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罗迪尼亚超大陆聚合在华南陆块北缘的镁铁质岩浆岩记录

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摘 要: 超大陆的聚合必然伴随着从大洋俯冲、弧陆碰撞到陆陆碰撞等一系列板块汇聚和造山过程,这些不同阶段的俯冲和汇聚过程会产生不同特征的岩浆岩记录.华南陆块是新元古代罗迪尼亚超大陆的重要组成部分,在这个超大陆聚合过程中有格林维尔期洋壳俯冲及其伴随的壳幔相互作用.总结了华南陆块北缘记录的罗迪尼亚超大陆聚合不同阶段发生的岩浆活动,比较了其产物的地球化学特征,探讨了它们对应的构造环境.华南陆块北缘900~950 Ma的岩浆活动产物以镁铁质岩浆岩为主,伴随有少量斜长花岗岩,为洋壳俯冲作用的产物.当洋壳俯冲到大陆边缘之下形成安第斯型俯冲带,古老陆源沉积物也被携带进入俯冲带,由此部分熔融产生的含水熔体交代上覆地幔楔形成极度富集的造山带岩石圈地幔,其在新元古代中期发生部分熔融形成具有极负锆石$\varepsilon_{Hf}(t)$值的镁铁质岩浆岩.因此,在罗迪尼亚超大陆聚合过程中地幔楔被交代形成镁铁质-超镁铁质交代岩,其中一部分在俯冲阶段就发生部分熔融形成大洋弧或大陆弧镁铁质岩浆岩,另一部分在俯冲之后由于大陆裂断引起造山带岩石圈拉张使其与上覆地壳一起部分熔融形成双峰式岩浆岩.

关键词: 华南陆块;罗迪尼亚超大陆;超大陆聚合;洋壳俯冲;地幔交代;岩石学.

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Mafic Magmatic Records of Rodinia Amalgamation in the Northern Margin of the South China Block

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Abstract: The amalgamation of supercontinents is associated with a series of orogenic processes during plate convergence from oceanic subduction, arc-continent collision and continent-continent collision. These processes are recorded in different types of magmatic rocks. The South China block is one of the most important continents in supercontinent Rodinia, whose amalgamation is caused by Grenvillian subduction of oceanic slabs with considerable crust-mantle interaction. This paper presents a summary of magmatic records in the northern margin of the South China block during the Rodinia amalgamation. The 900-950 Ma magmatic rocks are mainly of mafic to intermediate compositions with a few plagiogranites, and they are the products of intraoceanic subduction. As the subduction style evolved into Andean type, ancient terrigenous sediments were carried into subduction zones to undergo dehydration melting, giving rise to hydrous felsic melts which would react with the overlying mantle wedge. This results in the formation of highly enriched mantle sources, whose partial melting in the Middle Neoproterozoic to produced mafic magmatic rocks with very negative zircon $\varepsilon_{Hf}(t)$ values. In this regard, mafic to ultramafic rocks were generated in the mantle wedge

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through crustal metasomatism by subducting oceanic crust-derived fluids during the Rodinia amalgamation. Some of these rocks were partially melted in the subduction stage to form mafic arc volcanics along convergent plate boundaries, and the other parts were partially melted together with the overlying crust during lithospheric extension by continental rifting at a later time for bimodal magmatism.

Key words: South China block; Rodinia; supercontinent amalgamation; oceanic subduction; mantle metasomatism; petrology.

0 引言

罗迪尼亚超大陆形成于前寒武纪晚期,是地质历史上最重要的超大陆之一.罗迪尼亚超大陆基本上包含了全球所有的大陆,其聚合时间主要是1 300~1 000 Ma,但是在中国延迟到900 Ma(Li *et al.*,2008).超大陆聚合从大洋岩石圈俯冲开始,经历大陆边缘弧的形成、弧陆碰撞到陆陆碰撞等一系列过程,产生同时期增生和碰撞造山带,并以北美的格林威尔造山带为代表(Hoffman,1991;Moores,1991).华南陆块由扬子克拉通、江南造山带和华夏地块组成,其中江南造山带是华夏洋壳俯冲到扬子克拉通之下所引起的增生和碰撞造山作用的产物(Zhang and Zheng,2013).但是,华南陆块相对缺少1 300~900 Ma俯冲带变质作用和岩浆作用的岩石记录.从现今的位置来看,华南陆块是沿着其北缘从罗迪尼亚超大陆裂解开来的(Zheng *et al.*,2013),在这里与超大陆裂解相关的岩石记录较为丰富(Zheng *et al.*,2004,2009;Zhang *et al.*,2014).

根据已有资料,格林威尔期洋壳俯冲的岩石记录主要出现在扬子克拉通的周缘.在东南侧的江南造山带,Li *et al.*(2002,2007)根据华夏地块的中元古代年龄和格林威尔期的变质年龄,推测华夏地块是劳伦大陆的一部分,江南造山带是扬子克拉通与劳伦大陆碰撞形成的.但是,在江南造山带的赣东北地区发育有970~1 000 Ma西湾蛇绿岩(Gao *et al.*,2009;Sun *et al.*,2018)、900~930 Ma的双溪坞岛弧火山岩(Ye *et al.*,2007;陈志洪等,2009),指示扬子克拉通的东南缘在格林威尔期处于洋壳俯冲和增生阶段,还没有发育成碰撞造山带.在扬子克拉通崆岭杂岩的南部,Peng *et al.*(2012)和Deng *et al.*(2017)根据庙湾变质镁铁质岩石970~1 100 Ma的年龄及其地球化学特征,提出这是一套蛇绿混杂岩.该"蛇绿岩"的部分年龄与神农架群上部的1.0~1.1 Ga的火山岩年龄(Qiu *et al.*,2011;李怀坤等,2013;Wang *et al.*,2013)重叠,暗示神农架群中火山岩可能为岩浆弧,但神农架群的沉积特征为稳定的碳酸盐台地.在西侧的川滇裂断带,中元古代晚期的岩石主要以昆阳群、会理群、苴林群为代表的一些地层,岩性主要为陆源碎屑沉积岩和少量火山岩(Greentree *et al.*,2006;张传恒等,2007;杨崇辉等,2009),但是这些地层与典型的活动大陆边缘地层在沉积特征上存在显著差别.

