

华北克拉通东部地块和大别—苏鲁造山带印支期褶皱-逆冲构造与动力学背景^{*}

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2008-12-28 收稿, 2009-02-24 改回.

Li SZ, Liu X, Suo YH, Liu LP, Qian CC, Liu XC, Zhang GW and Zhao GC. 2009. Triassic folding and thrusting in the Eastern Block of the North China Craton and the Dabie-Sulu orogen and its geodynamics. *Acta Petrologica Sinica*, 25(9): 2031–2049

Abstract The Dabie-Sulu orogen consists of different slices and blocks undergoing multiple-stage folding and thrusting. Particularly some eclogite blocks and jadeite quartzite units underwent two-stage pre-UHP and syn-UHP deformation, following boudin-making and slicing during regional first-stage (D_1) deformation and D_2 folding during the regional second-stage deformation. However, other slices or units only underwent mainly regional three-stage folding. The regional first-stage deformation is shown as intra-folial minor folds, mainly preserved in amphibolite blocks. The regional second-stage deformation is commonly outcrop-scale. Its fold axial plane is crenulation cleavage, locally being foliated composite schistosity belt due to intensive displacement. After restoration of D_3 folding, it is shown that axial planes of different-scale tight, asymmetric D_2 folds in different units are southeastern-overturned and NNE-striking. D_2 fold asymmetry implies that it is related to southeast-directed thrusting. The third-stage folds are open folds with NWW-strike, western plunge consisting of deformed schistosity and crenulation cleavage. Unpenetrative ductile shearing related to these folding has two stages. The early ductile shear thrusting is south-directed in the north of the Xinxian dome and south-directed in the north of the Xinxian dome, cutting the second-stage folds and being associated with secondary-scale thrusts by the limb of the second-stage large-scale folds. The later ductile decollement zones only developed in the contact belts of obvious rock types around the Xinxian dome, with extensional crenulation cleavage, obviously reforming the previous structures. The Eastern Block is an important tectonic unit of North China Craton located at the hanging wall of the Dabie-Sulu organ, of which Paleozoic to Triassic sedimentary cover underwent one-stage regional folding during Indosinian (Late Triassic). Its axial trace is NWW-striking. It is consistent with that of the third-stage folds in the aspects of deformation time and fold style and spatial trending. This implies that they are related in geodynamics. At the same time, this study shows that the Eastern Block didn't undergo the other earlier regional two-stage deformation in the Dabie-Sulu orogen.

* 本文为 973 项目(2009CB825006)、国家自然科学基金(40776038, 90814011)和教育部新世纪人才项目(NCET-06-0595)联合资助成果。
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Therefore, the two-stage regional Triassic folding has no influence to the inner of North China plate, only happened in the southern margin of North China plate. Only in the case of unifying of North and South China plates after the regional second-stage folding, the third-stage deformation in the Dabie-Sulu orogen induced the first-stage folding in the inner of North China Craton. Diachronous exhumation of HP-UHP rocks in the Dabie-Sulu orogen is related this geodynamic setting and processes of structural evolution.

Key words Fold; Thrust; North China Craton; Dabie; Sulu; Ultrahigh-pressure; Triassic

摘要 大别-苏鲁造山带不同岩片(块)经历了不同的褶皱变形。榴辉岩块(或透镜体)和硬玉石英岩片经历了高压-超高压背景下的两幕褶皱变形之后,在区域性第一幕变形期间主要发生透镜化为主,后期与围岩共同经历紧闭同斜第二幕褶皱。而其它岩片主要经历了现今野外可见的区域性三幕褶皱,其中区域性第一幕褶皱为片内残留褶皱,在斜长角闪岩透镜体中多见,宏观规律不明。区域性第二幕褶皱在露头尺度多见,轴面为折劈理,局部强烈置换成片理化带(复合片理或第二期片理),恢复第三幕褶皱改造作用后,揭示出各种岩片中的各级尺度的第二幕褶皱都为轴面北西倾南东倒、轴迹走向为 NNE 向的紧闭不对称褶皱,不对称性一致反映其指向与各种岩片向南东的逆冲运动有关。第三幕褶皱为以片理或折劈理为变形面的宽缓褶皱,轴迹走向 NWW,枢纽向西倾伏。韧性剪切带为非透入性构造,分早晚两期,早期为韧性逆冲,新县穹隆以南,运动学标志指示向北逆冲,错切第二幕褶皱,结合新县穹隆北部向南的逆冲特征,反映这些韧性逆冲断层多数为第二幕大型褶皱翼部的次级逆冲断层;晚期为韧性滑脱带,其发育局限于几个岩性差异较大的接触带,带内伸展型折劈理发育,并对挤压构造样式有重要的改造作用。华北克拉通东部地块是华北克拉通的重要组成部分,其盖层古生界和三叠系在印支运动期间经历了一幕宽缓褶皱作用,其轴迹方向主体也为 NWW 向。这一褶皱构造明显在变形时间、变形样式和展布方向上都和大别-苏鲁造山带中的第三幕褶皱非常一致,说明它们具有动力学上的必然联系。同时,研究表明在华北克拉通东部地块中没有经历大别-苏鲁造山带中区域性第一、第二幕褶皱变形的记录,故本文认为印支期这两幕变形主要发生在华北板块东南缘的边界上,并没有波及到板内,而且从东向西高压—超高压岩石剥露具有穿时性。只有当华北板块和华南板块在第二幕变形之后构成了统一块体后,第三幕变形才波及华北板内。

关键词 褶皱;逆冲;华北克拉通;大别山;苏鲁;超高压;三叠纪

中图法分类号 P542

2008;郑永飞,2008;Xu *et al.*, 2006),进行上述问题的探讨。

1 引言

印支期是中国现今大地构造格局初步成型阶段。传统认为中国东部东西向构造格局就是这个时期形成的。这个构造格局的形成与横亘于中国中部的复合型造山带—中国中央造山带密切相关。该造山带位于中朝克拉通和扬子克拉通之间的段落称为东秦岭—桐柏—大别—苏鲁造山带(图1)。仅就其东段大别-苏鲁造山带而言,其南、北边界划分还存在非常大的分歧,而且,还存在许多科学问题没有解决。如,华北克拉通内部的印支期变形与南缘的大别-苏鲁造山带变形有无直接关系?若有联系,大别山-苏鲁造山带印支期强烈的造山运动可波及及其北部的华北克拉通内部多远?何时开始影响?

本文将就这些疑问,根据我们 2000~2008 年在整个东秦岭、桐柏山、西大别、东大别和苏鲁造山带近 3000 个站位的野外构造地质解析结果,结合 2002 年以来在整个华北克拉通东部地块(主要是鲁西、辽东、部分燕山地区)和大别山前陆地区的野外构造研究(李三忠等,2005,2009),还有 1999 年以来对渤海湾盆地中生代构造研究的成果(Li *et al.*, 2000;刘建忠等,2004;金宠等,2007;楼达等,2008),从该区不同构造单元中筛分出印支期的构造变形,并从变形角度,结合前人大量大别-苏鲁高压-超高压变质岩石学和年代学成果(Yao *et al.*, 2000;Zheng YF *et al.*, 2003,2005;Zheng,

2 区域地质背景

中国东部的中生代大地构造格局总体具有“三块两缝”和“一条走滑”的特征(Xu *et al.*, 1987;张国伟等,1996,2001,2003,2004;Zhu *et al.*, 2005;胡健民等,2008;刘少峰和张国伟,2008;图1),即从北到南,为华北板块、商丹缝合线、秦岭—大别微地块、勉略缝合线和华南板块。但是,越往东部,两条缝合线非常不明显,表现为隐形构造。尽管两条缝合线是否东延、东延位置如何、至朝鲜和韩国与哪个断裂带连接等问题还存在巨大争议(Faure *et al.*, 2001;Zhai, 2002;Jahn *et al.*, 2008),尽管东段没有西段那样明确的印支期岛弧型沉积-火山建造、岩浆建造,但大家都公认,大别—苏鲁造山带的印支期高压—超高压变质和胶北、下扬子之间存在显著的不同,其南北应当存在巨大的构造界面。由于不能仅考虑这些变质岩片的边界,在综合考虑其余一些岩片亲扬子还是亲华北的情况后,一般认为,商丹带东延至桐柏-大别—苏鲁以北,从西往东应当对应信阳-舒城断裂带、南华北盆地以下隐伏的信阳-梅山-六安断裂、五莲-烟台断裂(孙晓猛等,2004;郑永飞等,2008);勉略带东延至桐柏-大别-苏鲁以南,从西往东可能被城口-房县断裂带(也可能为安康断裂,见胡健民等,2008)、襄樊-广济断裂带、嘉山-响水断裂所掩覆(程裕淇,1994)。

