

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Dating of Carboniferous Metamorphism for Garnet Amphibolite from the Eastern Beihuaiyang Zone in the Dabie Orogen

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Abstract: In comparison with the Triassic ultra-high-pressure metamorphic belt in the southern Dabie orogen, the Beihuaiyang zone (BZ) is generally regarded to be a relatively low-grade metamorphic unit located in the northern part of the orogen. The BZ can be subdivided into eastern and western segments separated by Shangcheng-Macheng fault zone, respectively. Among of them, the eastern segment of the BZ has no record related to Paleozoic oceanic subduction similar to those in the western segment. Also, there are rare reports on the Paleozoic magmatism and metamorphism in the region. As a result, these have greatly impeded the deep understanding and precise recognition on the formation and evolution of the Dabie orogen. The eastern segment of the BZ is mainly composed of three groups of rocks: (1) metamorphic rocks, e.g., meta-granitoid (granitic gneiss), (garnet) amphibolite,

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marble, mica-quartz schist and meta-flysch; (2) igneous rocks mainly including Mesozoic granite, syenite and volcanics; (3) basin sediments mainly composed of Mesozoic-Cenozoic and subordinate Carboniferous rocks. However, no petrological record of the Paleozoic metamorphism has been reported in the region. Therefore, SHRIMP zircon U-Pb dating and preliminary petrographic observations on the garnet amphibolite coexisting with marble from Tiechong, Jinzhai in the eastern segment of the BZ are carried out in this study. The results suggest that the studied rocks experienced a strong metamorphism with the peak at 355 ± 5 Ma. It is reported for the first time on the Carboniferous metamorphism in the region, and thus provides new constraints on the eastern extension of the Qinling-Tongbai orogen and the Paleozoic tectonic evolution of the Dabie collisional orogen.

Key words: zircon; SHRIMP U-Pb dating; garnet amphibolite; Carboniferous metamorphism; eastern segment of the Beihuaiyang zone; Dabie orogen; geochemistry.

经典板块构造理论认为,碰撞造山带的形成通常涉及到威尔逊旋回(Wilson cycle)的洋盆的打开和关闭(Dewey and Spall, 1975),并伴随着与俯冲－碰撞相关的变形、变质作用和最终因陆－陆碰撞作用而形成造山带(Wilson, 1966; Dewey, 1969; Brown, 2009).通常,形成于汇聚板块边缘的造山带可以划分为增生型和碰撞型两大类.其中,增生造山带主要形成于大洋板块的俯冲时期;而碰撞造山带则形成于大洋板块俯冲结束后的陆－陆碰撞阶段,最典型的例子是阿尔卑斯和喜马拉雅造山带.然而,陆－陆碰撞之前往往涉及到洋盆的关闭,所以对于大陆碰撞造山带而言,碰撞之前的大洋俯冲及伴生的岛弧岩浆作用可能是必然的板块构造过程(O'Brien, 2001).因此,这种复合造山作用常造成碰撞构造叠加在早期增生构造之上(Brown, 2007, 2009),从而为识别和重建两期造山作用的精细过程增加了巨大困难.

中国中部近东西向延伸、长约2 000 km的秦岭－桐柏－大别－苏鲁造山带,主要是由华北和华南(扬子)两大陆块碰撞形成,并在陆－陆碰撞之前曾经历了长期的大洋俯冲、岛弧增生和弧－陆碰撞过程(张国伟等,1988, 2001;Xu *et al.*, 1992a;徐树桐等,1994, 2002;杨经绥等,2002;Dong *et al.*, 2011; Wu and Zheng, 2013; Dong and Santosh, 2016),形成了南、北分带的增生造山体系和碰撞造山体系(刘晓春等,2015).然而,由于沿造山带横向上构造过程的复杂性、多期性、复合性、叠置性和穿时性(许志琴等,2015),不同地段出露的构造岩石单元差别较大.其中,秦岭－桐柏－红安造山带均保留了明显的古生代洋壳俯冲的证据,如北秦岭商丹蛇绿混杂岩和古生代岛弧成因的岩石(如张国伟等,1988, 2001;孙卫东等,1995;裴先治等,2009; Dong *et al.*, 2011, 2016;Liu *et al.*, 2016)、桐柏－红安北缘古生代复理石(Liu *et al.*, 2004, 2011b)以及熊店、胡家湾和苏家河古生代洋壳成因榴辉岩(Sun *et al.*, 2002; Cheng *et al.*, 2009; Wu *et al.*, 2009).然而,东部大别－苏鲁造山带中却鲜见古生代大洋俯冲的记录和证据:一方面可能与三叠纪陆－陆强烈碰撞改造、燕山期热事件叠加以及多期构造作用和破坏等有关,进而影响了人们认识华北与华南板块之间的古生代－中生代演化的横向分布;另一方面也与研究程度有关.秦岭－大别－苏鲁造山带,又称中央造山带(杨经绥等,2002),晚元古代以来,从冈瓦纳大陆分离的南、北中国板块,经过原特提斯洋和古特提斯洋的演化以及板块多次离散、汇聚和碰撞,形成显生宙以来以原特提斯和古特提斯为主体的复合构造格架,以及以古生代和印支期为主体的秦岭－大别－苏鲁复合造山系(如,Mattauer *et al.*, 1985; Hsü *et al.*, 1987;张国伟等,1988, 2001;杨经绥等,2002;Ratschbacher *et al.*, 2003, 2006;刘良等,2013;许志琴等,2015; Liu *et al.*, 2016).实际上,北秦岭古生代造山带及商丹洋在大别山及相邻地区的东延问题至今仍没有解决.Dong *et al.*(2011)根据区域地质背景分析,认为商丹洋/商丹缝合带可能通过北秦岭向东延伸,但至大别山之后,如何衔接,仍是值得研究的问题;刘晓春等(2015)根据桐柏造山带的研究,推测古生代商丹洋可能向东延伸到信阳、乃至商城地区.然而,北淮阳带(尤其商－麻断裂以东;图1)尚缺乏与之相对应的古生代大洋俯冲、岩浆作用和变质作用等方面的岩石学记录及相关文献报道.为此,本文开展了北淮阳带东段金寨一带与大理岩相共生的石榴斜长角闪岩的锆石SHRIMP U-Pb定年和初步的岩石学研究,证明研究区经历了石炭纪变质作用,从而为秦岭－桐柏造山带的东延以及大别山碰撞造山带的古生代构造演化过程提供了新的制约.