综合上述资料可以看出,前人对罗迪尼亚超大陆汇聚过程中华南陆块如何响应的研究,主要关注的是华南陆块内部.前人对华南陆块如何参与罗迪尼亚超大陆的聚合过程一直存在不同的认识,大范围出露的830~740 Ma岩浆岩使更多学者关注华南陆块在新元古代中期的构造背景及其与罗迪尼亚超大陆裂解的关系.在威尔逊旋回中,超大陆往往沿着相对薄弱的板块缝合带裂解(Wilson,1966;Dewey and Burke,1974),也就是沿着增生或者碰撞造山带裂解(Cawood *et al.*,2009;Zheng and Chen,2017).在超大陆裂解之前,大陆裂断开始发育,其中成功的裂断发展成为裂解,夭折的裂断就是陆内拉张型造山带(Zheng and Chen,2017).在华南陆块内部的江南造山带出现有大量830~800 Ma长英质岩浆岩和少量基性岩浆岩,就是夭折的大陆裂断对造山带岩石圈再活化的结果(Zheng *et al.*,2007,2008).在华南陆块北缘广泛发育有低$\delta^{18}O$岩浆活动(Zheng *et al.*,2004,2007a,2009)、双峰式火山岩(Zheng *et al.*,2003)等,说明华南陆块北缘是其从罗迪尼亚超大陆裂解的地方.在华南陆块北缘也应该有岩石记录了华南陆块参与罗迪尼亚超大陆聚合的过程.本文总结了华南陆块北缘记录的罗迪尼亚超大陆聚合期间不同阶段的镁铁质岩浆活动,比较了其地球化学特征,探讨了它们对应的俯冲带壳幔相互作用,结果为重建华南陆块在罗迪尼亚超大陆聚合和裂解中的构造演化提供了制约.

1 新元古代早期岩浆记录

勉略带是介于秦岭造山带南缘与华南陆块北缘之间的结合带,整体呈近东西向带状展布.主体分布于甘肃省康县—陕西省略阳—勉县一线,南北

宽约8～10 km.向西可追索到甘肃康县、文县一带,向东沿巴山弧形断裂已可延伸至石泉、饶峰及西乡县五里坝一带,甚至可以沿桐柏－红安－大别造山带南缘的一些零星的基性－超基性岩体继续东延.勉略带内零散出露有多个镁铁质—超镁铁质岩块,主要由强烈剪切变形变玄武岩、玄武安山岩、安山岩、蛇纹岩、辉长岩和辉绿岩等组成,与片岩为主的基质为断层接触关系.带内超基性岩大多强烈蛇纹石化,且变形强烈,而呈蛇纹片岩;基性、中基性火山岩均已遭受绿片岩相变质作用,并显示多期韧性剪切变形的构造形迹.传统上,勉略带被视为古生代洋盆闭合的产物(张国伟等,1995,2001,2004;李曙光等,2003).但越来越多的资料显示,勉略带是一个包含不同时代地层碎块和岩块的构造混杂带(张国伟,2015),其中出露有大量的新元古代岩浆岩(张宗清等,2005;闫全人等,2007),可能记录了华南陆块在罗迪尼亚超大陆聚合期间的岩浆活动.

位于略阳县以西的三岔子剖面是勉略蛇绿岩的经典剖面,该剖面的经典露头在三岔子乡西南部的偏桥沟附近.偏桥沟剖面主要由强烈剪切变形的变火山岩、超基性岩、辉长辉绿岩以及变沉积岩组成的混杂岩块.变火山岩主要由绿片岩相变质的玄武岩、玄武安山岩和安山岩组成,变火山岩中段可见变辉长岩和蛇纹石化橄榄岩,并见2 m×3 m左右的斜长花岗岩体侵入到千枚岩中.Wu *et al.*(2019)研究了三岔子剖面的岩浆岩.锆石U-Pb定年显示,斜长花岗岩、变安山岩和辉长闪长岩的谐和年龄为分别为905±8 Ma、936±6 Ma和950±5 Ma,代表各自的岩浆结晶年龄.全岩地球化学分析显示,三岔子的辉长闪长岩、安山岩和斜长花岗岩都具有富集LILE和LREE、亏损HFSE的微量元素特征.其中,三岔子斜长花岗岩具有低TiO_2、高Na_2O的地球化学特征,无明显的Eu异常,REE含量与SiO_2含量表现为负相关或者基本不变.

Wu *et al.*(2019)的研究发现,三岔子岩浆岩都具有高度亏损的Sr-Nd-Hf同位素组成,其中斜长花岗岩$\varepsilon_{Nd}(t)$值和$\varepsilon_{Hf}(t)$值分别为5.9～6.8和11.1～11.2,中基性岩的$\varepsilon_{Nd}(t)$值和$\varepsilon_{Hf}(t)$值分别为4.1～5.5和12.1～16.0.如图1所示,这些岩石中的锆石$\varepsilon_{Hf}(t)$值不随U-Pb年龄变化而变化,都在亏损地幔值附近.斜长花岗岩的锆石$\delta^{18}O$值为4.6‰～6.5‰,加权平均值为5.8‰±0.3‰,略高于正常地幔值5.3‰±0.3 ‰(Valley *et al.*, 1998),并且比Grimes *et al.*(2013)统计的全球斜长花岗岩的锆石氧同位素值(4.9‰±0.6‰)也要略高,说明可能有经历了低温蚀变的岩石参与部分熔融.其锆石$\varepsilon_{Hf}(t)$范围为8.9～14.9,加权平均值为12.2±0.6.变安山岩锆石$\delta^{18}O$值为4.9‰～5.9‰,基本与地幔平衡,对应非常正的锆石$\varepsilon_{Hf}(t)$值,从11.8到15.6,加权平均值为14.0±0.5.辉长闪长岩锆石$\varepsilon_{Hf}(t)$值为8.6～15.8,加权平均值为12.2±0.7.锆石微量元素结果显示,斜长花岗岩锆石相对变安山岩和辉长闪长岩的锆石具有更高的Ce正异常和更弱的Eu负异常(Wu *et al.*, 2019),说明斜长花岗岩的结晶环境相对更加氧化.

Wu *et al.*(2019)的地球化学研究表明,三岔子的中基性岩石是由流体交代的、同位素上亏损的地幔楔内岩石部分熔融形成的,与典型的大洋弧相似;而斜长花岗岩是由蚀变的镁铁质洋壳岩石发生部分熔融形成的,反映洋盆逐渐闭合过程中蛇绿岩侵位过程中局部的岩浆活动.三岔子这一套岩浆岩最有可能的构造环境是大洋俯冲带,类似于现今伊豆－小笠原－马里亚纳(IBM)大洋岛弧体系,代表了新元古代早期的一套大洋弧及其新增生的大陆边缘.这一结果限定了华南陆块北缘大洋俯冲带在新元古代早期的发育,指示华南陆块在新元古代早期是通过增生型造山作用参与到罗迪尼亚超大陆的聚合过程中.