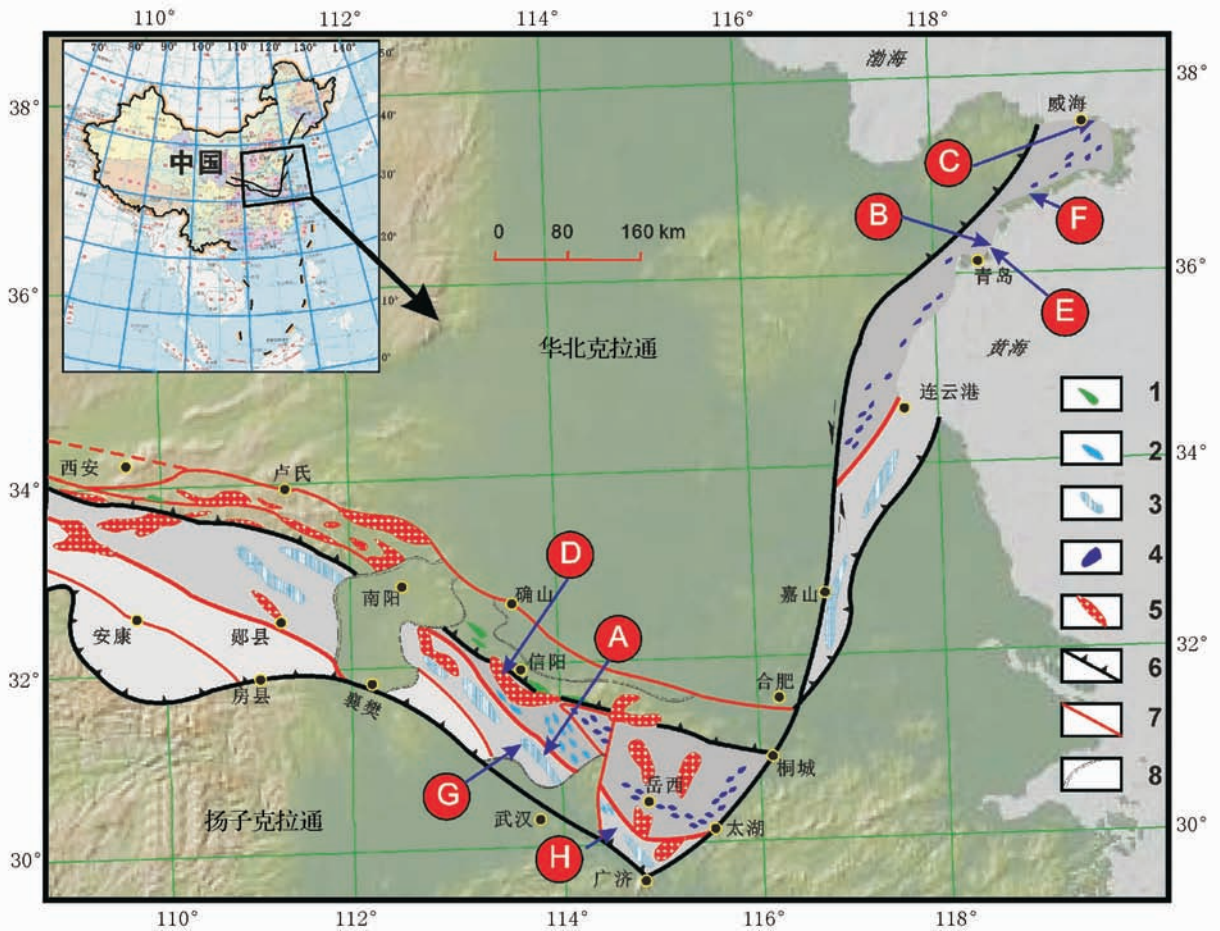


图1 秦岭-大别-苏鲁造山带构造略图

1-蛇绿岩或混杂岩; 2-蓝片岩; 3-高压榴辉岩; 4-超高压榴辉岩; 5-燕山期花岗岩; 6-边界断裂; 7-一般断裂; 8-白垩系-第四系. 图中字母为图3对应的照片位置

Fig. 1 Sketch map showing the tectonic units and the distributions of blueschists and eclogites in the Qinling-Dabie-Sulu orogen
1-ophiolite or mélange; 2-blueschist; 3-high-pressure eclogite; 4-ultrahigh-pressure eclogite; 5-Yanshanian granite; 6-border fault; 7-general fault; 8-Cretaceous-Quaternary. English characters showing the correspondent locations of photos in Figure 3

不可否认,两条缝合线内部的演化是复杂的过程,不同地段俯冲-碰撞的起始时间具有分段性和先后差异,商丹带是始于中奥陶世向北俯冲消减、直至中三叠世消亡的商丹洋收缩的结果(张国伟等, 2001);勉略带是始于二叠世向北俯冲消减、直至晚三叠世消亡的勉略洋收缩的结果(张国伟等, 2001;李三忠等, 2002)。目前,华北板块和华南板块碰撞的最终时限大致在晚三叠世-早侏罗世的事实已为年代、沉积、岩浆、变质等各方面的研究所证实(Li SG *et al.*, 1993)。

在这个复杂演化过程中,在该造山带内发育南、北两条时代不同的超高压变质带,北侧一条是北秦岭早古生代(500Ma左右)超高压-高压变质带(杨经绥等, 2003a),与商丹带的早期深俯冲有关。南侧一条是桐柏-大别-苏鲁三叠纪(250~220Ma)超高压-高压变质带(Li SG *et al.*, 1993; Yao *et al.*, 2000; Zheng YF *et al.*, 2003, 2005, 2008),分别与印支期华北与秦岭微板块沿商丹带碰撞和勉略带俯冲有关。这是中国中央造山带与世界其它造山带相比所表现出来的

独特性、唯一性、复杂性。其变质动力学演化必然有其独特的大地构造背景和构造过程。

3 大别-苏鲁造山带印支期褶皱-逆冲构造

以野外地质调查、地质剖面测量和区域构造解析为基础,对桐柏山、西大别山、东大别山和苏鲁造山带中的挤压构造和伸展构造进行了详细筛分。挤压构造变形在区域上是透入性的,而伸展构造变形主要集中发育在造山带内部的少数几个大型滑脱构造带内(图2)。剔除韧性伸展滑脱和晚白垩世的脆性正断两幕伸展构造变形,苏鲁-大别山-桐柏造山带的区域挤压构造变形形迹主要表现为三幕褶皱(按照造山带区域变形幕划分命名原则,我们分别称为 D_1 、 D_2 和 D_3)和两期逆冲构造。

野外可见的褶皱可分为三幕。区域性第一幕褶皱(D_1)

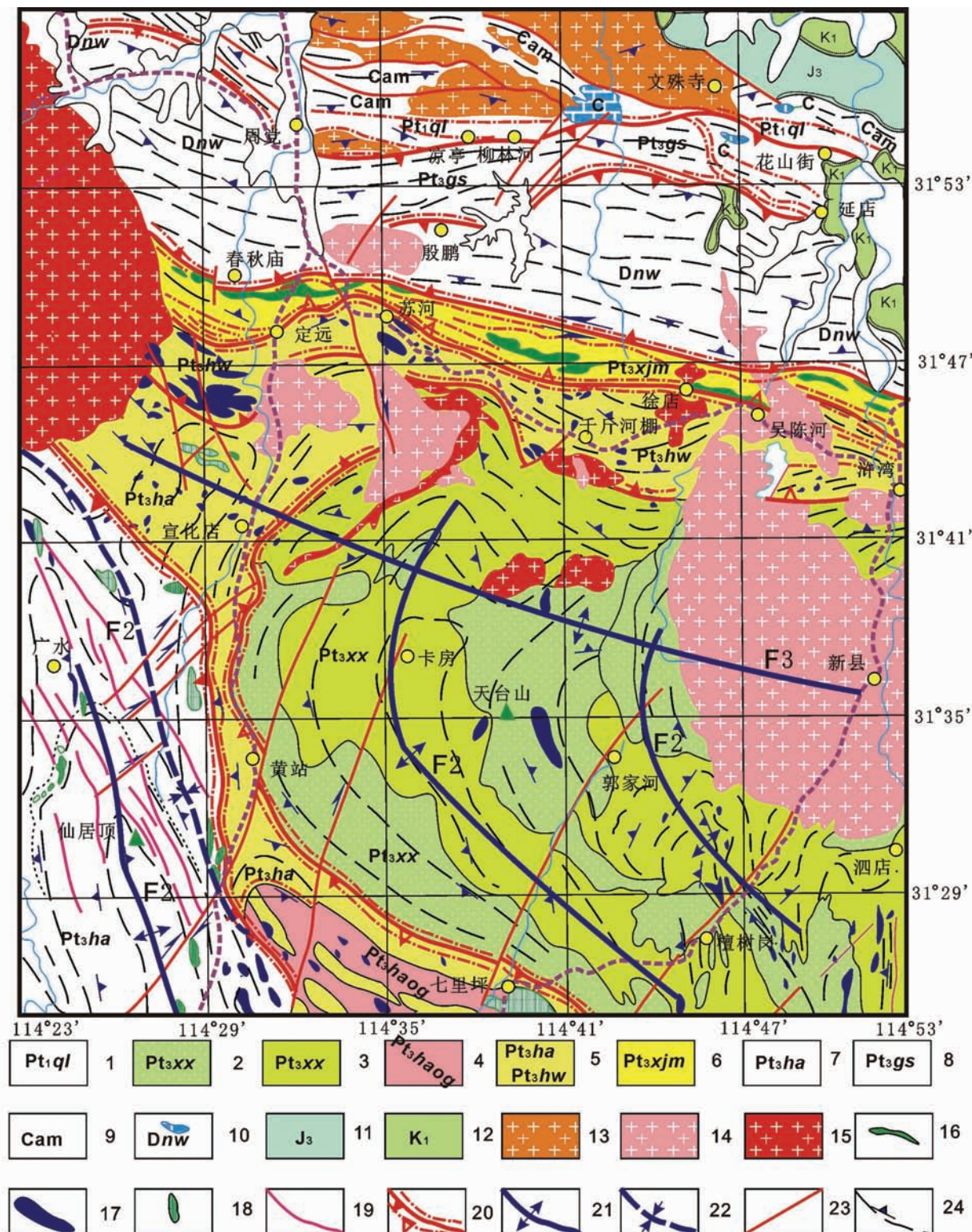


图2 西大别造山带宣化店地区第二幕(F2)和第三幕(F3)褶皱关系

1-古元古代秦岭群(Pt₁ql);2-新元古代新县超高压单元表壳岩(Pt₃xx);3-新元古代新县超高压单元正片麻岩(Pt₃xx);4-新元古代红安正片麻岩单元(Pt₃haog);5-新元古代红安高压-超高压单元(Pt₃ha)或新元古代滑湾高压-超高压单元(Pt₃hw);6-新元古代肖家庙单元(Pt₃xjm);7-新元古代红安高压单元(Pt₃ha);8-新元古代龟山组(Pt₃gs);9-寒武系(Cam);10-泥盆系南湾组(Dnw)或石炭系(C,蓝色);11-上侏罗统(J₃);12-下白垩统(K₁);13-晚古生代花岗闪长质片麻岩;14-燕山期花岗闪长岩;15-燕山期花岗岩;16-辉长岩;17-榴辉岩;18-斜长角闪岩;19-晚期岩脉;20-韧性逆冲或滑脱带;21-印支期背形;22-印支期向形;23-燕山晚期走滑断层;24-片麻理或片理及其迹线