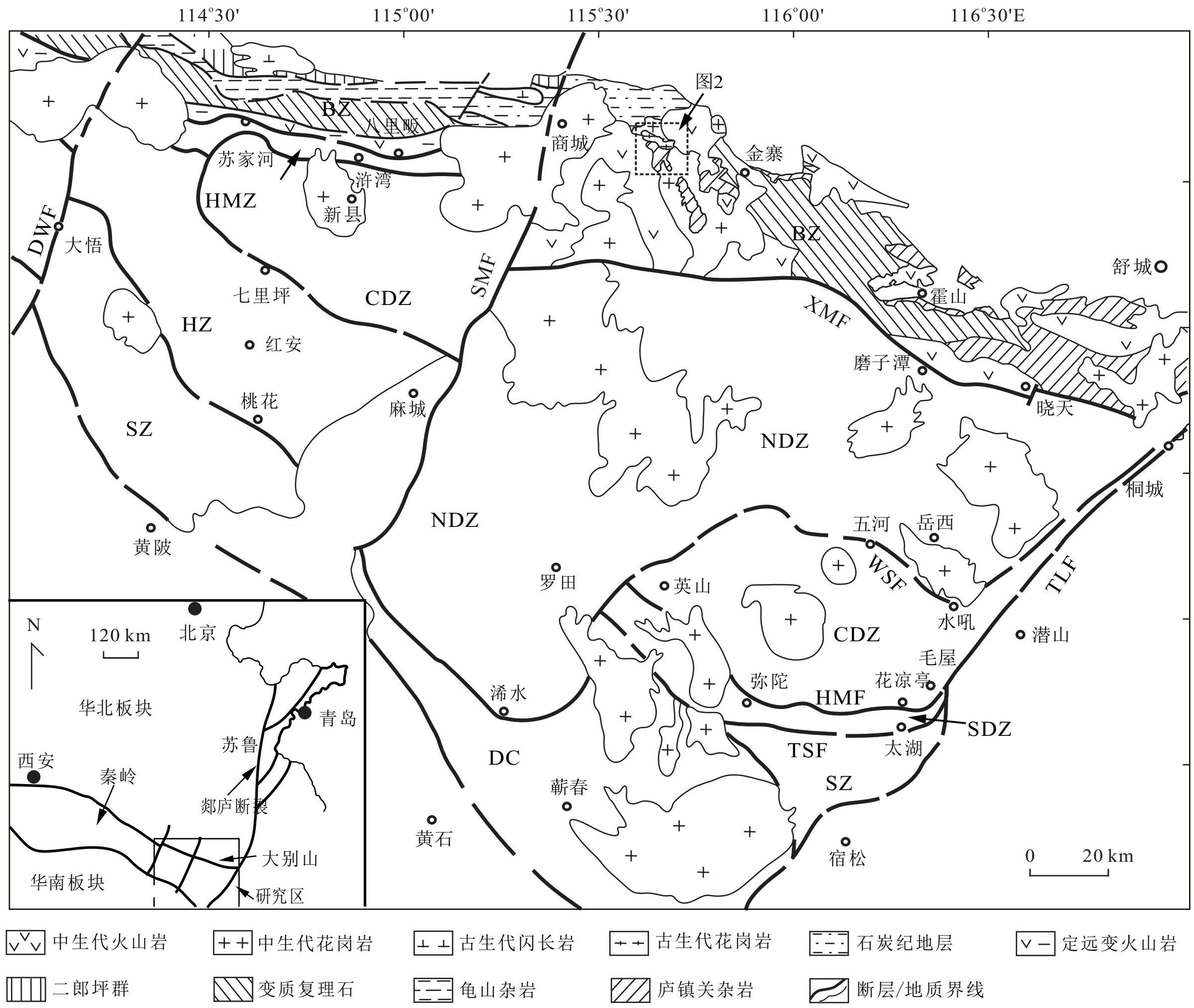

图1　大别山造山带的地质简图(据 Liu *et al.*, 2007 修改)

Fig.1　Schematic geological map of the Dabie orogen

BZ. 北淮阳带;NDZ. 北大别杂岩带;CDZ. 中大别超高压变质带;SDZ. 南大别低温榴辉岩带;SZ. 宿松变质带;HMZ. 浒湾混杂岩带;HZ. 红安低温榴辉岩带;DC. 角闪岩相大别杂岩;XMF. 晓天－磨子潭断裂;WSF. 五河－水吼断裂;HMF. 花凉亭－弥陀断裂;TSF. 太湖－山龙断裂;TLF. 郯庐断裂;SMF. 商城－麻城断裂;DWF. 大悟断裂

1　地质背景

大别山是秦岭造山带的东延部分,东端被郯－庐断裂带切割(图 1). 郯－庐断裂带以东的苏鲁造山带是大别山东延并位移了的部分. 在地质位置上,它位于华北和华南两个大陆板块之间,是华南板块向华北板块之下俯冲形成的三叠纪大陆碰撞造山带(Xu *et al.*, 1992a, 1992b; Li *et al.*, 1993). 而且,发育了与大陆俯冲和碰撞过程相关的、不同变质等级的构造岩石单位(徐树桐等, 2002; Liu *et al.*, 2007). 从南到北,大别山可分为宿松变质带、南大别低温榴辉岩带、中大别超高压变质带、北大别杂岩带及北淮阳带等构造岩石单位(图 1). 但根据区域地质背景分析和沉积地层的物源区研究等,大别山印支期陆－陆碰撞之前应该存在已经消失的古大洋(Xu *et al.*, 1992a; 徐树桐等, 1994, 2002; Li *et al.*, 2004; 李任伟等, 2005; 李双应等, 2011).

北淮阳带西段(商－麻断裂以西),主要由二郎坪群、原"信阳群"南湾组(变质复理石)和龟山组(又称龟山杂岩)、原"苏家河群"中定远组、原商城群"歪庙组"(可能对应于"二郎坪群"; 徐树桐等, 1994, 2002)和原石炭纪梅山群等岩石单位以及变质火成岩、古生代闪长岩等花岗岩类岩石和中生代岩石等组成(图 1). 其中,原岩时代为新元古代晚期(~630 Ma)(刘贻灿等, 2006; Liu *et al.*, 2017)的变质(橄榄)辉长岩沿苏家河－八里畈断裂的北侧,从千斤河棚乡王母观向西经苏家河至信阳南部西双河和桐柏一带呈大小不等的岩块或岩片出露,千斤

图2 北淮阳带东段金寨县铁冲地质简图

Fig.2 Schematic geological map of the Tiechong area, Jinzhai in the eastern segment of the Beihuaiyang zone

河棚乡向东经吴陈河乡至八里畈乡一带也有类似岩石断续分布.其围岩为原"定远组"变质火山岩，目前表现为含石榴子石绿帘云母石英片岩.二者之间为断层接触，统称为定远变质火山岩带(刘贻灿等，2006)或肖家庙—八里畈构造混杂岩带(刘晓春等，2015).其南、北分别与浒湾混杂岩带和"南湾组"变质复理石等构造岩石单位相邻，再向南为新县超高压变质带.原苏家河群"浒湾组"中既有石炭纪洋壳俯冲成因榴辉岩(如熊店)，又有三叠纪陆壳俯冲成因榴辉岩，它们的原岩时代分别为晚古生代和新元古代(Sun *et al.*, 2002; Cheng *et al.*, 2009; Wu *et al.*, 2009)，因而称之为浒湾混杂岩带(Ratschbacher *et al.*, 2006；刘贻灿等，2006)或浒湾高压榴辉岩带(刘晓春等，2015)，它的变质相及形成时代完全不同于岛弧成因的定远变质火山岩即峰期表现为绿帘角闪岩相变质作用和原岩时代为早古生代奥陶纪(Li *et al.*, 2001；刘贻灿等，2006).

北淮阳带东段(商—麻断裂以东)，主要由"佛子岭群"变质复理石(对应于秦岭的"刘岭群"和桐柏的"南湾组")和庐镇关杂岩(原"庐镇关群")和原石炭纪梅山群(梅山煤系)等构造岩石单位及中新生代岩浆岩和盆地沉积组成(徐树桐等，1994，2002；Chen *et al.*, 2003；吴元保等，2004；江来利等，2005；刘贻灿等，2006，2010；刘景波等，2013)(图1).其中，庐镇关杂岩主要包括原"小溪河组"新元古代变质花岗岩和变基性岩等和"仙人冲组"大理

岩及相伴生的(石榴)斜长角闪岩等.然而,由于研究区可能因印支期大陆的强烈碰撞改造和构造叠加,早期一些岩石单位被破坏或者被盆地沉积所掩盖(Xu *et al*., 1992a;徐树桐等,1994,2002),造成至今未发现确切的与古生代大洋俯冲相关的岩石单位或记录.然而,直到最近,刘贻灿等在金寨县西部查明存在古生代花岗岩(其时代为457±2 Ma,未发表资料;图2),而且证明研究区经历了石炭纪变质作用(见后文).