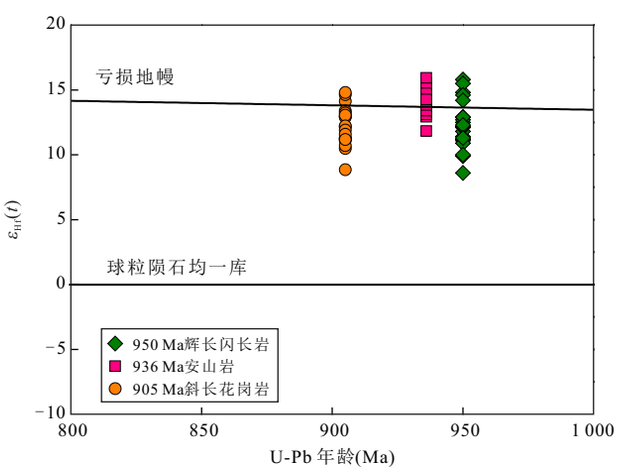

图1　勉略带三岔子岩浆岩中不同岩性的锆石U-Pb年龄和Lu-Hf同位素结果

Fig.1　Zircon U-Pb ages and Lu-Hf isotope results for different magmatic rocks from the Sanchazi area in the Mianlue belt

据Wu *et al.*(2019)

2 新元古代中期岩浆记录

在华南陆块北缘、大别造山带南缘的蕲春地区出露有一套镁铁质－超镁铁质岩石，呈北西向展布，与800 Ma的新元古代花岗岩(薛怀民等，2004)为断层接触.该地区出露的主要岩性为辉石岩、辉长岩和蛇纹岩，都经历了强烈的蚀变，岩体内部和岩体北部出露有灰绿色片岩.该岩体曾被视为勉略蛇绿岩在大别山地区的东延(赖绍聪和秦江峰，2010).这些幔源镁铁质－超镁铁质岩浆为限定扬子克拉通岩石圈地幔的地球化学性质，提供了绝佳的研究对象.

虽然蕲春地区辉石岩中的辉石和橄榄石大多已经蚀变成蛇纹石，但是辉石岩在薄片中保留了典型的堆晶结构.Zhang *et al.*(2016a)研究了这些镁铁质－超镁铁质岩石的地球化学.辉石岩SiO_2为43.19%～54.19%，MgO含量很高，为19.65%～29.36%，$Mg^{\#}$为69～80.其稀土元素模式平坦，伴有微弱的Eu负异常，富集Cr、Ni等相容元素，大离子亲石元素以及其他不相容元素浓度低，微量元素蛛网图上总体上表现为平坦的模式，只有Ba和Pb表现出弱正异常，Nb为弱负异常.两个片岩(变安山岩)具有高Si、高Ti、高Al、高Na、高K的特征.对辉石岩中的锆石进行了U-Pb定年，得到年龄为808±4 Ma(图2).两个片岩的稀土元素以及所有不相容元素含量都显著高于辉石岩，也富集大离子亲石元素，具有Nb、Ta和Sr的异常.从辉石岩中分选出的新鲜辉石和角闪石$\delta^{18}O$值为5.1‰～6.2‰，与地幔平衡值相当或略高.对辉石岩中的锆石进行了Lu-Hf同位素分析，得到的$\varepsilon_{Hf}(t)$值非常低，范围为－28.5～－16.7，加权平均值为－21.3±1.2，是目前已知的新元古代幔源岩浆最低的Hf同位素比值.这些Hf同位素数据表明，结晶出蕲春辉石岩的岩浆来自一个非常富集的地幔源区.

一般而言，辉石岩的成因有3种可能性：(1)镁铁质岩浆堆晶作用的产物(Irving，1980；Downes，2007)；(2)熔体与橄榄岩发生反应(Liu *et al.*，2005)，形成的辉石岩一般以脉体产出于地幔橄榄岩中；(3)洋壳辉长岩通过变质作用转变成辉石岩(Yu *et al.*，2010)，一般具有较高的Al_2O_3/MgO比值.蕲春辉石岩的岩石学和地球化学特征都符合堆晶成因.考虑到橄榄石和辉石的$D_{La/Yb}$都小于1，辉石岩平坦的稀土模式意味着其母岩浆具有轻稀土

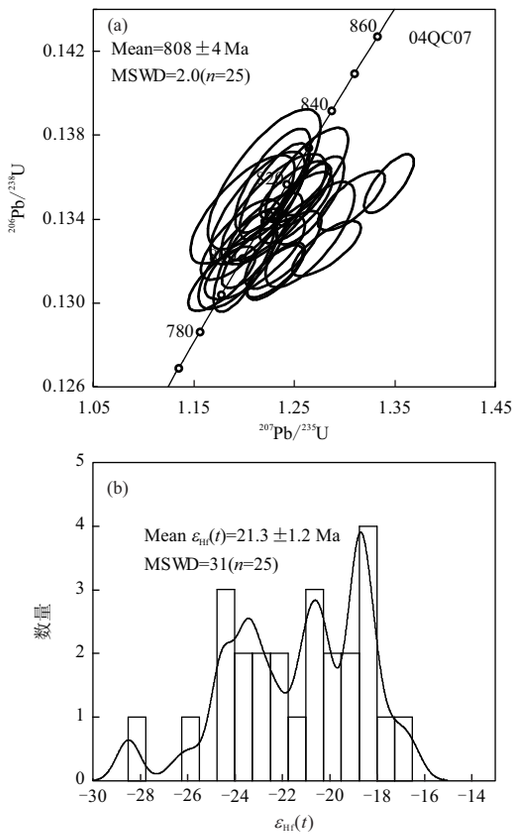

图2 蕲春辉石岩的锆石U-Pb年龄和Lu-Hf同位素分析结果

Fig.2 Zircon U-Pb ages and Lu-Hf isotope results for the Qichun pyroxenite

据Zhang *et al.*(2016a)

富集的模式，不可能是洋中脊玄武岩.辉石岩中Pb的正异常和Nb的负异常也说明其母岩浆形成于俯冲相关的过程.

根据Zhang *et al.*(2016a)的锆石Hf同位素地球化学研究，在新元古代中期，华南陆块北缘存在高度富集的大陆岩石圈地幔.考虑到扬子克拉通经历了从太古宙到元古宙的多次熔体抽取和地壳生长(Zhang and Zheng，2013)，残留的岩石圈地幔应该具有非常高的Hf同位素比值，必须通过地壳混染或者源区混合过程中的富集端元加入才能得到这样高度富集的Hf同位素特征.质量平衡模拟计算表明，地壳混染不可能形成具有如此富集的Hf同位素特征的镁铁质岩浆，只有来自古老大陆的太古宙陆源沉积物或者其熔体与地幔楔在源区发生反应，才有可能形成如此负的Hf同位素特征.这样的反应过程，必然发生在蕲春辉石岩的岩浆活动之前.古老陆源沉积物的加入，说明俯冲带已经发展到大陆边缘.结合上文的洋内俯冲的岩浆记录，蕲春辉石岩

说明华南陆块北缘的大洋板片俯冲已经从900 Ma之前的洋内俯冲转变为安第斯型俯冲.