Fig. 2 Relation between F2 and F3 folds in the Xuanhuadian area of the western Dabie orogen

1-Paleoproterozoic Qinling Group (Pt_1ql); 2-Neoproterozoic supercrustal rocks in the Xinxian UHP unit (Pt_3xx); 3-Neoproterozoic orthogneiss in the Xinxian UHP unit (Pt_3xx); 4-Neoproterozoic Hong'an orthogneiss unit (Pt_3haog); 5-Neoproterozoic Hong'an or Huwan HP-UHP unit (Pt_3ha or Pt_3hw); 6-Neoproterozoic Xiaojiamiao unit (Pt_3xjm); 7-Neoproterozoic Hong'an HP unit (Pt_3ha); 8-Neoproterozoic Guishan Formation (Pt_3gs); 9-Cambrian (Cam); 10-Devonian Nanwan Formation (Dnw) or Carboniferous (C, blue); 11-Upper Jurassic (J_3); 12-Lower Cretaceous (K_1); 13-Late Paleozoic granodioritic gneiss; 14-Yanshanian granodiorite; 15-Yanshanian granite; 16-gabbro block; 17-eclogite block; 18-amphibolite; 19-Late Yanshanian granitic vein; 20-ductile thrusting or decollement; 21-Indosinian anticline; 22-Indosinian syncline; 23-late Yanshanian strike-slip fault; 24-gneissosity or schistosity and its traces

仅在蓝片岩单元保存较好,但也是局部保留,为片内残留褶皱,在榴辉岩及斜长角闪岩透镜体中局部保存,宏观规律不明。此前,超高压岩石还经历了至少两幕强烈的进变质阶段的变形作用,分别体现在变斑晶中的残留的(角闪石+)黑云母+石英+长石等构成的定向的矿物组合(我们称为 D_{00} ,图3A),区域变形之前的第二幕变形主要表现为仅发育在榴辉岩等超高压岩块或岩片中的由超高压矿物定向排列的线理、褶皱等(由于其不具区域性,我们称为 D_0 ,图3B),最为典型的这幕变形可以在青岛仰口、安徽菖蒲等地观察到(图3B)。而且无论在桐柏-大别-苏鲁那个区域,绿辉石的优势定向排列总体为NWW或SEE向,这表明榴辉岩在最早的剥露阶段主体运动方向是向SEE方向运动的。而且,后期的第二幕和第三幕区域变形(D_2 和 D_3)都没有明显改变这种优势方位。由于这三幕区域性变形在西大别北部被晚侏罗世地层(J_3)的角度不整合覆盖,故这些变形至少发生在160Ma之前,进一步的年代学证实这些变形应当是印支期变形(见后文)。

第二幕褶皱在西大别的新县穹隆北部为北倾南倒的露头尺度的紧闭片麻理小褶皱,不对称性一致指向向南运动,轴面折劈理主体产状北倾;桐柏地区类似新县穹隆北部(图3D);在新县穹隆南部为南倾北倒的露头尺度的紧闭小褶皱,不对称性总体指向北东运动(图3G),轴面为折劈理,折劈理主体产状南倾,局部强烈置换成片理化带(复合片理或第二期片理)。在东大别,在超高压单元中表现为片麻理紧闭褶皱,在高压片岩单元中表现为片理紧闭褶皱(图3H),被第三幕宽缓褶皱改造明显;统计结果表明,西大别第二幕褶皱轴总体轴向为北东-北东东向。在苏鲁,第二幕褶皱表现为总体轴向北东的区域片麻理或片理(如蓬莱群石英岩中)的紧闭褶皱(图3C,E)。

第三幕褶皱在西大别的红安—黄陂段剖面上,为以片理或折劈理为变形面的宽缓褶皱,轴迹走向北北西;在白雀园-泮湾段剖面上不明显;在新县穹隆内部为以片麻理为变形面的宽缓褶皱。宣化店地区为新县穹隆的西北倾没端(图2),通过对片理及复合片理产状的大量测量及岩性界面的追踪,发现该区第二幕褶皱样式总体为轴面片理(即复合片理)走向为北北东向弧形展布的紧闭同斜褶皱构造,与新县穹隆西北部的片麻理构成的弧形构造一致,这些弧形构造为不同尺度第三幕褶皱的转折端,在该部位露头尺度上第三幕褶皱表现为枢纽向西倾伏的宽缓褶皱。因此,从构造特征上说明泮湾与红安单元应为统一的构造岩石单元。更重要的典型露

头解析表明,宣化店地区的构造格局主要为Ramsay III类叠加褶皱样式,在红石桥水库可见其叠加特征,其枢纽倾伏与后期新县穹隆伸展成穹过程有关。在东大别超高压单元中和苏鲁造山带的沿海一带可见露头尺度的这种叠加样式(图3F)。但在整个大别的蓝片岩单元中,也常见共轴叠加的Ramsay III类叠加褶皱样式(图3G)。而且,东大别和苏鲁地区的第三幕褶皱轴向都总体表现为NWW向。正是由于第二幕褶皱轴向总体近垂直、第三幕褶皱轴向又平行绿辉石线理,所以这种叠加不会改变其优势方位。

韧性剪切带为非透入性构造,分早、晚两期。早期为韧性逆冲,新县穹隆以南,运动学标志指示向北逆冲,错切第二幕褶皱,结合新县穹隆北部向南的逆冲特征,反映这些韧性逆冲断层多数为第二幕大型褶皱翼部的次级逆冲断层(图2);晚期为韧性滑脱带,其发育局限于几个岩性差异较大的接触带,带内伸展型折劈理发育,并对挤压构造样式有重要的改造作用。

脆性断层都为燕山期断裂,也包括三期,燕山早期的脆性逆冲断层产出状态与早期韧性逆冲带的一致,但发育时间大致在第三幕褶皱作用之后。燕山中期为脆性正断层在新县穹隆北部多见,产状较缓,发育时间晚于上述所有构造。燕山晚期为北北东走向的左行走滑剪切断裂,沿走滑断裂多数发育假玄武玻璃,错切上述所有构造形迹,且延伸到华北克拉通东部地块中。

4 华北克拉通东部地块印支期褶皱-逆冲构造

印支期是中国东部的一次革命性运动(翟明国等,2003),导致了华北克拉通内部盖层的最早一期构造变形。研究表明,扬子板块(或称华南板块)于中-晚三叠世强烈地向华北板块下俯冲(孟庆任等,1996;Meng *et al.*, 1999;李三忠等,2002;张国伟等,2003),在这一动力背景下,印支期渤海湾及邻区华北板块结晶基底上的盖层变形格局也残留了一些这次变形的迹象。虽然后期燕山和喜山期构造改造较强,但是我们还能对印支期构造形迹进行总体分析。分析表明发生在苏鲁-大别造山带中的强烈的第一幕区域性叶理化、透镜化、岩片化的变形在华北克拉通盖层中没有发生,且这些盖层经历的近东西走向的宽缓-紧闭褶皱及逆冲构造

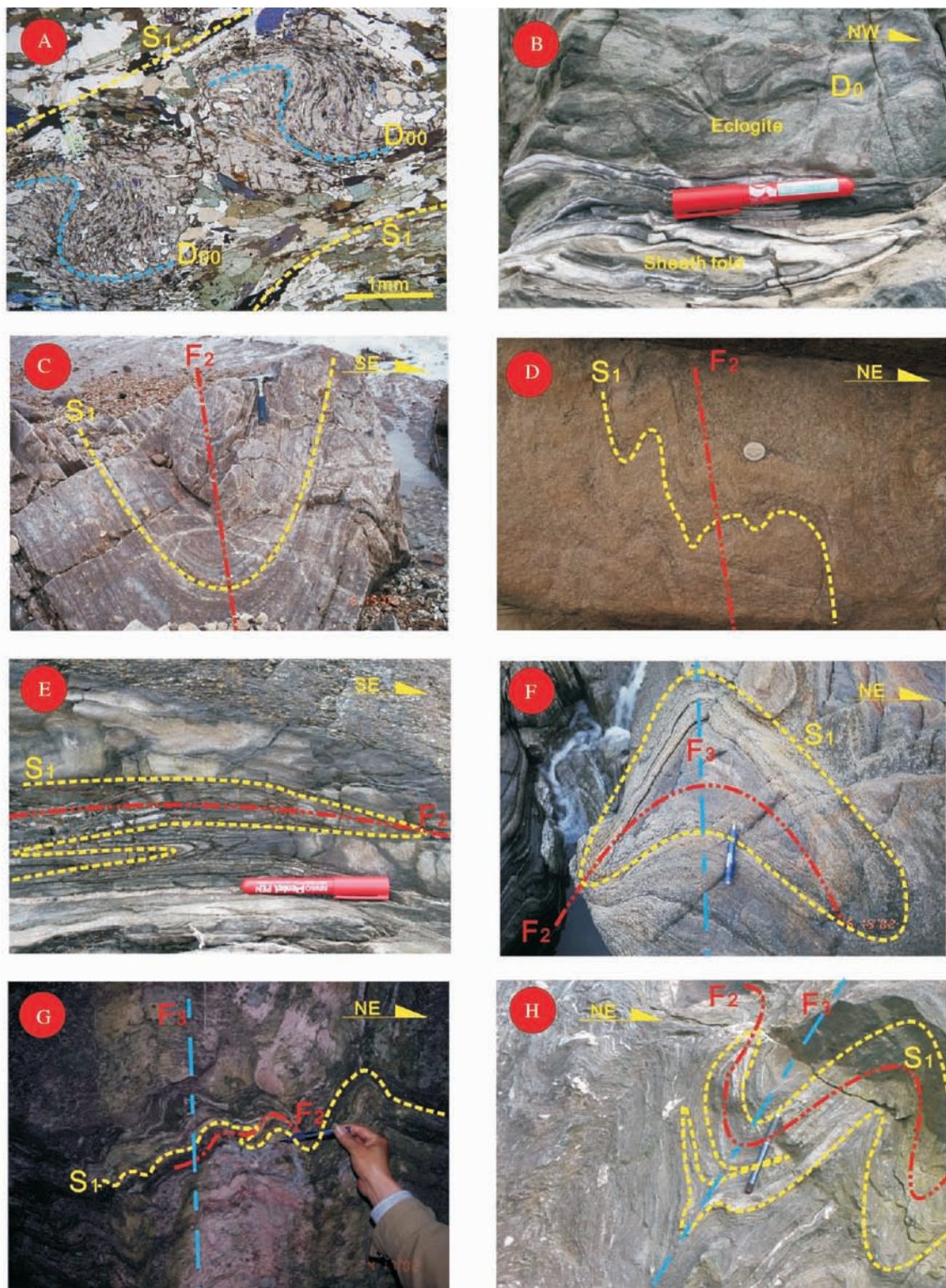


图3 大别—苏鲁造山带的五幕变形样式(照片地点见图1)