本文研究的样品为采集于李桥南(图2)原“仙人冲组”与大理岩相共生的石榴斜长角闪岩.其中,石榴斜长角闪岩以构造透镜体的形式产出于大理岩中,二者共同发生了复杂的变质、变形作用(图3).

2　样品描述和分析方法

岩相学研究表明,石榴斜长角闪岩的主要矿物有石榴子石、斜长石、单斜辉石、角闪石和少量的石英、方解石和榍石等(图4).其峰期变质矿物主要为石榴子石+斜长石+单斜辉石+石英等,至少达到麻粒岩相、甚至可能达到石英榴辉岩相条件(见后文分析),至于具体变质过程和峰期温压条件,还有待于进一步研究(将另文讨论).

岩石样品经破碎、筛选、电磁及重液分选分离出锆石,而后在体视显微镜下对未蚀变、透明等的颗粒进行挑选,再将其和标准锆石TEMORA(年龄为417 Ma)一起制成样品靶,磨至一半后抛光并在北京离子探针中心进行透射光、反射光和阴极发光(CL)显微照相.其中,锆石的分选工作由河北省区域地质矿产调查研究所实验室完成;锆石微区U-Pb定年测定在北京离子探针中心SHRIMP Ⅱ离子探针仪器上进行,详细测定程序见有关文献

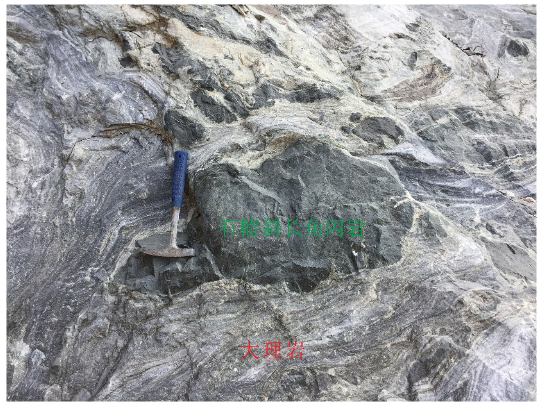

图3　北淮阳带东段金寨县李桥与大理岩相伴生的石榴斜长角闪岩野外照片

Fig.3　A field photograph showing garnet amphibolite coexisting with marble in the eastern segment of the Beihuaiyang zone at Liqiao, Jinzhai

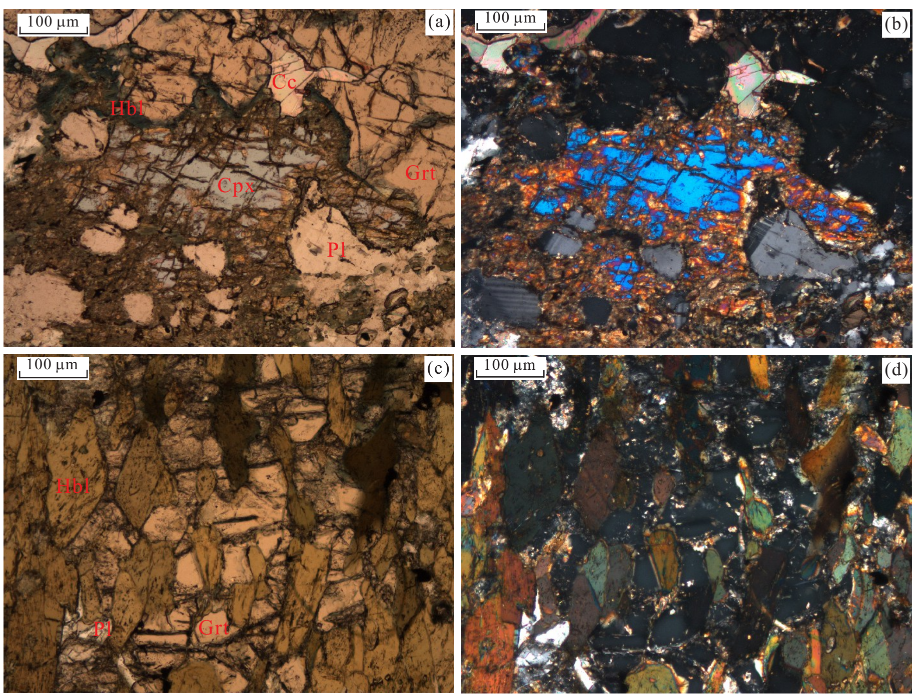

图4　北淮阳带东段石榴斜长角闪岩的显微照片

Fig.4　Photomicrographs of garnet amphibolite from the eastern Beihuaiyang zone

Grt. 石榴子石;Pl. 斜长石;Cpx. 单斜辉石;Hbl. 角闪石;Ttn. 榍石;Cc. 方解石

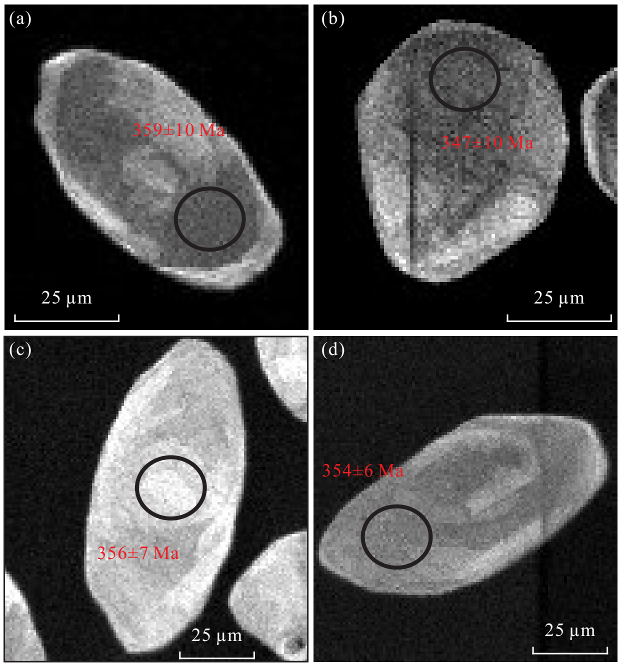

图5　代表性锆石的阴极发光图像

Fig.5　Cathodoluminescene (CL) images of representative zircons

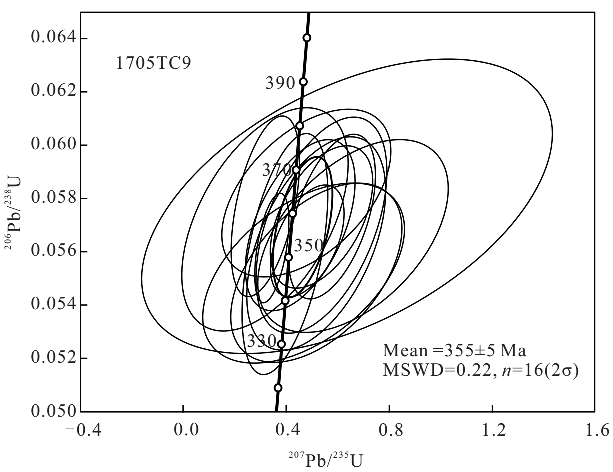

图6　锆石U-Pb谐和图

Fig.6　U-Pb concordia diagram of zircon

(Compston *et al*., 1992；Williams，1998；宋彪等，2002).测试时所用的标准锆石为M257和TEMORA，前者用于标定U含量，后者用于校正$^{206}Pb/^{238}U$比值(亦即$^{206}Pb/^{238}U$年龄).束斑直径约为20 μm.测定结果用^{208}Pb进行普通Pb校正，详细数据处理过程见Liu *et al*.(2017).测试数据列于表1中.