3　罗迪尼亚超大陆聚合和裂解在华南陆块的其他记录

罗迪尼亚超大陆聚合和裂解过程在华南陆块的其他地区也有记录,既有与格林威尔期同时或者略晚的俯冲相关的岩浆活动,也有与大陆裂断相关的岩浆活动和变质记录.例如,在北缘的勉略带东部、随州地区的花山蛇绿岩,其辉长岩和花岗岩年龄分别为947±14 Ma和876±17～858±15 Ma(Shi *et al.*,2007;Xu *et al.*,2016).花山蛇绿岩中花岗岩年龄相对三岔子蛇绿岩中斜长花岗岩较晚,说明大洋弧在华南北缘不同地区的就位时间不完全一致.另外,在北缘新元古代早期的岩浆记录还有西乡群中900～950 Ma的流纹岩和英安岩(Ling *et al.*,2003),碧口群中约880 Ma的闪长岩和辉长岩岩株(Xiao *et al.*,2007),汉南和米仓山地区870～900 Ma的辉长岩和花岗岩(Dong *et al.*,2011,2012;Zhou *et al.*,2018),南秦岭小茅岭岩基中850～960 Ma的基性、中性和酸性岩石(刘仁燕等,2011;刘春花等,2014;阎明等,2014;Zhang *et al.*,2016b;Dong *et al.*,2017).这些岩石大多具有与岛弧玄武岩相似的微量元素特征,暗示它们可能与勉略带中三岔子蛇绿岩一样,是同一个大洋俯冲体系岩浆活动的记录.

不考虑相对较老的基性岩,汉南岩基中的花岗岩年龄大多在830～780 Ma(Zhao and Zhou,2009;Dong *et al.*,2012),而且基本上都是I型花岗岩,同时期的基性岩也与更老的基性岩在地球化学和同位素特征上存在明显差别.这些显著晚于洋壳俯冲活动和蛇绿岩年龄的钙碱性岩浆岩不是大陆弧岩浆活动的产物,而是大陆弧地壳在超大陆聚合之后大陆裂断作用下的再造.

对江南造山带皖南地区伏川蛇绿岩的研究得到,其中锆石U-Pb年龄是840～820 Ma(Zhang *et al.*,2012;Wang *et al.*,2014),显著晚于罗迪尼亚超大陆聚合的最晚年龄900 Ma.我们先前将这个年龄解释为华夏地块聚合到扬子克拉通过程中的弧陆碰撞时间(Zhang *et al.*,2012),但是江南造山带在830～800 Ma发生大面积花岗质岩浆作用(Zheng *et al.*,2007b,2008b),对应的是构造拉张(裂断造山)而不是构造挤压(碰撞造山)环境(Zheng and Chen,2017).从这个角度来看,皖南伏川蛇绿岩有可能不是真正的蛇绿岩,而是超大陆聚合之后大陆裂断作用下出露的造山带岩石圈地幔及其熔融产物.

前人对华南陆块的大量研究表明,大陆裂断岩浆作用和变质作用记录的罗迪尼亚超大陆裂解年龄范围是740～780 Ma(Zheng *et al.*,2004,2008a,2008b,2009),峰期是750 Ma(Zheng *et al.*,2007a,2008a;He *et al.*,2018).在大别造山带北淮阳地区的高温低压角闪岩相变质花岗岩中出现红柱石向夕线石转变的矿物组合,变质温压条件为560～660 ℃和1.0～3.5 kba,记录了超大陆裂解峰期750 Ma发生的巴肯式变质作用(He *et al.*,2018).不过,罗迪尼亚超大陆从裂断转为裂解在华南陆块北缘的具体转折时间节点可能在780 Ma左右.

在秦岭造山带南缘的陡岭地区,Hu *et al.*(2019)报道了820～815 Ma和790～780 Ma这两个范围变质年龄的角闪岩相变泥质岩和石榴角闪岩,其中石榴角闪岩的变质温压条件是614～713 ℃和10.2～11.8 kbar,变泥质岩的变质温压条件是486～721 ℃和6.4～11.3 kbar.变泥质岩中出现从蓝晶石向夕线石转变的矿物组合,尽管表现出顺时针*P-T*轨迹,但是进变质温度增加幅度较大而压力增加幅度较小,与巴罗式变质过程中温度压力同步增加的轨迹还是存在一定差别.尤其值得注意的是,那些变质年龄显著晚于超大陆聚合结束的年龄(＞900 Ma),而与华南陆块内部和边缘出现的大陆裂断时间(830～740 Ma)一致.类似的变质年龄在前人文献中也有零星报道(Ratschbacher *et al.*,2003;Nie *et al.*,2016).因此,对陡岭角闪岩相变质事件构造属性的解释还有待进一步研究.如果是巴罗式变质作用产物,则指示华南陆块北缘在820～790 Ma这个年龄段还在发生碰撞造山作用.如果单从变质年龄来看,这个年龄段的角闪岩相变质也可以是超大陆聚合之后大陆裂断作用引起的,只是变质压力较高些.

4　结语

通过总结华南陆块北缘在罗迪尼亚超大陆聚合过程中的岩浆记录可以看到,华南陆块是通过新元古代早期一系列洋壳俯冲和增生造山过程逐渐拼合到罗迪尼亚超大陆的.总体而言,华南陆块聚合到罗迪尼亚超大陆通过以下过程实现(图3):(1)

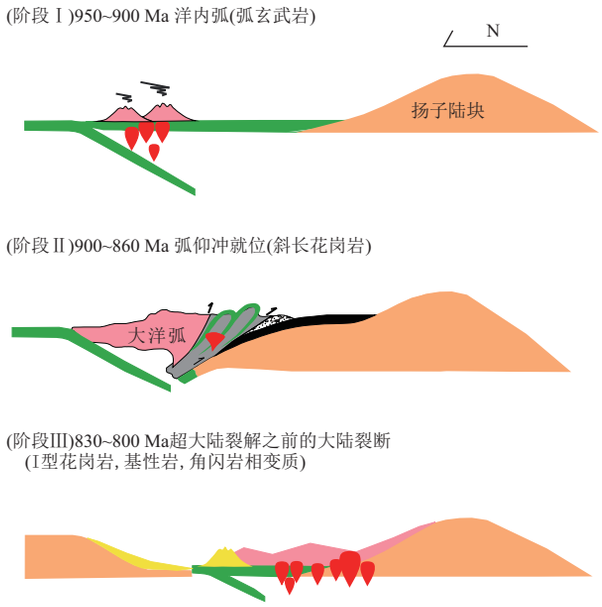

图 3 华南聚合到罗迪尼亚超大陆的过程

Fig.3 The tectonic evolution during the assemblage of South China into Rodinia supercontinent

据 Wu *et al.*(2019)

950～900 Ma期间,华南北缘以发育以岛弧玄武岩为代表的大洋弧体系,华南还没有聚合到超大陆中;(2) 900～860 Ma期间,斜长花岗岩的发育说明大洋弧开始仰冲就位,华南陆块开始聚合到罗迪尼亚超大陆中.随着俯冲和弧陆碰撞的持续发展,到830～780 Ma期间,华南陆块已经成为罗迪尼亚超大陆的一部分,先前形成的造山带逐渐开始垮塌,以大面积的I型花岗岩和少量同时期基性岩以及角闪岩相变质为代表,并逐渐从780 Ma开始向大陆裂解转变.