Fig. 3 Five-stage structural styles in the Dabie-Sulu Orogen (locations shown in Figure 1)

主要是印支晚期的变形,因为上三叠统卷入这幕变形,其几何学及展布等特征可初步总结如下。

(1) 印支晚期褶皱轴迹在今鲁西地块、黄骀坳陷内主

要为基本一致的东西走向或 NWW 走向(李三忠等, 2005; 金宠等, 2007; 楼达等, 2008)(图4, 图5), 但轴面倾角差别较大, 故可分为两幕, 早幕为局部的紧闭褶皱, 类似的紧闭褶皱

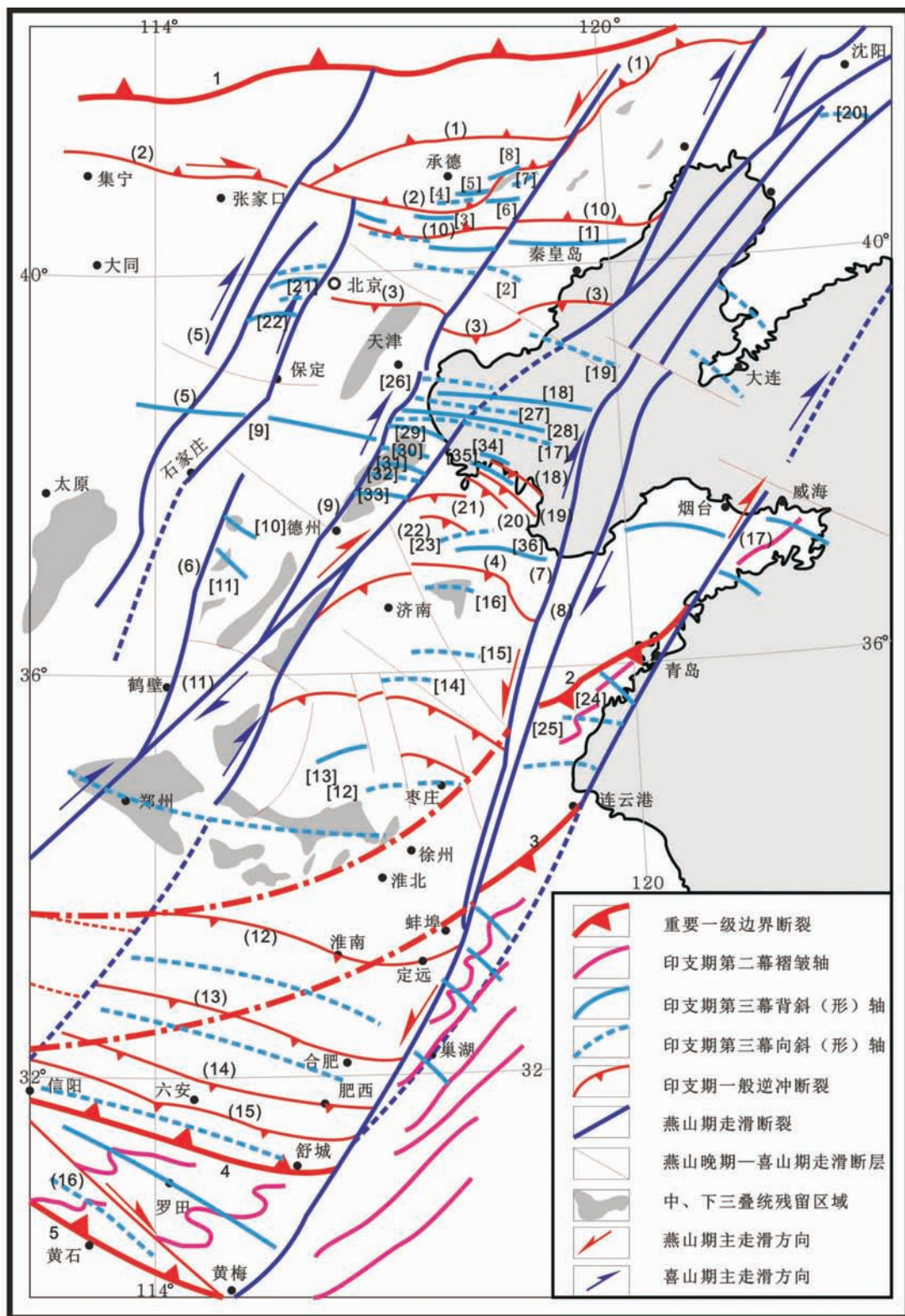


图4 东部地块三叠系残留盆地及东西走向的印支期褶皱(据宗国洪等, 1998; 赵宗举等, 2000; 于福生等, 2002; 汤家富等, 2003; 郝天璈, 2006^①; 许世红等, 2007; 侯明金等, 2007; Li *et al.*, in revised 等资料综合补充)

^① 郝天璈. 2006. 环渤海(湾)地区前新生代海相残留盆地分布的综合地质地球物理研究. 北京: 中国科学院知识创新工程重大项目课题中期评估报告(KZCX1-SW-18-01)

1-康保-围场-赤峰-开原断裂;2-五莲-烟台断裂;3-嘉山-响水断裂;4-信阳-舒城断裂;5-襄樊-广济断裂。(1)-丰宁-隆化-北票-沙河断裂;(2)-尚义-平原断裂;(3)-固安-昌黎断裂;(4)-齐河-广饶断裂;(5)-紫荆关-灵山-乌龙沟-上黄旗断裂;(6)-怀柔-石家庄-邢台-安阳断裂;(7)-葛沟-唐吾-营口-沈阳断裂;(8)-安丘-莒县断裂;(9)-沧州-大名断裂;(10)-密云-喜峰口-明水断裂;(11)-兰考-聊城-大港滩海-法哈牛断裂;(12)-定远断裂;(13)-肥中断裂;(14)-肥西断裂;(15)-六安断裂;(16)-殷店断裂;(17)-即墨-陡山-桃村断裂;(18)-埕北-一号桩断裂;(19)-埕南-孤西断裂;(20)-车西-罗西-陈南断裂;(21)-无棣南-石村-阳信断裂;(22)-宁津南-一曲堤-滋镇断裂。[1]-马兰峪背斜;[2]-蓟县向斜;[3]-孙杖子背斜;[4]-柳河向斜;[5]-涝洼背斜;[6]-黄土梁-张家台背斜;[7]-营子向斜;[8]-双洞子背斜;[9]-阜平-定州-河间背斜;[10]-南宫向斜;[11]-巨鹿背斜;[12]-枣庄向斜;[13]-济宁背斜;[14]-汶口向斜;[15]-莱芜向斜;[16]-昆仑山向斜;[17]-歧口向斜;[18]-沈青庄背斜;[19]-乐亭向斜;[20]-辽河-本溪向斜;[21]-京西向斜;[22]-房山向斜;[23]-滨县向斜;[24]-桃林背斜;[25]-小庄-日照向斜;[26]-长芦向斜;[27]-港西-马棚口向斜;[28]-六间房背斜;[29]-孔店背斜;[30]-舍女寺-黄骅向斜;[31]-南皮-徐杨桥背斜;[32]-盐山向斜;[33]-灯明寺背斜;[34]-桩西倒转背斜;[35]-埕西背斜;[36]-东营-沾化宽缓背斜

Fig. 4 Indosinian folds with EW strike and Triassic relics in the Eastern Block (revised from Zong *et al.*, 1999; Zhao *et al.*, 2000; Yu *et al.*, 2002; Tang *et al.*, 2003; Hao, 2006; Xu *et al.*, 2007; Hou *et al.*, 2007; Li *et al.*, in revised)