3　分析结果

阴极发光(CL)图像(图5)显示，样品中的锆石都表现为无分带或区域分带及浑圆状外形等、无明显岩浆结晶环带，结合它们的低Th/U值(0.02～0.31)，应为变质生长锆石或变质重结晶锆石(Vavra *et al*., 1999；Pidgeon *et al*., 2000；Rubatto *et al*., 2001；Schmitz and Bowring，2003).

锆石U-Pb同位素数据和年龄结果如表1和图6所示.本文分析了16颗锆石，获得的年龄都为谐和年龄，而且$^{206}Pb/^{238}U$年龄为346±15～365±12 Ma，加权平均值为355±5 Ma(MSWD＝0.22).

因此，根据锆石的阴极发光图像特点和低的低Th/U值，355±5 Ma应为石榴斜长角闪岩的变质时代.

4　讨论

Mattauer *et al*.(1985)在商丹断裂南侧刘岭群(武关杂岩)的变泥质岩中获得314±6 Ma的黑云母$^{40}Ar/^{39}Ar$年龄，Zhai *et al*.(1998)在桐柏龟山杂岩斜长角闪岩中获得两个角闪石$^{40}Ar/^{39}Ar$年龄，分别为316±1 Ma和304±14 Ma，从而证实秦岭—桐柏造山带中确实存在晚古生代构造事件.近年来，桐柏—红安造山带北部的龟山杂岩被确定是秦岭大陆弧与弧前复理石的混杂体，其在340～310 Ma经历了角闪岩相变质过程(Liu *et al*., 2011a, 2013a, 2013b；曲玮等，2018).同时，对秦岭造山带商丹断裂南侧从刘岭群中解体出来的武关杂岩的研究表明，该套以沉积岩为主体的中级变质杂岩中含有大陆弧成因变质火成岩，包括原岩时代分别为446±2 Ma的斜长角闪岩、368±3 Ma的安山质片麻岩和351±2 Ma的糜棱岩化花岗岩脉，其变质时代为～320 Ma(Chen *et al*., 2014).而且，已有研究表明，北秦岭(包括秦岭、二郎坪和宽坪岩群等)的变质时代至少包括两期即450～420 Ma和310～350 Ma(Ratschbacher *et al*., 2003, 2006；Dong *et al*., 2011, 2016；Liu *et al*., 2011a；Chen *et al*., 2014；刘晓春等，2015，及所引文献；Yan *et al*., 2016)，经历了早古生代(500～400 Ma)大洋俯冲、岛弧增生与弧—陆碰撞及晚古生代(340～310 Ma)大洋俯冲与增生等复杂的构造过程(王涛等，2009；裴先治等，2007，2009；第五春荣等，2010；刘良等，2013；Wang *et al*., 2013a, 2013b；张成立等，2013；王晓霞等，2015；Liu *et al*., 2016)；北淮阳带西段熊店榴辉岩带的原岩应主要是洋壳成因，其形成时代主要为425～410 Ma，并经历了石炭纪(～310 Ma)洋壳俯冲及榴辉岩相高压变质作用(Sun *et al*., 2002；

表 1　北淮阳带东段石榴斜长角闪岩的锆石 SHRIMP U-Pb 数据[a]

Table 1　SHRIMP zircon U-Pb data for garnet amphibolite from the eastern Beihuaiyang zone

分析点号	$^{206}Pb_c$ (%)	U 10^{-6}	Th 10^{-6}	$^{232}Th/^{238}U$	$^{206}Pb^*$ 10^{-6}	$^{207}Pb^*/^{206}Pb^*$ (±%)		$^{207}Pb^*/^{235}U$ (±%)		$^{206}Pb^*/^{238}U$ (±%)		$^{206}Pb/^{238}U$ 年龄(Ma)
1705TC9_1.1	4.17	6.3	1.30	0.21	0.31	0.051 6	16.0	0.397	17.0	0.055 9	3.3	350±13
1705TC9_2.1	7.57	5.3	0.12	0.02	0.27	0.062 0	34.0	0.470	34.0	0.055 2	2.5	347±10
1705TC9_3.1	8.93	3.6	0.11	0.03	0.19	0.041 0	41.0	0.320	41.0	0.057 2	3.0	359±19
1705TC9_4.1	4.19	6.3	1.40	0.24	0.32	0.073 5	12.0	0.581	12.0	0.057 3	2.2	359±10
1705TC9_5.1	8.93	4.7	0.77	0.17	0.25	0.084 0	23.0	0.660	23.0	0.056 6	2.6	355±12
1705TC9_6.1	2.50	8.9	2.00	0.23	0.45	0.059 6	10.0	0.467	10.0	0.056 9	1.9	356±7
1705TC9_7.1	3.83	15.0	2.30	0.16	0.77	0.062 3	11.0	0.485	12.0	0.056 4	1.5	354±6
1705TC9_8.1	2.06	15.0	4.60	0.31	0.76	0.044 9	7.6	0.347	7.8	0.056 1	1.5	352±6
1705TC9_9.1	9.13	4.2	0.61	0.15	0.22	0.067 0	21.0	0.520	21.0	0.056 3	2.9	353±13
1705TC9_10.1	4.29	5.8	0.74	0.13	0.30	0.040 3	17.0	0.321	17.0	0.057 7	2.4	362±10
1705TC9_11.1	5.34	4.2	0.72	0.18	0.22	0.069 0	19.0	0.540	19.0	0.057 0	2.9	358±12
1705TC9_12.1	3.20	6.0	1.00	0.17	0.30	0.058 0	19.0	0.457	19.0	0.057 0	2.3	357±9
1705TC9_13.1	2.24	11.0	2.40	0.22	0.55	0.068 5	15.0	0.541	15.0	0.057 3	1.9	359±8
1705TC9_14.1	7.63	10.0	2.00	0.21	0.53	0.060 0	28.0	0.480	28.0	0.058 2	2.2	365±12
1705TC9_15.1	10.08	6.0	1.00	0.17	0.32	0.068 0	26.0	0.520	26.0	0.055 2	2.5	346±15
1705TC9_16.1	24.60	4.5	0.82	0.19	0.29	0.080 0	51.0	0.640	51.0	0.057 7	3.9	361±27

注：(a) 误差为 1σ，Pb_c 和 Pb^* 分别表示普通铅和放射性成因铅；用 ^{208}Pb 进行普通铅扣除．

Cheng *et al.*, 2009, 2016, 2018; Wu *et al.*, 2009).

此外，刘贻灿等（未发表资料）最新野外地质调查和锆石 U-Pb 定年结果表明，北淮阳带东段金寨一带发育具有岛弧成因的早古生代（457±2 Ma）花岗岩．该花岗岩的形成时代类似于北秦岭二郎坪地区的满子营岛弧成因花岗岩（459.5±0.9 Ma；郭彩莲等，2010）以及桐柏地区的马畈闪长岩（463.5±3.4 Ma；马昌前等，2004）和“定远组”岛弧成因的变质火山岩（464±7 Ma；刘贻灿等，2006）等．由此证明，北淮阳带东段存在早古生代（奥陶纪—志留纪）与大洋俯冲相关的岩浆作用．结合本文石炭纪变质时代的确定，证明北淮阳带东段的大洋俯冲可能从早古生代奥陶纪（～450 Ma）即已开始，并在石炭纪发生变质作用．