总体来说,华南陆块北缘900～950 Ma的岩浆活动产物以镁铁质岩浆岩为主,为洋壳俯冲作用的产物.俯冲的古老陆源沉积物析出流体交代上覆地幔楔,导致该时期发育了极度富集的造山带岩石圈地幔,其部分熔融产物就是这些镁铁质岩浆岩.到了新元古代中期的830～740 Ma,岩浆作用产物以长英质成分为主,伴随有少量的基性岩浆,是大陆裂断对造山带岩石圈再活化的产物.在罗迪尼亚超大陆聚合过程中,俯冲板片析出流体交代地幔楔形成镁铁质－超镁铁质交代岩,其中一部分在大洋板片俯冲阶段发生部分熔融形成大洋弧和大陆弧镁铁质岩浆岩,另一部分在俯冲后的大陆裂断阶段造山带岩石圈拉张过程中与上覆地壳一起部分熔融形成双峰式岩浆岩.

References

Cawood, P.A., Kröner, A., Collins, W.J., et al., 2009. Accretionary Orogens through Earth History. *Geological Society, London, Special Publications*, 318(1):1－36.

Chen, Z.H., Guo, K.Y., Dong, Y.G., et al., 2009. Possible Early Neoproterozoic Magmatism Associated with Slab Window in the Pingshui Segment of the Jiangshan-Shaoxing Suture Zone:Evidence from Zircon LA-ICP-MS U-Pb Geochronology and Geochemistry. *Science China:Earth Sciences*, 39(7):994－1008(in Chinese).

Deng, H., Peng, S.B., Polat, A., et al., 2017. Neoproterozoic IAT Intrusion into Mesoproterozoic MOR Miaowan Ophiolite, Yangtze Craton:Evidence for Evolving Tectonic Settings. *Precambrian Research*, 289: 75－94. https://doi.org/10.1016/j.precamres.2016.12.003

Dewey, J.F., Burke, K., 1974. Hot Spots and Continental Break-up:Implications for Collisional Orogeny. *Geology*, 2(2):57－60.

Dong, Y.P., Liu, X.M., Santosh, M., et al., 2011. Neoproterozoic Subduction Tectonics of the Northwestern Yangtze Block in South China:Constrains from Zircon U-Pb Geochronology and Geochemistry of Mafic Intrusions in the Hannan Massif. *Precambrian Research*, 189: 66－90. https://doi.org/10.1016/j.precamres.2011.05.002

Dong, Y.P., Liu, X.M., Santosh, M., et al., 2012. Neoproterozoic Accretionary Tectonics along the Northwestern Margin of the Yangtze Block, China: Constraints from Zircon U-Pb Geochronology and Geochemistry. *Precambrian Research*, 196－197:247－274.

Dong, Y.P., Sun, S.S., Yang, Z., et al., 2017. Neoproterozoic Subduction-Accretionary Tectonics of the South Qinling Belt, China. *Precambrian Research*, 293:73－90.

Downes, H., 2007. Origin and Significance of Spinel and Garnet Pyroxenites in the Shallow Lithospheric Mantle:Ultramafic Massifs in Orogenic Belts in Western Europe and NW Africa. *Lithos*, 99(1－2):1－24.

Gao, J., Klemd, R., Long, L.L., et al., 2009. Adakitic Signature Formed by Fractional Crystallization:An Interpretation for the Neo-Proterozoic Meta-Plagiogranites of the NE Jiangxi Ophiolitic Mélange Belt, South China. *Lithos*, 110:277－293.

Greentree, M.R., Li, Z.X., Li, X.H., et al., 2006. Late Mesoproterozoic to Earliest Neoproterozoic Basin Record of the Sibao Orogenesis in Western South China and Relationship to the Assembly of Rodinia. *Precambrian Research*, 151(1－2):79－100.

Grimes, C.B., Ushikubo, T., Kozdon, R., et al., 2013. Perspec-

tives on the Origin of Plagiogranite in Ophiolites from Oxygen Isotopes in Zircon. *Lithos*, 179:48－66.

He, Q., Zhang, S.B., Zheng, Y.F., 2016. High Temperature Glacial Meltwater-Rock Reaction in the Neoproterozoic: Evidence from Zircon In-Situ Oxygen Isotopes in Granitic Gneiss from the Sulu Orogen. *Precambrian Research*, 284: 1－13. https://doi. org/10.1016/j. precamres.2016.07.012

He, Q., Zhang, S.B., Zheng, Y.F., 2018. Evidence for Regional Metamorphism in a Continental Rift during the Rodinia Breakup. *Precambrian Research*, 314: 414－427. https://doi.org/10.1016/j.precamres.2018.06.009

Hoffman, P. F., 1991. Did the Breakout of Laurentia Turn Gondwanaland Inside-Out? *Science*, 252:1409－1412.

Hu, J., Liu, X.C., Qu, W., et al., 2019. Mid-Neoproterozoic Amphibolite Facies Metamorphism at the Northern Margin of the Yangtze Craton. *Precambrian Research*, 326: 333－343.

Irving, A.J., 1980. Petrology and Geochemistry of Composite Ultramafic Xenoliths in Alkali Basalts and Implications for Magmatic Processes within the Mantle. *American Journal of Science*, 280:389－426.

Lai, S.C., Qin, J.F., 2010. The Ophiolite and Volcanics of the Mianlue Zone in South Qinling. Science Press, Beijing (in Chinese).

Li, H.K., Zhang, C.L., Xiang, Z.Q., et al., 2013. Zircon and Baddeleyite U－Pb Geochronology of the Shennongjia Group in the Yangtze Craton and Its Tectonic Significance. *Acta Petrologica Sinica*, 29(2): 673－697(in Chinese with English abstract).

Li, S.G., Hou, Z.H., Yang, Y.C., et al., 2003. Timing and Geochemistry Characters of the Sanchazi Magmatic Arc in Mianlue Tectonic Zone, South Qinling. *Science China: Earth Sciences*, 33(12):1163－1173(in Chinese).