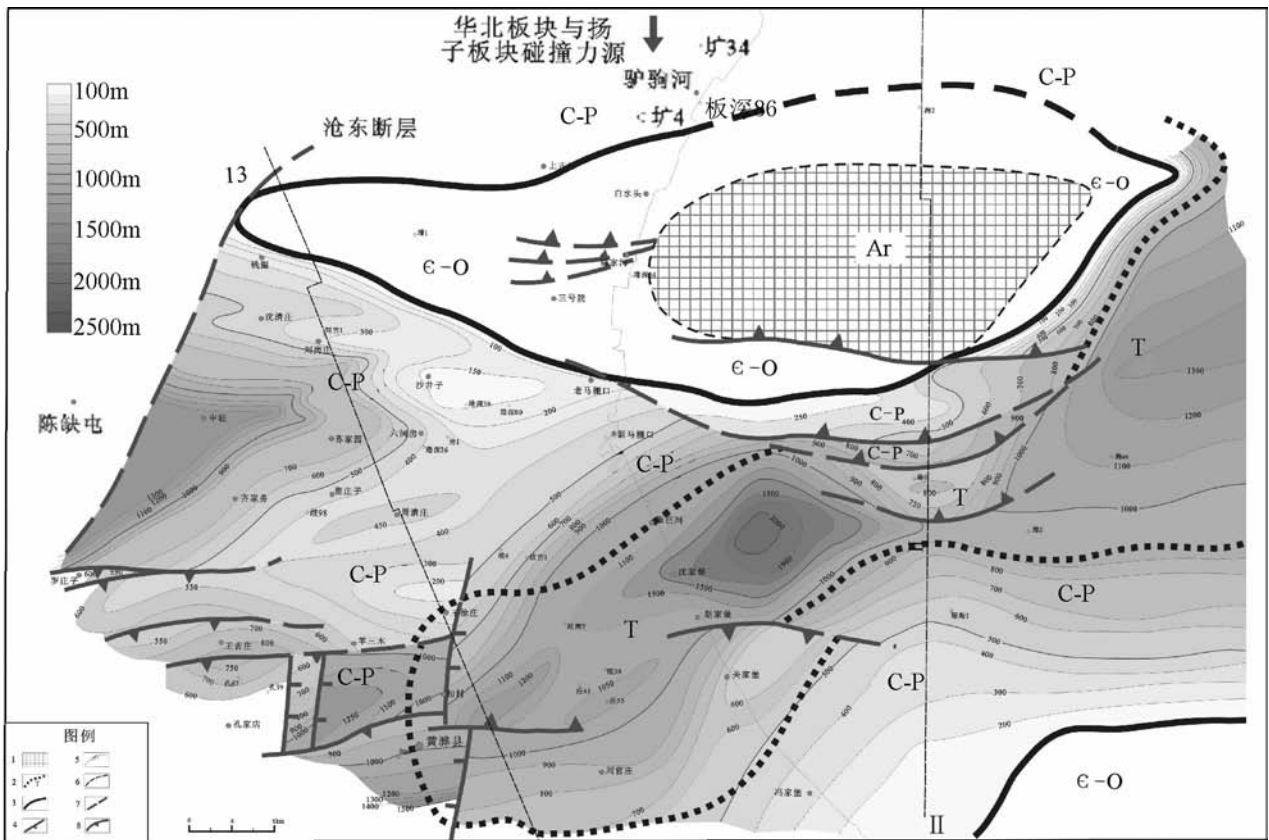


图5 黄骅拗陷中区印支末期沈青庄背斜复原及 C-P 底面图 (据楼达等, 2008)

1-太古宙;2-三叠系出露区;3-0-C出露区;4-正断层;5-等深线;6-推测的出露界线;7-推测断层;8-逆断层

Fig. 5 Late Indosinian Shenqingzhuang anticline and its subsurface map during Permian-Carboniferous system in the middle Huanghua depression (after Lou *et al.*, 2008)

1-Archean basement; 2-Triassic system; 3-Ordovician-Cambrian system; 4-normal fault; 5-contour line; 6-deduced stratigraphic boundary; 7-deduced fault; 8-reverse fault

通过钻孔在济阳拗陷的桩西古潜山中也有揭示,轴迹总体 NE 向,从轴向的一致性和褶皱不对称性分析,可能对应苏鲁-大别造山带中的区域性第二幕变形(图4)。印支晚幕褶皱在整个华北克拉通东部总体为近东西轴向的宽缓褶皱(图4),和早幕总体为近共轴叠加。但是,从大比例尺区域地质

图上可以看出,在聊城-兰考断裂以西,晚幕褶皱轴迹总体由华北南部的 NEE,山西一带的 NE 向和燕山板内造山带 NWW 向扭动转变为 NEE 走向,表明是在南部和北部板缘动力同时作用的结果,且燕山以北的印支期动力在印支晚期具有楔入南部华北的趋势。印支晚幕褶皱之后,这也可能导致

郯庐断裂南段先成核生长而发生左旋错动(Zhu *et al.*, 2005),并导致东部地块向南运移。而且,在燕山末期的左行错动期间,整个大别山造山带随之南移至现今位置,同时,整个郯庐断裂南段和北段贯通为整一的断裂带,也就是说,郯庐断裂即使有巨大位移,也是多幕事件的综合结果,且总的视位移量在500km左右(图1和图4)。朱光等(2006)认为晚侏罗世至早白垩世位移约350km,张岳桥和董树文(2008)认为印支末期(183Ma左右)的错移量有145km。

(2)逆冲推覆带也与褶皱轴迹走向一致(图4和图5),在聊城-兰考断裂以西,北部主体为由NNW向SSE方向的逆冲;在鲁西地块内为由南往北的逆冲占主导,总体逆冲断裂有左阶斜列特征(图4),尽管后期有改造,但依然有归并到兰考-聊城断裂的趋势,说明兰考聊城断裂可能在印支末期具有左行走滑特点,这表明华南板块在印支晚期有沿聊城-兰考断裂楔入华北板块的趋势(周立宏等,2003;刘建忠等,2004)。前文分析表明,印支末期的华北板块北部在燕山地区具有向SE楔入的趋势,而华南板块具有向NE楔入的趋势,这种两个块体斜交式的差异楔入,具有导致东部变形强于西部的特点。这也正是燕山期郯庐断裂形成的先存构造背景。研究表明,聊城-兰考断裂燕山期依然保持这种走滑方向(周立宏等,2003;刘建忠等,2004),局部也存在反向逆冲推覆,它们中的部分逆冲断面,被后期新生代正断层继承(李三忠等,2004)。逆冲断裂未截断燕山期闪长岩体,表明其形成于印支期(李三忠等,2005)。

(3)角度不整合分布也揭示印支期局部存在两幕变形。首先,在辽西,表现为上三叠统老虎沟组角度不整合在中三叠统后富隆山组或超覆在三叠纪以前的地层之上。从中下三叠统的残留分布分析,其主要分布在图4的点线以北,该线和苏鲁带方向和位置一致,可能说明印支早期苏鲁-大别山造山带的边界应当位于这一线。而且,岩相分析表明,未见中下三叠统边缘相沉积建造,表明印支运动导致可以波及该区,宽缓挠曲导致边缘相不明显,且不会使得该区大规模变形,但可以产生局部印支早期变形。目前,发现印支早期变形和角度不整合主要残存在燕山地区,表明华北克拉通印支早期变形可能受北部板缘印支期作用强(Xiao *et al.*, 2009),而受南部印支早期变形弱。其后的印支晚期,在辽西,下侏罗统北票组与上三叠统老虎沟组微角度不整合接触;在辽东,表现为下侏罗统长梁子组角度不整合在石炭、二叠系之上;在渤海湾盆地区,普遍缺失晚三叠世沉积,且地震剖面和钻井资料揭示中-下侏罗统不整合于中-下三叠统或前三叠系之上,如济阳拗陷的桩西、大王庄、埕北等地见中一下侏罗统角度不整合在晚古生代地层之上;在鲁西,淄川、蒙阴等地区的印支运动表现为中一下侏罗统坊子组不整合在早-中三叠世或早古生代地层之上;而大规模上三叠统主要分布在鄂尔多斯盆地中,表明华北克拉通东部受南北挤压明显强于西部(赵重远和刘池洋,1990)。

(4)正是华北克拉通东部印支晚期变形强于西部,导致

上三叠统没有沉积,或有沉积而保存较少(宋明水,2004;陈中红等,2008;图4)。无论这两种情况是何者,都表明兰考-聊城断裂两侧存在明显落差。有研究表明,华北克拉通东部在早、中三叠世为大型内陆沉积,厚达2500m(吴智平等,2007),而现在没有或很少保存,因此至少表明存在巨大剥蚀。关于剥蚀时间限和剥蚀量,有人提出是在晚三叠世就剥露厚度达3000m(宋明水,2004)或3100~4100m(陈中红等,2008),其中,古生界顶面剥蚀厚度达2000m,最小也有600m(李伟等,2005)。而且,下-中侏罗统顶面在J₃-K期间也剥露达1000m(李伟等,2005)。现今,在新生界凸起区,侏罗-白垩系顶面剥露达2500~3000m(李伟等,2005;纪友亮等,2006),也就是说,在现今平原基准面之上,还有约3000m的中生界盖层被夷平。根据地层关系,我们合理假设晚三叠世的28myr期间剥露了3000m,其剥蚀速率为0.1mm/a,这和渐新世以来松潘-甘孜造山带北部0.1mm/a的抬升速率一样(肖序常和李廷栋,2000);而J₃-K的96myr期间剥露1000m,其剥蚀速率才近似0.01mm/a,这比摩天岭地块古近纪-新近纪以来的0.06mm/a的抬升速率低很多(肖序常和李廷栋,2000);而新生代的65myr期间剥露3000m,其平均剥蚀速率也近似0.05mm/a,这和摩天岭地块古近纪-新近纪以来的0.06mm/a的抬升速率相当(肖序常和李廷栋,2000)。晚三叠世(挤压情况)和新生代(伸展情况)两次快速大面积、大规模、区域性的剥蚀速率仅差一倍,而J₃-K期间平均剥蚀速率比晚三叠世的低一个数量级。虽然抬升速率和剥蚀速率不一定等同,如剧烈运动期间,隆升速率可以是剥蚀速率的数倍,而且隆升存在时空上的阶段性、不均一性,剥蚀也存在长期性、持续性(杨坤光和马昌前,1996),它们和古高度的对应关系也非常复杂。但是统计表明,逆冲推覆常导致快速剥蚀,而伸展只能导致中等剥蚀,而最低剥蚀速率往往对应的伸展和逆冲达到某种平衡,也就是说处于抬升和剥蚀的平衡期。这似乎意味着晚三叠世不一定形成高原,因为剥蚀速率太高。若中侏罗世的中燕山期导致抬升高程较大,而J₃-K期间剥蚀速率很低,则有可能存在一个高原,但其古高度采用古高度重建方法还有待获得。若这个高原确实得到今后更多证据证实,那么,结合前述构造变形和角度不整合分布分析,该高原区也正好是由于印支期北部变形早,南部影响晚,高原萌芽应当始于印支期,且是从北逐渐南进的过程,高原存留的时间大致为175~113Ma(中侏罗世-早白垩世)(张旗等,2008)。

总之,印支期构造变形波及了华北板块内部的结晶基底之上的Pt₂-T₁₊₂盖层,而且从T₁₊₂盖层在华北克拉通大范围内没有边缘相保存,仅在东北角有局部残留边缘相的情况分析(宋建国等,1997),印支期对华北克拉通的影响应当在T₃期间。它们主要表现为一系列的逆冲推覆及宽缓的褶皱变形。构造形迹明显受早期薄弱构造带的制约,动力机制上,印支早期应当受北部影响较大(Lu *et al.*, 2003; Xiao *et al.*, 2009),印支晚期受南部大别-苏鲁造山带的动力因素影响较大。