正如前文所述，本文研究样品的锆石具有一致的阴极发光图像（图 5）和低的 Th/U 值（0.02～0.31）（表 1），为变质生长或变质重结晶锆石，偶尔见残留的岩浆核（图 5a, 5c），证明该样品经历了较高温的变质作用（Liu *et al.*, 2015；王程程等，2018）．结合石榴子石＋斜长石＋单斜辉石＋石英等变质矿物组合，推断该石榴斜长角闪岩的峰期变质作用至少达到麻粒岩相、甚至榴辉岩相变质 P-T 条件，可能与泥盆纪晚期弧－陆碰撞有关．这也与北淮阳带石炭纪沉积地层学记录相吻合：

（1）金福全等（1987）的古生物地层学研究表明：①早石炭世杨山组砾石中含有形成时代主要为晚奥陶世－早志留世的珊瑚类、介形类和牙形石类等化石组合．特别是砾石中所含 *Heliolites cf. Anhuiensis*（安徽日射珊瑚比较种），则见于扬子陆块的安徽含山早志留世高家边组和三峡早志留世罗惹坪组，证明灰岩砾石的源区为扬子陆块，也就是说，北淮阳地区存在类似于扬子的早古生代地层；②晚石炭世胡油坊组发现了丰富的小型 *Protomonocarina*（原单脊叶肢介）化石（仅见于华北陆块），指示晚石炭世北淮阳带和华北陆块处于同一个古生物区系，两者是联为一体的．因此，这不仅反映了北淮阳带与扬子陆块之间在石炭纪没有分隔性大洋，而且也证明扬子陆块和华北陆块在石炭纪以前已经拼接．

（2）北淮阳带石炭系未变质或轻微变质的沉积地层（如胡油坊组、杨山组等），记录了其物源信息和古生代的构造演化（李双应等，2011）．其中：①碎屑岩的微量元素地球化学特征揭示其物源区的大地构造属性为岛弧；②碎屑锆石 U-Pb 年龄和碎屑白云母的 Rb-Sr 年龄也进一步确定了岛弧的时代为古生代（400～500 Ma）（Li *et al.*, 2004；李任伟等，2005；Chen *et al.*, 2009；杨栋栋等，2012），这与北秦岭、桐柏及北淮阳带西段（定远变质火山岩）的岛弧

时代相一致．因此，石炭纪沉积地层的部分物源区类似于北秦岭等地的古生代岛弧岩石，也就是说，北淮阳带在早古生代也应发育岛弧体系及相关岩石并为石炭纪盆地沉积提供了重要的物源．

综上所述，北淮阳带东段存在类似于北秦岭和桐柏造山带的早古生代岩浆热事件和晚古生代变质作用，而且，研究区向北的（大洋）板块俯冲作用可能从早古生代开始，一直延续到石炭纪；同时，在（晚泥盆纪－）早石炭纪时，发生了弧－陆碰撞作用．由此证明北秦岭古生代造山带及商丹洋向东延伸到大别山北淮阳带及相邻地区．然而，北淮阳带东段石炭纪变质作用的大地构造背景、古生代的构造演化过程和汇集过程与拼贴机制以及与北秦岭和桐柏造山带的不同构造岩石单位之间相互关系尚需进一步查明，尤其需要详细的野外地质调查及系统的岩石学、年代学和地球化学等方面制约．

5 结论

（1）北淮阳带东段与大理岩相伴生的石榴斜长角闪岩经历了355±5 Ma变质作用．

（2）北淮阳带东段石炭纪变质作用的厘定，为秦岭－桐柏造山带的东延以及大别山碰撞造山带的古生代构造演化过程提供了新的制约．

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References

Brown, M., 2007. Metamorphic Conditions in Orogenic Belts: A Record of Secular Change. *International Geology Review*, 49(3): 193－234. https://doi.org/10.2747/0020-6814.49.3.193

Brown, M., 2009. Metamorphic Patterns in Orogenic Systems and the Geological Record. In: Cawood, P.A., Kröner, A., eds., Earth Accretionary Systems in Space and Time. *The Geological Society*, *London, Special Publications*, 318:37－74. https://doi.org/10.1144/SP318.2

Chen, F. K., Guo, J. H., Jiang, L. L., et al., 2003. Provenance of the Beihuaiyang Lower-Grade Metamorphic Zone of the Dabie Ultrahigh-Pressure Collisional Orogen, China: Evidence from Zircon Ages. *Journal of Asian Earth Sciences*, 22(4): 343－352. https://doi.org/10.1016/s1367-9120(03)00068-3

Chen, F. K., Zhu, X. Y., Wang, W., et al., 2009. Single-Grain Detrital Muscovite Rb-Sr Isotopic Composition as an Indicator of Provenance for the Carboniferous Sedimentary Rocks in Northern Dabie, China. *Geochemical Journal*, 43(4): 257－273. https://doi.org/10.2343/geochemj.1.0023

Chen, L. Y., Liu, X. C., Qu, W., et al., 2014. U-Pb Zircon Ages and Geochemistry of the Wuguan Complex in the Qinling Orogen, Central China: Implications for the Late Paleozoic Tectonic Evolution between the Sino-Korean and Yangtze Cratons. *Lithos*, 192－195: 192－207. https://doi.org/10.1016/j.lithos.2014.01.014

Cheng, H., King, R.L., Nakamura, E., et al., 2009. Transitional Time of Oceanic to Continental Subduction in the Dabie Orogen: Constraints from U-Pb, Lu-Hf, Sm-Nd and Ar-Ar Multichronometric Dating. *Lithos*, 110(1/2/3/4): 327－342. https://doi.org/10.1016/j.lithos.2009.01.013

Cheng, H., Liu, X. C., Vervoort, J. D., et al., 2016. Micro-Sampling Lu-Hf Geochronology Reveals Episodic Garnet Growth and Multiple High-Pmetamorphic Events. *Journal of Metamorphic Geology*, 34(4): 363－377.

Cheng, H., Vervoort, J. D., Dragovic, B., et al., 2018. Coupled Lu-Hf and Sm-Nd Geochronology on a Single Eclogitic Garnet from the Huwan Shear Zone, China. *Chemical Geology*, 476: 208－222.

Compston, W., Williams, I. S., Kirschvink, J. L., et al., 1992. Zircon U-Pb Ages for the Early Cambrian Time-Scale. *Journal of the Geological Society*, 149(2): 171－184. https://doi.org/10.1144/gsjgs.149.2.0171

Dewey, J. F., 1969. Evolution of the Appalachian/Caledonian Orogen. *Nature*, 222(5189): 124－129. https://doi.org/10.1038/222124a0

Dewey, J.F., Spall, H., 1975. Pre-Mesozoic Plate Tectonics. *Geology*, 3:422－424. https://doi.org/10.1130/0091－7613(1975)3<422:PPTHFB>2.0.CO;2

Diwu, C.R., Sun, Y., Liu, L., et al., 2010. The Disintegration of Kuanping Group in North Qinling Orogenic Belts and Neo-Proterozoic N-MORB. *Acta Petrologica Sinica*, 26(7):2025－2038 (in Chinese with English abstract).

Dong, Y. P., Zhang, G. W., Neubauer, F., et al., 2011. Tectonic Evolution of the Qinling Orogen, China: Review and Synthesis. *Journal of Asian Earth Sciences*, 41(3): 213－237. https://doi.org/10.1016/j.jseaes.2011.03.002

Dong, Y. P., Santosh, M., 2016. Tectonic Architecture and Multiple Orogeny of the Qinling Orogenic Belt, Central China. *Gondwana Research*, 29(1): 1－40.

Guo, C.L., Chen, D.L., Fan, W., et al., 2010. Geochemical and Zircon U-Pb Chronological Studies of the Manziying

Granite in Erlangping Area, Western Henan Province. *Acta Petrologica et Minerlogica*, 29(1): 5—22 (in Chinese with English abstract).