Li, Z., 2003. Geochronology of Neoproterozoic Syn-Rift Magmatism in the Yangtze Craton, South China and Correlations with Other Continents: Evidence for a Mantle Superplume That Broke up Rodinia. *Precambrian Research*, 122(1－4):85－109.

Li, Z.X., Bogdanova, S.V., Collins, A.S., et al., 2008. Assembly, Configuration, and Break-up History of Rodinia: A Synthesis. *Precambrian Research*, 160(1－2):179－210.

Li, Z.X., Li, X.H., Kinny, P.D., et al., 1999. The Breakup of Rodinia: Did It Start with a Mantle Plume beneath South China? *Earth and Planetary Science Letters*, 173(3): 171－181. https://doi. org/10.1016/s0012 - 821x(99)00240-x

Li, Z.X., Li, X.H., Zhou, H.W., et al., 2002. Grenvillian Continental Collision in South China: New SHRIMP U-Pb Zircon Results and Implications for the Configuration of Rodinia. *Geology*, 30(2):163.

Li, Z.X., Wartho, J.A., Occhipinti, S., et al., 2007. Early History of the Eastern Sibao Orogen (South China) during the Assembly of Rodinia: New Mica $^{40}Ar/^{39}Ar$ Dating and SHRIMP U-Pb Detrital Zircon Provenance Constraints. *Precambrian Research*, 159(1－2):79－94.

Ling, W., 2003. Neoproterozoic Tectonic Evolution of the Northwestern Yangtze Craton, South China: Implications for Amalgamation and Break-up of the Rodinia Supercontinent. *Precambrian Research*, 122(1－4):111－140.

Liu, C.H., Wu, C.L., Gao, Y.H., et al., 2014. Zircon LA-ICP-MS U-Pb Dating and Lu-Hf Isotopic System of Dongjiangkou, Zhashui, and Liyuantang Granitoid Intrusions, South Qinling Belt, Central China. *Acta Petrologica Sinica*, 30(8): 2402－2420(in Chinese with English abstract).

Liu, R.Y., Niu, B.G., He, Z.J., et al., 2011. LA-ICP-MS Zircon U-Pb Geochronology of the Eastern Part of the Xiaomaoling Composite Intrusives in Zhashui Area, Shaanxi, China. *Geological Bulletin of China*, 30(2－3):448－460 (in Chinese with English abstract).

Liu, Y., Gao, S., Lee, C., et al., 2005. Melt-Peridotite Interactions: Links between Garnet Pyroxenite and High-$Mg^{\#}$ Signature of Continental Crust. *Earth and Planetary Science Letters*, 234(1－2):39－57.

Moores, E. M., 1991. Southwest U. S. - East Antarctic (SWEAT) Connection: A Hypothesis. *Geology*, 19 (5):425.

Nie, H., Yao, J., Wan, X., et al., 2016. Precambrian Tectonothermal Evolution of South Qinling and Its Affinity to the Yangtze Block: Evidence from Zircon Ages and Hf-Nd Isotopic Compositions of Basement Rocks. *Precambrian Research*, 286:167－179.

Peng, S.B., Kusky, T.M., Jiang, X.F., et al., 2012. Geology, Geochemistry, and Geochronology of the Miaowan Ophiolite, Yangtze Craton: Implications for South China's Amalgamation History with the Rodinian Supercontinent. *Gondwana Research*, 21(2－3):577－594.

Qiu, X.F., Ling, W.L., Liu, X.M., et al., 2011. Recognition of Grenvillian Volcanic Suite in the Shennongjia Region and Its Tectonic Significance for the South China Craton. *Precambrian Research*, 191(3－4):101－119.

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.

Shi, Y.R., Liu, D.Y., Zhang, Z.Q., et al., 2007. SHRIMP Zircon U-Pb Dating of Gabbro and Granite from the Huashan Ophiolite, Qinling Orogenic Belt, China: Neoproterozoic Suture on the Northern Margin of the Yangtze Craton. *Acta Geologica Sinica(English Edition)*, 81(2):239－243.

Sun, Z.M., Wang, X.L., Qi, L., et al., 2018. Formation of the Neoproterozoic Ophiolites in Southern China: New Constraints from Trace Element and PGE Geochemistry and Os Isotopes. *Precambrian Research*, 309:88－101.

Valley, J.W., Kinny, P.D., Schulze, D.J., et al., 1998. Zircon Megacrysts from Kimberlite: Oxygen Isotope Variability among Mantle Melts. *Contributions to Mineralogy and Petrology*, 133(1－2): 1－11. https://doi. org/10.1007/s004100050432

Wang, J., Deng, Q., Wang, Z.J., et al., 2013. New Evidences for Sedimentary Attributes and Timing of the "Macaoyuan Conglomerates" on the Northern Margin of the Yangtze Block in Southern China. *Precambrian Research*, 235: 58－70. https://doi. org/10.1016/j. precamres.2013.06.003

Wang, X.L., Zhou, J.C., Griffin, W.L., et al., 2014. Geochemical Zonation across a Neoproterozoic Orogenic Belt: Isotopic Evidence from Granitoids and Metasedimentary Rocks of the Jiangnan Orogen, China. *Precambrian Research*, 242: 154－171. https://doi. org/10.1016/j. precamres.2013.12.023

Wilson, J.T., 1966. Did the Atlantic Close and then Re-Open? *Nature*, 211:676－681.

Wu, P., Zhang, S.B., Zheng, Y.F., et al., 2019. Amalgamation of South China into Rodinia during the Grenvillian Accretionary Orogeny: Geochemical Evidence from Early Neoproterozoic Igneous Rocks in the Northern Margin of the South China Block. *Precambrian Research*, 321: 221－243. https://doi. org/10.1016/j. precamres.2018.12.015

Wu, Y.B., Zheng, Y.F., Tang, J., et al., 2007. Zircon U-Pb Dating of Water-Rock Interaction during Neoproterozoic Rift Magmatism in South China. *Chemical Geology*, 246(1－2): 65－86. https://doi. org/10.1016/j. chemgeo.2007.09.004

Xiao, L., Zhang, H.F., Ni, P.Z., et al., 2007. LA-ICP-MS U-Pb Zircon Geochronology of Early Neoproterozoic Mafic-Intermediate Intrusions from NW Margin of the Yangtze Block, South China: Implication for Tectonic Evolution. *Precambrian Research*, 154(3－4):221－235. https://doi. org/10.1016/j.precamres.2006.12.013

Xu, Y., Yang, K.G., Polat, A., et al., 2016. The ～860 Ma Mafic Dikes and Granitoids from the Northern Margin of the Yangtze Block, China: A Record of Oceanic Subduction in the Early Neoproterozoic. *Precambrian Research*, 275: 310－331. https://doi. org/10.1016/j. precamres.2016.01.021

Xue, H. M., Liu, D. Y., Dong, S. W., et al., 2004. U-Pb SHRIMP Zircon Ages of the Qichun Granitoids, Hubei Province: Discovery of Neoproterozoic Weakly Metamorphosed - Unmetamorphosed Granitoids in the Dabie Mountains. *Acta Geologica Sinica*, 78(1):81－88 (in Chinese with English abstract).