5 大别—苏鲁造山带和华北克拉通东部地块印支期褶皱-逆冲构造关系

华北克拉通东部地块(图1)是华北克拉通的重要组成部分(Zhao *et al.*, 2005),由于华北克拉通自中元古代至中生代初长期处于岩浆作用的静寂期(翟明国等, 2003),所以长期被认为是一个稳定的前寒武纪地块,而且,这个演化时期很少有构造活动。然而,中生代初由于东部地块处于北倾的大别—苏鲁构造带的上盘,所以,这个稳定地块的印支期变形是否与南部发生强烈的造山作用或深俯冲作用有关?若有关,又是何种关系?若无关,该印支期变形又是与华北克拉通岩石圈破坏之前的何种机制有关?这种机制与尚存争论的燕山期破坏机制(吴福元等, 2008)肯定不同。总之,华北克拉通的不稳定性起始于印支期(Yang *et al.*, 2008; 张旗等, 2008),明显于燕山期(吴福元等, 2008; 张旗等, 2008)。

为了解决这个问题,需要选择一个区域可对比的参考变形幕。这里,选择各区带 J_1 不整合之下的最晚一幕褶皱。据多数野外构造调查、统计分析,发现这幕褶皱轴向总体近东西-北西西向。如在韩国京畿地块中,发现了近东西向变形记录;在济阳凹陷、黄骅拗陷等华北地区中,NWW走向褶皱很晚发育,也是古生界一中、下三叠统经历的唯一一幕广泛发育的褶皱(宗国洪等, 1998);在苏鲁造山带,第三幕褶皱为NWW轴向(顾德林等, 1996; Li *et al.*, in revised);在张八岭地区,第三幕褶皱轴向同样为NWW(汤家富等, 2003; 鲁如魁等, 2004; 侯明金等, 2007);再往南,在安徽巢湖地区,第三幕褶皱依然如此,但不甚明显(李三忠等, 2009);再往西,在桐柏-大别造山带,第三幕褶皱也同样是NWW向轴向(Li *et al.*, in revised)。从济阳拗陷地层残存和大别地区变形年代等结果分析,上述NWW或东西走向变形的时间可能为中三叠末期,因为它们明显地被鲁西地块边界附近的燕山期变形(包括渤海湾中西部地区)改造,燕山期变形带切割了地块内部(包括渤海湾盆地东部地区)的构造带(李三忠等, 2005)。因此,只能将这种构造解释为形成于比鲁西地块边界上或附近的燕山期构造早,即印支晚期,华北与扬子板块碰撞拼合为一体了之后,变形才波及到板内,所以无论华北还是华南,整个在统一应力场作用下,全区褶皱具有统一的轴向。

再依据上述参考变形幕,通过区域对比表明,苏鲁-大别造山带与安徽巢湖前陆区等印支期的区域性第一和第二幕变形主体NE轴向,期间在华北克拉通内部没有相应变形发生,因为华北克拉通盖层只发生了一幕印支期褶皱变形。安徽巢北第一幕变形卷入变形最新地层为中三叠统,故形成于中三叠世末期,正与大别-苏鲁高压-超高压岩石向南初始折返剥露时期相同(Zheng *et al.*, 2008),说明动力来源相关。第二幕变形才形成该区“两向一背”的褶皱格局,褶皱轴面都为北西倾,表明褶皱动力来自北西部,而且随后的叠瓦式逆冲断裂组合也是由北西向南东逆冲的,形成时间仍然在中三

叠世末期,可能是大别山前陆褶皱-逆冲带中第一幕变形的持续和强化,应当和高压-超高压岩石快速剥露阶段对应(李三忠等, 2009)。再往区域第一幕变形之前,在苏鲁-大别造山带的一些超高压透视镜中或其它变斑晶中还保存有两幕变形,一幕与进变质有关,另一幕为超高压相变形,而其前陆区没有这两幕变形记录(Li *et al.*, in revised)。

6 印支期褶皱-逆冲构造与变质动力学过程讨论

变质动力学最初是运用化学动力学方法来研究岩石变质反应的速度和结晶作用动力学的一门新的边缘交互学科,主要研究内容包括通过研究变质反应过程中矿物组合及其结构构造的变化来研究反应过程及速率,具体包括晶核作用及晶体生长、渗透实验、扩散效应、局部平衡、镶嵌平衡研究等。这些都是微观尺度的研究内容。但是,变质动力学也包括变质作用演化样式及其 P - T 轨迹的时空变化,可有效反映大地构造环境及各种地质动力学机制(卢良兆等, 1998)。因此,本文通过宏观构造解析,结合变质世代划分及其对应的定年工作,结合前述野外调查可知,大别-苏鲁造山带中的印支期变形记录要比华北克拉通的全面而复杂,是揭示中国东部印支期变质动力学和构造动力学的重要场所。为了理顺该造山带印支期事件序列,我们综合了近十年来大别山-苏鲁造山带的年代学资料,并侧重前侏罗纪变质动力学和构造动力学事件的时空演化研究,发现不同造山带段落同一事件具有穿时性,造山带的时空演化更为复杂(图6)。

图6横坐标为构造-热(包括岩浆、变质、Ar-Ar同位素系统封闭)事件的相对时序,是根据各研究人员所测年代的特殊变质矿物组合确定的,并按照原岩形成事件、高压-超高压变质前、高压-超高压变质峰期、高压(角闪岩相)变质阶段、绿片岩相变质阶段五个阶段划分。纵坐标则为该事件的绝对年代。同一事件又按照从西往东的空间顺序从左向右排列。

值得指出的是,在图6中,UHP变质年龄统计中也包括了一些Ar-Ar定年数据,考虑到Ar-Ar体系较低的封闭温度和超高压岩石中过剩Ar的可能性,我们在同幕事件中没有把这些数据统计为UHP变质年龄;我们在考虑了不同作者采集样品的空间位置不同的基础上,基本按照原作者解释,把变质锆石的SHRIMP年龄作为超高压岩石变质作用时间,Ar-Ar定年数据则反映的是同该幕超高压变质作用同时发生的其它事件,如有的岩石还在深部发生超高压变质,有的则同期在剥露,剥露达到封闭温度,便反映的是剥露事件;因此,从整个造山带来说,可以作为不同属性单元内或地质过程具有同时段不同热事件处理。为了避免错误理解,我们将图6横坐标意义定义为:某变质相变质作用的同期热事件(包括变质、岩浆和剥露同位素系统封闭事件)。从而,结果显示了造山带内同期不同地段这些复杂的、不同事件的穿时

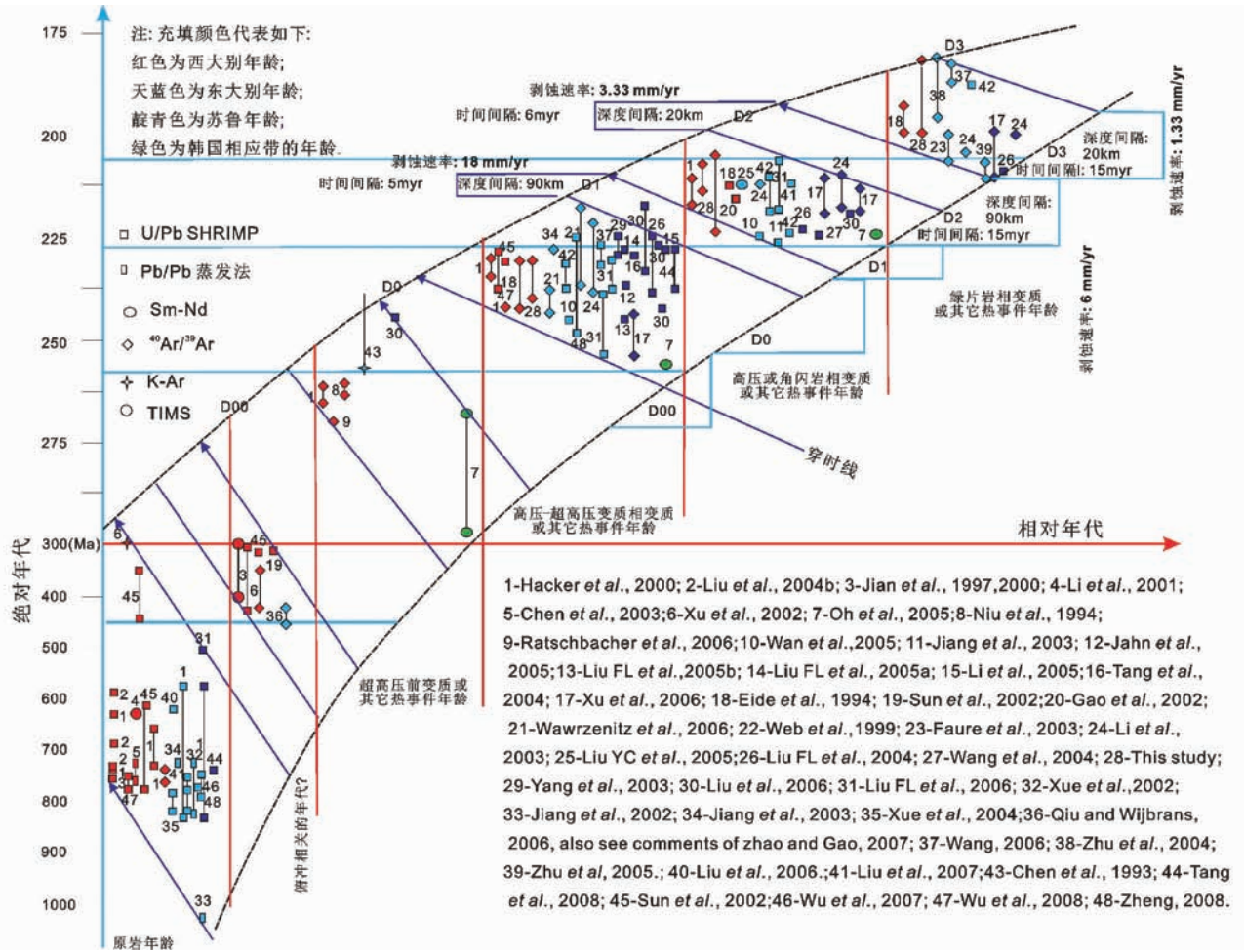


图6 大别—苏鲁造山带高压-超高压变质岩时空演化

Fig.6 Diagram of absolute time vs. relative time showing two-stage rapid exhumation of HP-UHP terrane and diachronous evolutions of different deformation stages in different segments along the western Dabie, the eastern Dabie, the Sulu and the Odesan (Korean) orogens from west to east