Hsü, K.J., Wang, Q.C., Li, J.L., et al., 1987. Tectonic Evolution of Qinling Mountains, China. *Eclogae Geologicae Helvetiae*, 80:735—752.

Jiang, L.L., Siebel, W., Chen, F.K., et al., 2005. U-Pb Zircon Ages for the Luzhenguan Complex in Northern Part of the Eastern Dabie Orogen. *Science in China (Series D)*, 48(9):1357—1367 (in Chinese).

Jin, F.Q., Yan, H.X., Lü, P.J., et al., 1987. New Advance on the Stratigraphy of North Huaiyang Region. *Journal of Hefei Poly Technic University*, 9(9):3—12 (in Chinese).

Li, R. W., Li, S. Y., Jin, F. Q., et al., 2004. Provenance of Carboniferous Sedimentary Rocks in the Northern Margin of Dabie Mountains, Central China and the Tectonic Significance: Constraints from Trace Elements, Mineral Chemistry and SHRIMP Dating of Zircons. *Sedimentary Geology*, 166(3/4): 245—264. https://doi. org/10.1016/j.sedgeo.2003.12.009

Li, R.W., Meng, Q.R., Li, S.Y., 2005.Coupling of the Jurassic and Carboniferous Basins with the Orogens in the Dabie Shan and Adjacent Area: Constraints from Sedimentary Record. *Acta Petrologica Sinica*, 21(4):1133—1143 (in Chinese with English abstract).

Li, S. G., Xiao, Y. L., Liou, D. L., et al., 1993. Collision of the North China and Yangtse Blocks and Formation of Coesite-Bearing Eclogites: Timing and Processes. *Chemical Geology*, 109(1/2/3/4): 89—111. https://doi.org/10.1016/0009-2541(93)90063-o

Li, S. G., Huang, F., Nie, Y. H., et al., 2001. Geochemical and Geochronological Constraints on the Suture Location between the North and South China Blocks in the Dabie Orogen, Central China. Physics and Chemistry of the Earth, *Part A: Solid Earth and Geodesy*, 26(9/10): 655—672. https://doi.org/10.1016/s1464-1895(01)00117-x

Li, S.Y., Jin, F.Q., Wang, D.X., et al., 2011. Stratigraphic Evidence for the Convergence History in the Dabie Orogenic Belt. *Chinese Journal of Geology*, 46(2):288—307 (in Chinese with English abstract).

Liu, J.B., Zhang, L.M., Ye, K., et al., 2013. Oxygen Isotopes of Whole-Rock and Zircon and Zircon U—Pb Ages of Meta-Rhyolite from the Luzhenguan Group and Associated Met-Granite in the Northern Dabie Mountains. *Acta Petrologica Sinica*, 29(5):1511—1524 (in Chinese with English abstract).

Liu, L., Liao, X.Y., Zhang, C.L., et al., 2013. Multi-Metamorphic Timings of HP-UHP Rocks in the North Qinling and their Geological Implications. *Acta Petrologica Sinica*, 29(5):1634—1656 (in Chinese with English abstract).

Liu, L., Liao, X. Y., Wang, Y. W., et al., 2016. Early Paleozoic Tectonic Evolution of the North Qinling Orogenic Belt in Central China: Insights on Continental Deep Subduction and Multiphase Exhumation. *Earth-Science Reviews*, 159: 58—81.

Liu, X., Wei, C., Li, S., et al., 2004. Thermobaric Structure of a Traverse Across Western Dabieshan: Implications for Collision Tectonics between the Sino-Korean and Yangtze Cratons. *Journal of Metamorphic Geology*, 22(4): 361—379. https://doi.org/10.1111/j.1525-1314.2004.00519.x

Liu, X. C., Jahn, B. M., Hu, J., et al., 2011a. Metamorphic Patterns and SHRIMP Zircon Ages of Medium-to-High Grade Rocks from the Tongbai Orogen, Central China: Implications for Multiple Accretion/collision Processes Prior to Terminal Continental Collision. *Journal of Metamorphic Geology*, 29(9): 979—1002. https://doi. org/10.1111/j.1525-1314.2011.00952.x

Liu, X. C., Wu, Y. B., Gao, S., et al., 2011b. Zircon U—Pb and Hf Evidence for Coupled Subduction of Oceanic and Continental Crust during the Carboniferous in the Huwan Shear Zone, Western Dabie Orogen, Central China. *Journal of Metamorphic Geology*, 29(2): 233—249. https://doi.org/10.1111/j.1525-1314.2010.00914.x

Liu, X. C., Jahn, B. M., Li, S. Z., et al., 2013a. UPb Zircon Age and Geochemical Constraints on Tectonic Evolution of the Paleozoic Accretionary Orogenic System in the Tongbai Orogen, Central China. *Tectonophysics*, 599: 67—88. https://doi.org/10.1016/j.tecto.2013.04.003

Liu, X.C., Li, S.Z., Jahn, B.M., 2015. Tectonic Evolution of the Tongbai-Hong'an Orogen in central China: from Oceanic Subduction/Accretion to Continent-Continent Collision. Science China: Earth Sciences, 58: 1477—1496 (in Chinese).

Liu, Y.C., Li, S.G., Gu, X.F., et al., 2006. Zircon SHRIMP U-Pb Dating for Olivine Gabbro at Wangmuguan in the Beihuaiyang Zone and Its Geological Significance. *Chinese Science Bulletin*, 51(20):2500—2506 (in Chinese).

Liu, Y. C., Li, S. G., Gu, X. F., et al., 2007. Ultrahig-Pressure Eclogite Transformed from Mafic Granulite in the Dabie Orogen, East-Central China. *Journal of Metamorphic Geology*, 25(9): 975—989. https://doi. org/10.1111/j.1525-1314.2007.00739.x

Liu, Y. C., Wang, A. D., Rolfo, F., et al., 2009. Geochronological and Petrological Constraints on Palaeoproterozoic Granulite Facies Metamorphism in Southeastern Margin of the North China Craton. *Journal of Metamorphic Geology*, 27(2): 125−138. https://doi.org/10.1111/j.1525-1314.2008.00810.x

Liu, Y.C., Liu, L.X., Gu, X.F., et al., 2010. Occurrence of Neoproterozoic Low-Grade Metagranite in the Western Beihuaiyang Zone, the Dabie Orogen. *Chinese Science Bulletin*, 55(24):2391−2399 (in Chinese).

Liu, Y. C., Wang, A. D., Li, S. G., et al., 2013b. Composition and Geochronology of the Deep-Seated Xenoliths from the Southeastern Margin of the North China Craton. *Gondwana Research*, 23(3): 1021−1039. https://doi.org/10.1016/j.gr.2012.06.009

Liu, Y. C., Deng, L. P., Gu, X. F., et al., 2015. Application of Ti-in-Zircon and Zr-in-Rutile Thermometers to Constrain High-Temperature Metamorphism in Eclogites from the Dabie Orogen, Central China. *Gondwana Research*, 27(1): 410−423.

Liu, Y. C., Liu, L. X., Li, Y., et al., 2017. Zircon U-Pb Geochronology and Petrogenesis of Metabasites from the Western Beihuaiyang Zone in the Hong'an Orogen, Central China: Implications for Detachment within Subducting Continental Crust at Shallow Depths. *Journal of Asian Earth Sciences*, 145: 74−90. https://doi.org/10.1016/j.jseaes.2016.12.021

Ma, C.Q., Ming, H.L., Yang, K.G., 2004. An Ordovician Magmatic Arc at the Northern Foot of Dabie Mountains: Evidence from Geochronology and Geochemistry of Intrusive Rocks. *Acta Petrologica Sinica*, 20(3):393−402 (in Chinese with English abstract).