Yan, M., Liu, S.W., Li, Q.G., et al., 2014. LA-ICP-MS Zircon U-Pb chronology and Lu-Hf Isotopic Features of the Mihunzhen Pluton in the South Qinling Tectonic Belt. *Acta Petrologica Sinica*, 30(2):390－400(in Chinese with English abstract).

Yan, Q.R., Wang, Z.Q., Yan, Z., et al., 2007. SHRIMP Analyses for Ophiolitic-Mafic Blocks in the Kangxian-Mianxian Section of the Mianxian - Lueyang Melange: Their Geological Implications. *Geological Review*, 53(6):755－764 (in Chinese with English abstract).

Yang, C.H., Geng, Y.S., Du, L.L., et al., 2009. The Identification of the Grenvillian Granite on the Western Margin of the Yangtze Block and Its Geological Implications. *Geology in China*, 36(3): 647－657(in Chinese with English abstract).

Ye, M.F., Li, X.H., Li, W.X., et al., 2007. SHRIMP Zircon U-Pb Geochronological and Whole-Rock Geochemical Evidence for an Early Neoproterozoic Sibaoan Magmatic Arc along the Southeastern Margin of the Yangtze Block. *Gondwana Research*, 12(1－2): 144－156. https://doi. org/10.1016/j.gr.2006.09.001

Yu, S.Y., Xu, Y.G., Ma, J.L., et al., 2010. Remnants of Oceanic Lower Crust in the Subcontinental Lithospheric Mantle: Trace Element and Sr-Nd-O Isotope Evidence from Aluminous Garnet Pyroxenite Xenoliths from Jiaohe, Northeast China. *Earth and Planetary Science Letters*, 297(3－4): 413－422. https://doi. org/10.1016/j. epsl.2010.06.043

Zhang, C.H., Gao, L.Z., Wu, Z.J., et al., 2007. SHRIMP U-Pb Zircon Age of Tuff from the Kunyang Group in Central Yunnan: Evidence for Grenvillian Orogeny in South China. *Chinese Science Bulletin*, 52(7): 818－824(in Chinese).

Zhang, G.W., 2015. The Mianlue Tectonic Zone of the Qinling Orogen and China Continental Tectonics. Science Press, Beijing (in Chinese).

Zhang, G.W., Cheng, S.Y., Guo, A.L., et al., 2004. Mianlue

Paleo-Suture on the Southern Margin of the Central Orogenic System in Qinling-Dabie: With a Discussion of the Assembly of the Main Part of the Continent of China. *Geological Bulletin of China*, 23(9): 846－853(in Chinese with English abstract).

Zhang, G. W., Meng, Q. R., Lai, S. C., 1995. Tectonics and Structure of Qinling Orogenic Belt. *Science China (Series B)*, 25(9):994－1003(in Chinese).

Zhang, G.W., Meng, Q.R., Yu, Z.P., et al., 1996. Orogenesis and Dynamics of the Qinling Orogen. *Science China (Series D)*, 26(3):193－200(in Chinese).

Zhang, G.W., Zhang, B.R., Yuan, X.C., et al., 2001. The Qinling Orogenic Belt and Continental Geodynamics. Science Press, Beijing(in Chinese).

Zhang, R.Y., Sun, Y., Zhang, X., et al., 2016b. Neoproterozoic Magmatic Events in the South Qinling Belt, China: Implications for Amalgamation and Breakup of the Rodinia Supercontinent. *Gondwana Research*, 30: 6－23. https://doi.org/10.1016/j.gr.2015.06.015

Zhang, S.B., Tang, J., Zheng, Y.F., 2014. Contrasting Lu-Hf Isotopes in Zircon from Precambrian Metamorphic Rocks in the Jiaodong Peninsula: Constraints on the Tectonic Suture between North China and South China. *Precambrian Research*, 245: 29－50. https://doi. org/10.1016/j.precamres.2014.01.006

Zhang, S. B., Wu, R. X., Zheng, Y. F., 2012. Neoproterozoic Continental Accretion in South China: Geochemical Evidence from the Fuchuan Ophiolite in the Jiangnan Orogen. *Precambrian Research*, 220－221: 45－64. https://doi.org/10.1016/j.precamres.2012.07.010

Zhang, S.B., Zheng, Y.F., 2013. Formation and Evolution of Precambrian Continental Lithosphere in South China. *Gondwana Research*, 23(4):1241－1260.https://doi.org/10.1016/j.gr.2012.09.005

Zhang, S.B., Zheng, Y.F., Zhao, Z.F., et al., 2016a. The Extremely Enriched Mantle beneath the Yangtze Craton in the Neoproterozoic: Constraints from the Qichun Pyroxenite. *Precambrian Research*, 276: 194－210. https://doi.org/10.1016/j.precamres.2016.02.002

Zhang, Z.Q., Tang, S.H., Zhang, G.W., et al., 2005. Ages of Metamorphic Mafic-Andesitic Volcanic Rock Blocks and Tectonic Evolution Complexity of Mianxian-Lueyang Ophiolitic Mélange Belt. *Acta Geologica Sinica*, 79(4): 531－539 (in Chinese with English abstract).

Zhao, J.H., Zhou, M.F., 2009. Secular Evolution of the Neoproterozoic Lithospheric Mantle underneath the Northern Margin of the Yangtze Block, South China. *Lithos*, 107(3－4): 152－168. https://doi. org/10.1016/j. lithos.2008.09.017

Zheng, Y. F., Chen, R. X., 2017. Regional Metamorphism at Extreme Conditions: Implications for Orogeny at Convergent Plate Margins. *Journal of Asian Earth Sciences*, 145: 46－73.

Zheng, Y.F., Chen, R.X., Zhao, Z.F., 2009. Chemical Geodynamics of Continental Subduction-Zone Metamorphism: Insights from Studies of the Chinese Continental Scientific Drilling (CCSD) Core Samples. *Tectonophysics*, 475(2): 327－358.https://doi.org/10.1016/j.tecto.2008.09.014

Zheng, Y. F., Chen, Y. X., 2016. Continental versus Oceanic Subduction Zones. *National Science Review*, 3: 495－519.

Zheng, Y.F., Chen, Y.X., Dai, L.Q., et al., 2015. Developing Plate Tectonics Theory from Oceanic Subduction Zones to Collisional Orogens. *Science China:Earth Sciences*, 58: 1045－1069.