性和空间迁移特征。统计时,也考虑了每种方法的测年误差,所以在标定年代范围时给予了考虑。但是,即使在误差范围之内,也不可能所有作者都得到同样一个误差值;甚至同幕事件的误差高达 40Ma,这远远高于现今 Ar-Ar 和 SHRIMP 的测年误差,因此,我们考虑同一幕事件不可能每个作者都测得如此不准,而是这个数值反映了同幕事件的穿时性。

基于上述讨论,据图 6 和该区变质动力学、年代学资料可得出以下几点变质动力学背景和过程的事实:1) 图中每幕事件的穿时线反映,每幕事件都具有从东向西逐渐变新的趋势,东部先碰撞,西部碰撞晚,说明苏鲁-大别山-桐柏具有剪刀式拼合的特征,而且这种剪刀式拼合也保留在雁列式的特征变质分带上,即(不考虑郟庐错移的情况下)从东北向西南分别为高压-超高压变质岩片、高压兰片岩带和一般的中压变质岩片;而且,2) 先经历高压-超高压变质的岩片先剥露; 3) 就目前研究积累可知,总体苏鲁高压-超高压变质岩片最

深可超过 200 Km (Ye et al., 2000),而在大别地区有金刚石和一些特殊的出溶结构显示岩石形成在超过 150km 的深度,就目前积累的这些最大俯冲深度而言,说明大别地区俯冲相对较浅,苏鲁相对较深,且俯冲最深的最先剥露,该结论至少目前的岩石学和年代学资料和证据还没有给予证伪;4) 再根据 *P-T* 计算结果,假设榴辉岩相和角闪岩相变质的深度差异为 90km (Liu et al., 2006),并因为板片断离往往是个突发事件,所以,所有榴辉岩相单元在榴辉岩相变质之后很可能同期发生剥露 (Li et al., in revised; Liu FL et al., 2006),从图 6 中相邻事件的相邻穿时线间隔,即榴辉岩相事件的穿时剥露到同深度的时间减去相邻角闪岩相事件发生的最早穿时时间,得到这个突发事件的时间间隔为 5myr,故其剥露速率为 18mm/yr。然而,剥露作用也可能同时发生在榴辉岩相变质作用发生同期,其时间间隔为 15myr,其剥蚀速率为 6mm/yr (图 6)。再假设角闪岩相或兰片岩相到绿片岩相深度差异为 20km,所有单元在角闪岩相或兰片岩相变质后才发生剥

露,那么其时间间隔为大约 6myr,其剥露速率为 3.33mm/yr (图 6)。然而,剥露作用也可以和角闪岩相或片麻岩相变质作用同期发生,时间间隔为 15myr,其剥露速率为 1.33mm/yr (图 6)。氧同位素研究揭示榴辉岩不可能在深部保存超过 10~20myr (Zheng *et al.*, 2003; Zheng, 2008; 郑永飞, 2008), 因此,第一次快速剥露速率为 18~6mm/yr,第二次快速剥露速率为 3.33~1.33mm/yr。这就意味着先前根据变质作用和地质年代学计算的剥露速率偏低。这里我们的估计倒是和 Liu FL *et al.* (2006) 获得的最新的 6.4mm/yr 一致。可见,这个剥露速率明显大于或接近于其 6mm/yr (Liu *et al.*, 2006) 和 9~10mm/yr (Liu FL *et al.*, 2006) 的俯冲速率,与郑永飞(2008)和 Zheng(2008) 计算的也总体一致。

为了说明上述四个事实和新发现的其它地质事实,如在鲁西中生代岩体中发现榴辉岩包体(许文良等, 2002)等等,近 15 年来,提出了大量的构造模型,从侵蚀模式(Okay *et al.*, 1989)、喜马拉雅式逆冲模式(Okay *et al.*, 1993)、楔入模式(Yin and Nie, 1993, 1996)、地壳拆离模式(Li, 1994)、垂向挤出模式(Maruyama *et al.*, 1994)、撕裂模式(Chang, 1996)、浮力驱动模式(Ernst *et al.*, 1997)、浮力-楔入-热穹隆模式(Dong *et al.*, 1998)、角流及浮力联合模式(Wang and Cong, 1999)、平行于造山带的向右侧向挤出及伴随减薄模式(Hacker *et al.*, 2000)、复合旋转模式(肖文交等, 2000)、侧向挤出+旋转模式(Wang *et al.*, 2003)、连续俯冲-折返-热穹隆模式(Liu XC *et al.*, 2004)、到向西挤出模式(张岳桥和董树文, 2008)、多板片差异折返模式(Liu *et al.*, 2008)等等。此外,几个关于东北亚构造演化的重要构造模型也涉及到了东部地块印支期变形问题(洪作民, 1989; Faure *et al.*, 2001; 杨天南等, 2002; Xiao *et al.*, 2009)。

无论何种模型,都不能回避讨论三组基本问题:①郯庐走滑距离多少、形成时间起始于何时、演化阶段如何、Honam 断裂和郯庐断裂时代是否相同、运动方向是否相反,这涉及大别-苏鲁造山带的原始位置;②郯庐断裂两侧的运动极性何时、如何翻转的,这涉及现今郯庐两侧印支期最终几何学格架为何不同;和③郯庐两侧其它构造差异问题,如徐淮推覆体问题(舒良树等, 1994),这涉及这些差异是否印支期就存在。

已有研究表明,鲁西地块周边走滑带在印支末期出现(李三忠等, 2005),即郯庐断裂南段印支期已形成(朱光等, 2006),但并非与北部依兰-舒兰断裂贯通。到燕山早期,在朝鲜半岛与此相关的 Honam (湖南)断裂也已形成(Cluzel *et al.*, 1991, 1992)。而且,从前陆推隆区的逆冲断裂时代判断,这些断裂活动时期可能主要发生在中侏罗世(Chough *et al.*, 2000),而且,最近韩国的同位素年代研究结果表明, Honam 断裂的形成时代为 170 Ma 左右(Cho, 2001),最新的郯庐断裂测年结果总体反映现今鲁西地块边界主要为强烈的燕山早中期的产物(Wang, 2006; 孙晓猛等, 2008)。前者表现为左行压扭,后者性质为右行压扭。Yin and Nie(1993)

认为这种齿状几何形态被认为是印支期不规则的扬子板块被动陆缘向华北板块南缘的主动陆缘楔入(indentation)所致显然不对。造山带尺度上,从桐柏、西大别到东大别,总体构造运动指向南,但在苏鲁造山带总体构造运动指向向北西。显然楔入不是扬子楔入华北,而是华北克拉通东部地块楔入扬子之下,导致苏鲁地区发生造山带尺度的构造翻转。而且,这是燕山期的产物,即这种运动方向的翻转并不能说明其早期就是如此,因为层析成像结果揭示在郯庐断裂两侧的更深处,早期总体都是华南板块向华北板块下面俯冲(徐佩芬等, 1999),而且前陆褶皱带的变形、大别-苏鲁造山带内的兰闪石、绿辉石优势方位等也指示大别-苏鲁造山带早期应当向南东 120°方位运动(张永军和黄钟瑾, 1998)。我们根据构造分析表明,主要是燕山期以来在郯庐断裂以西,由于郯庐左行走滑导致华北克拉通向桐柏、西大别到东大别地段俯冲,高压-超高压单元以北的亲扬子的浅变质地层产状都比较陡立,有的也局部翻转,而且这个华北克拉通向大别下作陆内俯冲已经从合肥盆地的许多地震剖面得到揭示(张国伟等, 2001; 赵宗举等, 2000; 许世红等, 2007; 张岳桥和董树文, 2008); 苏鲁带向北的逆冲也是无疑的(Xu *et al.*, 2006),构造分析表明,这是由于早期东部碰撞就比较强烈,收缩明显,超高压岩石的巨大、快速剥露,导致在郯庐断裂东侧抬升较高,而华北克拉通最低耗能就是进一步向苏鲁造山带下快速陆内俯冲,并在郯庐断裂左行位移明显,并导致向北东方向楔入的情况下,刚性相对弱的高压-超高压单元必然仰冲。所以苏鲁造山带就是阿尔卑斯造山带模式中的根部带的残存,因此,这种运动极性的倒转并不是俯冲阶段或早期造山阶段的产物,而是晚期多幕事件的最终结果。

据此,郯庐断裂带的错距问题就得重新考虑,以复原大别造山带印支末期是如何和苏鲁造山带相连(图 7)。首先,我们认定郯庐断裂在燕山晚期位移 350km(朱光等, 2006),这样我们将大别造山带北退 350km,显然徐淮推覆体在苏鲁造山带以北 200km 处,这就导致不可能从苏鲁造山带中向西挤出。这有两种情况:第一,所有估计位移都是正确的,这种逻辑计算不合理;第二,总位移 500km 是事实,但不同时期的位移估计有问题。我们先假定估计位移正确,来重新建立计算方法,用构造解析结果建立构造模型来检验这个假定。如果成立,则两种情况都解决了。

若张岳桥和董树文(2008)提出的印支末期(约 184Ma)错距约 150km 结论正确(虽然其主要依据为徐淮推覆体的挤出及其以北标志,实际此时可能郯庐断裂并未贯通并延伸到北部),加上燕山晚期总位移 350km,那么,这 500km 的位移总量正好对应苏鲁造山带北界和大别造山带北界的现今错移总量(图 1 和图 4)。由于郯庐断裂两侧这个位移总量是两盘相对运动的总和,因此,平分这个总位移,苏鲁造山带北界应南退 250km,而大别造山带北界也应当向北移 250km,它们这个复位后的位置就是原始大别-苏鲁造山带北界印支早期的位置,且没有被错断。由此可知其为一条 NE 向的造山