Mattauer, M., Matte, P., Malavieille, J., et al., 1985. Tectonics of the Qinling Belt: Build-Up and Evolution of Eastern Asia. *Nature*, 317(6037): 496−500. https://doi.org/10.1038/317496a0

O'Brien, P. J., 2001. Subduction Followed by Collision: Alpine and Himalayan Examples. *Physics of the Earth and Planetary Interiors*, 127(1/2/3/4): 277−291. https://doi.org/10.1016/s0031-9201(01)00232-1

Pei, X.Z., Ding, S.P., Zhang, G.W., et al., 2007. Zircons LA-ICP-MS U-Pb Dating of Neoproterozoic Granitoid Gneisses in the North Margin of West Qinling and Geological Implication. *Acta Geologica Sinica*, 81(6):772−786 (in Chinese with English abstract).

Pei, X.Z., Ding, S.P., Li, Z.C., et al., 2009. Early Paleozoic Tianshui-Wushan Tectonic Zone of the Northern Margin of West Qinling and Its Tectonic Evolution. *Acta Geologica Sinica*, 83(11):1547−1564 (in Chinese with English abstract).

Pidgeon, R. T., Macambira, M. J. B., Lafon, J. M., 2000. Th-U-Pb Isotopic Systems and Internal Structures of Complex Zircons from an Enderbite from the Pium Complex, Carajás Province, Brazil: Evidence for the Ages of Granulite Facies Metamorphism and the Protolith of the Enderbite. *Chemical Geology*, 166(1/2): 159−171. https://doi.org/10.1016/s0009-2541(99)00190-4

Qu, W., Liu, X.C., Cui, J.J., et al., 2018. ^{40}Ar-^{39}Ar Dating of Muscovite from the Gaishan Complex in the Tonghai Orogen, Central China, and Its Geological Implications. *Earth Science*, 43(1):247−258 (in Chinese with English abstract).

Ratschbacher, L., Hacker, B. R., Calvert, A., et al., 2003. Tectonics of the Qinling (Central China): Tectonostratigraphy, Geochronology, and Deformation History. *Tectonophysics*, 366(1/2): 1−53. https://doi.org/10.1016/s0040-1951(03)00053-2

Ratschbacher, L., Franz, L., Enkelmann, E., et al. 2006. The Sino-Korean-Yangtze Suture, the Huwan Detachment, and the Paleozoic-Tertiary Exhumation of (Ultra)High-Pressure Rocks along the Tongbai-Xinxian-Dabie Mountains. *Geological Society of America Special Publication*, 403:45−75.

Rubatto, D., Williams, I. S., Buick, I. S., 2001. Zircon and Monazite Response to Prograde Metamorphism in the Reynolds Range, Central Australia. *Contributions to Mineralogy and Petrology*, 140(4): 458−468. https://doi.org/10.1007/pl00007673

Schmitz, M. D., Bowring, S. A., 2003. Ultrahigh−Temperature Metamorphism in the Lower Crust during Neoarchean Ventersdorp Rifting and Magmatism, Kaapvaal Craton, Southern Africa. *Geological Society of America Bulletin*, 115: 533−548. https://doi.org/10.1130/0016−7606(2003)115<0533:umitlc>2.0.co;2

Song, B., Zhang, Y.H., Wan, Y.S., et al., 2002. Mount Making and Procedure of the SHRIMP Dating. *Geological Review*, 48(Suppl. 1):26−30 (in Chinese with English abstract.

Sun, W.D., Li, S.G., Xiao, Y.L., et al., 1995. The Discovery of Island Arc Andesite from Danfeng Group Heihe, North Qinling Area and Its Tectonic Significance. *Geotectonic et Metallogenia*, 19(3): 227−236 (in Chinese with English abstract).

Sun, W. D., Williams, I. S., Li, S. G., 2002. Carboniferous and Triassic Eclogites in the Western Dabie Mountains, East-Central China: Evidence for Protracted Convergence of the North and South China Blocks. *Journal of Metamorphic Geology*, 20(9): 873−886. https://doi.org/10.1046/j.1525-1314.2002.00418.x

Vavra, G., Schmid, R., Gebauer, D., 1999. Internal Morphology, Habit and U-Th-Pb Microanalysis of Amphibolite-to-Granulite Facies Zircons: Geochronology of the Ivrea Zone (Southern Alps). *Contributions to Mineralogy and Petrology*, 134(4): 380－404. https://doi.org/10.1007/s004100050492

Wang, C.C., Liu, Y.C., Yang, Y., et al., 2018. Metamorphic Evolution of Mafic Granulites from the Wuhe Complex at the Southeastern Margin of the North China Craton. *Earth Science*, 43(1): 296－316 (in Chinese with English abstract).

Wang, H., Wu, Y.B., Qin, Z.W., et al., 2013a. Age and Geochemistry of Silurian Gabbroic Rocks in the Tongbai Orogen, Central China: Implications for the Geodynamic Evolution of the North Qinling Arc Back-Arc System. *Lithos*, 179: 1－15. https://doi.org/10.1016/j.lithos.2013.07.021

Wang, X. X., Wang, T., Zhang, C. L., 2013b. Neoproterozoic, Paleozoic, and Mesozoic Granitoid Magmatism in the Qinling Orogen, China: Constraints on Orogenic Process. *Journal of Asian Earth Sciences*, 72: 129－151. https://doi.org/10.1016/j.jseaes.2012.11.037

Wang, T., Wang, X.X., Tian, W., et al., 2009. North Qinling Paleozoic Granite Associations and Their Variation in Space and Time: Implications for Orogenic Processes in the Orogens of Central China. Science China: Earth Sciences, 52 (in Chinese).

Wang, X.X., Wang, T., Zhang, C.L., et al., 2015. Granitoid Magmatism in the Qinling Orogen, Central China and Its Bearing on Orogenic Evolution. Science China: Earth Sciences, 58:1497－1512 (in Chinese).

Williams, I.S., 1998. U-Th-Pb Geochronology by Ion Microprobe. In: McKibben, M.A., Shanks, III, W.C., Ridley, W.I. eds., Applications of Microanalytical Techniques to Understanding Mineralizing Processes. *Reviews in Economic Geology*, 7:1－35.

Wilson, J. T., 1966. Did the Atlantic Close and then Re-Open? *Nature*, 211(5050): 676－681. https://doi.org/10.1038/211676a0

Wu, Y.B., Zheng, Y.F., Gong, B., et al., 2004. Zircon U-Pb Ages and Oxygen Isotope Compositions of the Luzhenguan Magmatic Complex in the Beihuaiyang Zone. *Acta Petrologica Sinica*, 20(5): 1007－1024 (in Chinese with English abstract).

Wu, Y. B., Hanchar, J. M., Gao, S., et al., 2009. Age and Nature of Eclogites in the Huwan Shear Zone, and the Multi-Stage Evolution of the Qinling-Dabie-Sulu Orogen, Central China. *Earth and Planetary Science Letters*, 277(3/4): 345－354. https://doi.org/10.1016/j.epsl.2008.10.031

Wu, Y. B., Zheng, Y. F., 2013. Tectonic Evolution of a Composite Collision Orogen: An Overview on the Qinling-Tongbai-Hong'an-Dabie-Sulu Orogenic Belt in Central China. *Gondwana Research*, 23(4): 1402－1428.

Xu, S. T., Jiang, L. L., Liu, Y. C., et al., 1992a. Tectonic Framework and Evolution of the Dabie Mountains in Anhui, Eastern China. *Acta Geologica Sinica*, 5(3):221－238.