Zheng, Y. F., Fu, B., 1998. Estimation of Oxygen Diffusivity from Anion Porosity in Minerals. *Geochemical Journal*, 32(2):71－89.https://doi.org/10.2343/geochemj.32.71

Zheng, Y. F., Fu, B., Gong, B., et al., 2003. Stable Isotope Geochemistry of Ultrahigh Pressure Metamorphic Rocks from the Dabie-Sulu Orogen in China: Implications for Geodynamics and Fluid Regime. *Earth-Science Reviews*, 62:105－161.

Zheng, Y.F., Gong, B., Zhao, Z.F., et al., 2008a. Zircon U-Pb Age and O Isotope Evidence for Neoproterozoic Low-^{18}O Magmatism during Supercontinental Rifting in South China: Implications for the Snowball Earth Event. *American Journal of Science*, 308(4):484－516.

Zheng, Y.F., Wu, R.X., Wu, Y.B., et al., 2008b. Rift Melting of Juvenile Arc-Derived Crust: Geochemical Evidence from Neoproterozoic Volcanic and Granitic Rocks in the Jiangnan Orogen, South China. *Precambrian Research*, 163(3－4): 351－383. https://doi. org/10.1016/j. precamres.2008.01.004

Zheng, Y.F., Wu, Y.B., Chen, F.K., et al., 2004. Zircon U-Pb and Oxygen Isotope Evidence for a Large-Scale ^{18}O Depletion Event in Igneous Rocks during the Neoproterozoic. *Geochimica et Cosmochimica Acta*, 68(20): 4145－4165.

Zheng, Y.F., Wu, Y.B., Gong, B., et al., 2007a. Tectonic Driving of Neoproterozoic Glaciations: Evidence from Extreme Oxygen Isotope Signature of Meteoric Water in Granite. *Earth and Planetary Science Letters*, 256: 196－210.

Zheng, Y.F., Zhang, S.B., Zhao, Z.F., et al., 2007b. Contrasting Zircon Hf and O Isotopes in the Two Episodes of

Neoproterozoic Granitoids in South China: Implications for Growth and Reworking of Continental Crust. *Lithos*, 96(1－2): 127－150. https://doi. org/10.1016/j. lithos.2006.10.003

Zheng, Y. F., Xiao, W. J., Zhao, G. C., 2013. Introduction to Tectonics of China. *Gondwana Research*, 23(4): 1189－1206.https://doi.org/10.1016/j.gr.2012.10.001

Zheng, Y. F., Zhao, Z. F., Chen, R. X., 2018. Ultrahigh-Pressure Metamorphic Rocks in the Dabie-Sulu Orogenic Belt:Compositional Inheritance and Metamorphic Modification. *Geological Society, London, Special Publications*, 474(1):89－132.

Zheng, Y. F., Zhao, Z. F., Wu, Y. B., et al., 2006. Zircon U-Pb Age, Hf and O Isotope Constraints on Protolith Origin of Ultrahigh-Pressure Eclogite and Gneiss in the Dabie Orogen. *Chemical Geology*, 231:135－158.

Zheng, Y. F., Zhou, J. B., Wu, Y. B., et al., 2005. Low-Grade Metamorphic Rocks in the Dabie-Sulu Orogenic Belt: A Passive-Margin Accretionary Wedge Deformed during Continent Subduction. *International Geology Review*, 47(8):851－871.

Zhou, J. L., Li, X. H., Tang, G. Q., et al., 2018. Ca. 890 Ma Magmatism in the Northwest Yangtze Block, South China:SIMS U-Pb Dating, In-Situ Hf-O Isotopes, and Tectonic Implications. *Journal of Asian Earth Sciences*, 151: 101－111.https://doi.org/10.1016/j.jseaes.2017.10.029

附中文参考文献

陈志洪，郭坤一，董永观，等，2009. 江山－绍兴拼合带平水段可能存在新元古代早期板片窗岩浆活动:来自锆石LA-ICP-MS年代学和地球化学的证据. 中国科学:地球科学，39(7):994－1008.

赖绍聪，秦江峰，2010. 南秦岭勉略缝合带蛇绿岩与火山岩. 北京:科学出版社.

李怀坤，张传林，相振群，等，2013. 扬子克拉通神农架群锆石和斜锆石U-Pb年代学及其构造意义. 岩石学报，29(2): 673－697.

李曙光，侯振辉，杨永成，等，2003. 南秦岭勉略构造带三岔子古岩浆弧的地球化学特征及形成时代. 中国科学(D辑)，33(12):1163－1173.

刘春花，吴才来，郜源红，等，2014. 南秦岭东江口、柞水和梨园堂花岗岩类锆石LA-ICP-MSU-Pb年代学与锆石Lu-Hf同位素组成. 岩石学报，30(8):2402－2420.

刘仁燕，牛宝贵，和政军，等，2011. 陕西柞水地区小茅岭复式岩体东段LA-ICP-MS锆石U-Pb定年. 地质通报，30(2－3):448－460.

薛怀民，刘敦一，董树文，等，2004. 湖北蕲春花岗岩类锆石SHRIMP年龄:大别山造山带内弱变质－未变质晋宁期花岗岩类的发现. 地质学报，78(1):81－88.

阎明，刘树文，李秋根，等，2014. 南秦岭迷魂阵岩体LA-ICP-MS锆石U-Pb年代学和Lu-Hf同位素特征. 岩石学报，30(2):390－400.

闫全人，王宗起，闫臻，等，2007. 秦岭勉略构造混杂带康县——勉县段蛇绿岩块－铁镁质岩块的SHRIMP年代及其意义. 地质论评，53(6):755－764.

杨崇辉，耿元生，杜利林，等，2009. 扬子地块西缘Grenville期花岗岩的厘定及其地质意义. 中国地质，36(3): 647－657.

张传恒，高林志，武振杰，等，2007. 滇中昆阳群凝灰岩锆石SHRIMP U-Pb年龄:华南格林威尔期造山的证据. 科学通报，52(7):818－824.

张国伟，孟庆任，赖绍聪，1995. 秦岭造山带的结构构造. 中国科学(B辑)，25(9):994－1003

张国伟，孟庆任，于在平，等，1996. 秦岭造山带的造山过程及其动力学特征. 中国科学(D辑)，26:193－200.

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

张国伟，程顺有，郭安林，等，2004. 秦岭－大别中央造山系南缘勉略古缝合带的再认识——兼论中国大陆主体的拼合. 地质通报，23(9):846－853.

张国伟，2015. 秦岭勉略构造带与中国大陆构造. 北京:科学出版社.

张宗清，唐索寒，张国伟，等，2005. 勉县－略阳蛇绿混杂岩带镁铁质－安山质火山岩块年龄和该带构造演化的复杂性. 地质学报，79(4):531－539.