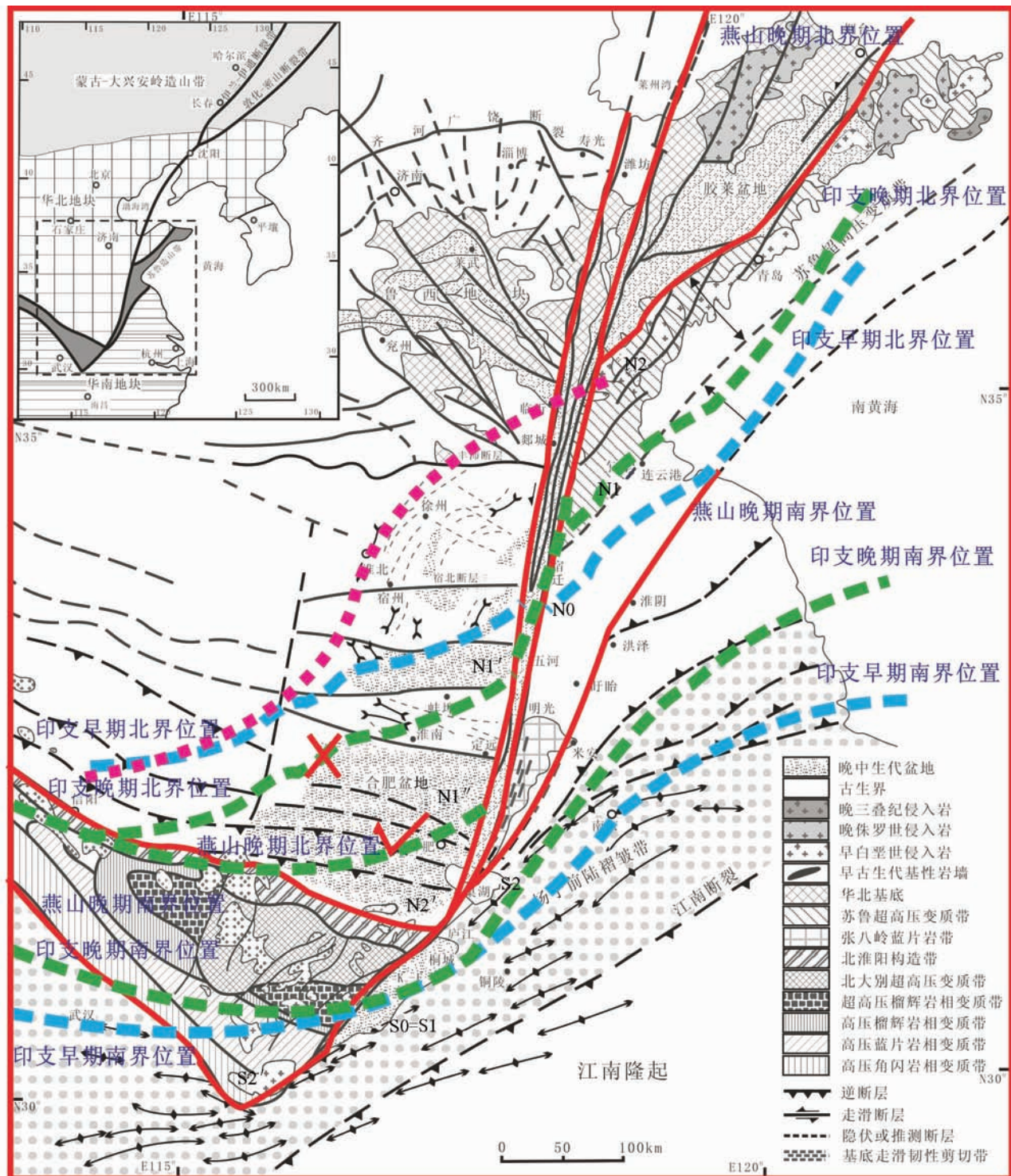


图7 郯庐断裂位移问题和大别—苏鲁造山带原位恢复(底图据张岳桥和董树文, 2008;说明见正文)

Fig.7 Displacement of Tanlu fault for recovering the initial location of Dabie-Sulu Orogen (revised after Zhang and Dong, 2008; details in text)

带,这和我们构造解析出的第一幕变形和第二幕变形总体向SE方向逆冲,褶皱主要为NE轴向的结果一致。

虽然大别造山带的北界和苏鲁造山带的北界总位移差是500km,但是,应当注意到张八岭兰片岩带南界和宿松兰

片岩带南界的位移实际只有约150km。同样,两盘平分这个总位移,得出大别前缘的襄樊-广济断裂逆掩了前陆约75km,由于卷入最新地层为侏罗系,应当是这个错距和逆掩是燕山期产物。回退这个燕山期南界错距,得到原始大别-苏鲁造

山带印支期南界原始位置也应当在现今潜山县附近,且印支期原始大别-苏鲁造山带南界没有被错断(图7)。

若前文假定的位移正确,我们已知,大别-苏鲁造山带北界被错断的150km也只是印支末期的产物,而前述事实表明,南界在印支末期就没有错断,准确一点说,此时是南界断裂之上的上盘造山带开始撕裂(Chang, 1996;图7)。此时,徐淮推覆体应当对应其造山带后缘的逆冲前锋,并始终残存至今,但也有可能但不能肯定就是从苏鲁造山带北部西向挤出的(张岳桥和董树文, 2008)。因为这里也是印支早期大别-苏鲁造山带影响到的最前缘(图7中粉色虚线),这与华北克拉通东部地块中、下三叠统的残存分布一致(图4中红色点虚线以北),和复原后的造山带展布方向也一致(图7中蓝色线)。

南、北边界确定后,我们可以得出,大别造山带印支末期与郯庐断裂交线长度达250km长,而现今大别造山带与郯庐断裂交线长度只有约150km长,差别100km。这个差值只能从徐淮推覆体(此时位置已经固定)以南(即图7的点N0以南)寻求解释。这有三种可能:一就是北淮阳构造带以北燕山期逆冲推覆带还有100km宽被收缩,而不能是走滑(因为走滑会导致徐淮推覆体变质),撕裂并推动大别造山带北界再向南移动至现今位置,剩余的空间后被合肥盆地伸展占据;二就是因为在大别造山带我们没有识别出燕山期NWW向褶皱(但可能存在逆冲),故只有在东大别造山带南界发生燕山晚期走滑错断前的印支末期(最好是220~190Ma期间)先褶皱或逆冲收缩了100km;三就是两者总量100km收缩。但实际,只能是第二种情况,因为第一种情况,依然不能改变大别造山带和苏鲁造山带北界错距问题。这样在印支末期,N0点实际在西侧移到了N'的位置,而不是N''的位置(图7),由此,西侧北界实际向南的位移总量为175km;东侧北界实际向北位移总量为75km;且郯庐断裂南段,大别-苏鲁造山带的北界已经达到250km的视总错移量,而南界没有错断。这样N''点离现今大别北界N2'点只有75km,这样郯庐断裂西侧南界和北界的燕山期位移就完全可以和东侧的对上了。

现今按照北界和南界错断情况分析,郯庐断裂两侧燕山期总位移是不相同的。按北界分析,西侧位移为现今总位移500km减去印支期150km,等于燕山期350km;按南界分析,东侧燕山期位移只有150km。我们简单计算会发现西侧多出了200km燕山期的位移。而上一段已经解决了燕山期南界和大别造山带北界错距问题。这样,西侧多出了的200km燕山期的位移纯粹是苏鲁造山带的北部边界问题。它有可能有下面四个可能因素产生的:北淮阳构造带收缩、大别造山带收缩、合肥盆地伸展和渤海湾盆地伸展(因为后两者也在燕山晚期就开始形成)。前两者不能再考虑了,因为徐淮推覆体以南都合理化了,只有考虑渤海湾盆地伸展了。再进一步分析郯庐断裂西侧地质事实,如果郯庐断裂东北段(如敦化-密山段)在燕山晚期错距只有约100km是可靠的话

(Xu *et al.*, 1987),这样,西侧这100km错断完全对应燕山期渤海湾盆地的伸展总量,这和渤海湾盆地中计算得出的10%~20%的伸展率是一致的。对应的苏鲁造山带北界也应当运移向北100km,加上南界的75km向北运移,总共为175km(图7中N1与N2之间距离)。实际上,苏鲁造山带北界这个100km的向北东的位移,完全可能是造山带挤窄、拉长应变所致的“假位移”、“假错距”,因为该区燕山中晚期存在一幕NE向褶皱作用,包括胶莱盆地成因在内,完全可以用胶辽地块向北东方向的挤出构造来解释(周立宏等, 2003;刘建忠等, 2004)。

从图7分析,华南也没有顺时针作70°的旋转(Lin and Fuller, 1990),这是因为该图表示的是剥露阶段的情况,推测古地磁确定的旋转可能是初始俯冲至碰撞前之间发生的。总体分析表明,郯庐断裂“视位移”非常大,但实际走滑作用导致的真实“错距”在南部不超过75km,在北部不超过100km。这样,就恢复出印支早期,大别-苏鲁造山带为一条NE向展布的造山带,之后北部边界“撕裂”,在这个背景下,大别-苏鲁造山带对应发生了变质动力学中的重要问题—剥露过程:印支期两阶段性的剥露和穿时性的剥露,先是垂向朝SE的挤出,之后是向NE的侧向挤出(Li *et al.*, in revised)。

致谢 值此卢良兆教授80华诞,作为学生谨以此文表示庆贺!真诚感谢恩师十多年来,在学术道路上对我的鼓励、扶持和帮助!在我的学术成长道路上,也得到了各位师兄们的大力支持和帮助!在此,一并致以诚挚谢意!非常感谢香港大学罗彦博士,美国 Saint Louis University 的 Tim Kusky 教授和 Erkan Toraman 博士,日本高知大学(Kochi University)的 M. Santosh 教授和硕士 A. Katsube,加拿大 University of Manitoba 的 Alfredo Camacho 副教授和王璐博士,他们先后参加了2002年以后的部分野外考察工作。感谢郑永飞教授提供了大量他的课题组及其同事的最新研究成果,也感谢他建设性的建议和与他深入的讨论。最后,要感谢张建新研究员提出的宝贵修改建议!

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