Xu, S.T., Okay, A.I., Ji, S., et al., 1992b. Diamond from the Dabie Shan Metamorphic and Its Implication for Tectonic Setting. *Science*, 256: 80－82. https://doi.org/10.1126/science.256.5053.80

Xu, S.T., Liu, Y.C., Jiang, L.L., et al., 1994. Tectonic Regime and Evolution of Dabie Mountains. Science Press, Beijing (in Chinese).

Xu, S.T., Liu, Y.C., Jiang, L.L., et al., 2002. Architecture and Kinematics of the Dabie Mountains Orogen. University of Science and Technology of China Press, Hefei(in Chinese).

Xu, Z.Q., Li, Y., Liang, F.H., et al., 2015. A Connection between of the Paleo-Tethys Suture Zone in the Qinling-Dabie-Sulu Orogenic Belt. *Acta Geologica Sinica*, 89(4): 671－680 (in Chinese with English abstract).

Yan, Z., Fu, C. L., Wang, Z. Q., et al., 2016. Late Paleozoic Subduction-Accretion along the Southern Margin of the North Qinling Terrane, Central China: Evidence from Zircon U-Pb Dating and Geochemistry of the Wuguan Complex. *Gondwana Research*, 30: 97－111. https://doi.org/10.1016/j.gr.2015.05.005

Yang, D.D., Li, S.Y., Zhao, D.Q., et al., 2012. Geochemistry and Detrial Zircon Geochronology of Carboniferous Detrital rocks in the Northern Margin of Dabie Mountains, Central China and Constraints to Distinguishing the Provenance Tectonic Attribute. *Acta Petrologica Sinica*, 28(8):2619－2628 (in Chinese with English abstract).

Yang, J.S., Xu, Z.Q., Pei, X.Z., et al., 2002. Discovery of Diamond in North Qinling: Evidence for a Giant UHPM Belt Across Central China and Recognition of Paleozoic and Mesozoic Dual Deep Subduction Between North China and Yangtze Plates. *Acta Geological Sinica*, 76(4):484－495 (in Chinese with English abstract).

Zhai, X. M., Day, H. W., Hacker, B. R., et al., 1998. Paleozoic Metamorphism in the Qinling Orogen, Tongbai Mountains, Central China. *Geology*, 26(4): 371.

Zhang, C.L., Liu, L., Wang, T., et al., 2013. Granitic Magmatism Related to Early Paleozoic Continental Collision in the North Qinling Belt. *Chinese Science Bulletin*, 58(23):2323－2329 (in Chinese).

Zhang, G.W., Mei, Z.C., Zhou, D.W., et al., 1988. Formation and Evolution of the Qinling Orogen Belt. Northwest University Press, Xi'an, 1—74 (in Chinese with English abstract).

Zhang, G.W., Zhang, B.R., Yuan, X.C., et al., 2001. Qinling Orogenic Belt and Continental Dynamics. Science Press, Beijing, 1—854 (in Chinese with English abstract).

附中文参考文献

第五春荣,孙勇,刘良,等,2010.北秦岭宽坪岩群的解体及新元古代N-MORM.岩石学报,26:2025—2038.

郭彩莲,陈丹玲,樊伟,等,2010.豫西二郎坪满子营花岗岩体地球化学及年代学研究.岩石矿物学杂志,29(1):15—22.

江来利,Wolfgang,S.,陈福坤,等,2005.大别造山带北部卢镇关杂岩的U-Pb锆石年龄.中国科学(D辑),35:411—419.

金福全,颜怀学,吕培基,等,1987.北淮阳区地层研究的新进展—论北淮阳区的地层层序.合肥工业大学学报,9:3—12.

李任伟,孟庆任,李双应.2005.大别山及邻区侏罗和石炭纪时期盆—山耦合.岩石学报,21(4):1133—1143.

李双应,金福全,王道轩,等,2011.地层证据—对大别造山带汇聚历史的制约.地质科学,46(2):288—307.

刘景波,张灵敏,叶凯,等,2013.大别山北部卢镇关群变质火山岩和共生变质的花岗岩全岩和锆石氧同位素、锆石U-Pb年代学研究.岩石学报,29(5):1511—1524.

刘良,廖小莹,张成立,等,2013.北秦岭高压—超高压岩石的多期变质时代及其地质意义.岩石学报,29(5):1634—1656.

刘晓春,李三忠,江博明,2015.桐柏—红安造山带的构造演化:从大洋俯冲/增生到陆陆碰撞.中国科学:地球科学,45:1088—1108.

刘贻灿,李曙光,古晓锋,等,2006.北淮阳王母观橄榄辉长岩的锆石SHRIMP U-Pb年龄及其地质意义.科学通报,51:2175—2180.

刘贻灿,刘理湘,古晓锋,等,2010.大别山北淮阳带西段新元古代浅变质花岗岩的发现及其大地构造意义.科学通报,55:2391—2399.

马昌前,明厚利,杨坤光,2004.大别山北麓的奥陶纪岩浆弧:侵入年代学和地球化学证据.岩石学报,20(3):393—402.

裴先治,丁仨平,张国伟,等,2007.西秦岭北缘新元古代花岗质片麻岩的LA-ICP-MS锆石U-Pb年龄及其地质意义.地质学报,81:772—786.

裴先治,丁仨平,李佐臣,等,2009.西秦岭北缘早古生代天水—武山构造带及其构造演化.地质学报,83:1547—1564.

曲玮,刘晓春,崔建军,等,2018.桐柏造山带中龟山杂岩的白云母$^{40}Ar/^{39}Ar$年龄及其地质意义.地球科学,43(1):247—258.

宋彪,张玉海,万渝生,等,2002.锆石SHRIMP样品靶制作、年龄测定及有关现象讨论.地质论评,48(增刊):26—30.

孙卫东,李曙光,肖益林,等,1995.北秦岭黑河丹凤群岛弧火山岩建造的发现及其构造意.大地构造与成矿学,19,227—236.

王程程,刘贻灿,杨阳,等,2018.华北东南缘五河杂岩中镁铁质麻粒岩的变质演化.地球科学,43(1):296—316.

王涛,王晓霞,田伟,等,2009.北秦岭古生代花岗岩组合、岩浆时空演变及其对造山作用的启示.中国科学(D辑),39:949—971.

王晓霞,王涛,张成立,2015.秦岭造山带花岗质岩浆作用与造山带演化.中国科学(D辑),45:1109—1125.

吴元保,郑永飞,龚冰,等,2004.北淮阳庐镇关岩浆岩锆石U-Pb年龄和氧同位素组成.岩石学报,20:1007—1024.

徐树桐,刘贻灿,江来利,等,1994.大别山的构造格局和演化.北京:科学出版社.

徐树桐,刘贻灿,江来利,等,2002.大别山造山带的构造几何学和运动学.合肥:中国科学技术大学出版社.

许志琴,李源,梁凤华,等,2015."秦岭—大别—苏鲁"造山带中"古特提斯缝合带"的连接.地质学报,89(4):671—680.

杨栋栋,李双应,赵大千,等,2012.大别山北缘石炭系碎屑岩地球化学及碎屑锆石年代学分析及其对物源区大地构造属性判别的制约.岩石学报,28:2619—2628.

杨经绥,许志琴,裴先治,等,2002.秦岭发现金刚石:横贯中国中部巨型超高压变质带新证据及古生代和中生代两期深俯冲作用的识别.地质学报,76(4):484—495.

张成立,刘良,王涛,等,2013.北秦岭早古生代大陆碰撞过程中的花岗岩浆作用.科学通报,58:2323—2329.

张国伟,1988.秦岭造山带的形成及其演化.西安:西北大学出版社.

张国伟,张本仁,袁学成,等,2001.秦岭造山带与大陆动力学.北京:科学出版社.