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兴蒙造山带的基底属性与构造演化过程

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摘要: 为了解兴蒙造山带基底属性和多个构造体系演化与叠加历史,系统总结了近年来在基础地质研究中取得的新成果,并利用这些成果讨论了兴蒙造山带的基底属性与演化历史.兴蒙造山带是指我国东北地区古生代构造作用影响的地区,这些地区也遭受了中生代构造作用的叠加与改造.兴蒙造山带主要由微陆块和其间的造山带组成.虽然传统上认为属于前寒武纪结晶基底的地质体主要已解体为古生代和早中生代,但随着新太古代和古元古代地质体的相继发现,以及新生代玄武岩中幔源古元古代橄榄岩包体的发现,可以判定兴蒙造山带内微陆块应具有古老的前寒武纪基底,并且壳幔是耦合的.微陆块内部地壳增生以垂向增生为主,且主要发生在新元古代和中元古代,以及次要的新太古代和古生代.相反,陆块间造山带或岛弧地体的陆壳则以侧向增生为主,且主要发生在新元古代和古生代.额尔古纳地块与兴安地块的拼合发生在早古生代早期;兴安地块与松嫩地块的拼合发生在早石炭世晚期;松嫩地块与佳木斯地块的拼合发生在早古生代晚期,中生代早期又经历了裂解与再闭合的构造演化过程;华北克拉通北缘增生杂岩带与北方微陆块群的最终拼合发生在晚二叠世—中三叠世,古亚洲洋的最终闭合发生在中三叠世,且为剪刀式闭合.晚古生代晚期蒙古—鄂霍茨克大洋板块南向俯冲作用的发生以及早中生代(三叠纪—早侏罗世)的持续南向俯冲,控制了大兴安岭—冀北—辽西地区的岩浆活动,蒙古—鄂霍茨克大洋的闭合发生在中侏罗世,晚侏罗世—早白垩世主要表现为闭合后的伸展环境.古太平洋板块中生代的俯冲起始时间为早侏罗世,晚侏罗世—早白垩世早期东北亚陆缘主要表现为走滑的构造属性和陆缘地体从低纬度到高纬度的构造就位过程,早白垩世晚期—古近纪岩浆作用的向东收缩揭示了古太平洋板块的持续俯冲和俯冲板片的后撤过程,古近纪晚期日本海的打开标志着东北亚陆缘从活动陆缘已经转变为沟—弧—盆体系,并且标志着东亚大地幔楔的形成.

关键词: 兴蒙造山带;微陆块;地壳增生与再造;古亚洲洋构造体系;蒙古—鄂霍茨克构造体系;环太平洋构造体系;构造地质.

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Basement Nature and Tectonic Evolution of the Xing'an-Mongolian Orogenic Belt

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Abstract: This paper summarizes recent achievements in basic geological studies in NE China, with the aim of understanding the basement nature and the evolution and overprinting processes of multiple tectonic regimes within the Xing'an-Mongolian Orogenic Belt (XMOB). In this paper, the XMOB only includes the northeastern China which influenced by the Paleozoic orogenic processes, where the overprinting and modification of the Mesozoic tectonic processes took place. The XMOB mainly consists of microcontinental massifs and several orogenic belts between them. Although the so-called Precambrian basement has been dated as Paleozoic and Mesozoic terranes, the new discoveries of the Neoarchean and Paleoproterozoic terranes, together with the Paleoproterozoic mantle-derived xenoliths hosted in Cenozoic basalts, indicate that the microcontinental massifs in the XMOB have the Precambrian basement, and the mantle-crust is coupling within the microcontinental massifs. The crustal ac-

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cretion within the microcontinental massifs mainly happened in the Neoproterozoic and Mesoproterozoic as well as Neoarchean and Paleozoic by vertical accretion. In contrast, the crustal accretion within intercontinental orogenic belts or island arc terranes mainly took place in the Neoproterozoic and Paleozoic by lateral accretion. The amalgamation of the Erguna and Xing'an massifs happened in the Early stage of Early Paleozoic. The collision between the Xing'an and Songnen massifs took place in the late Early Carboniferous. The amalgamation of the Songnen and Jiamusi massifs occurred in the late stage of Early Paleozoic, the breakup and second amalgamation of these two massifs happened in the Early Mesozoic (the Middle Triassic to Early Jurassic). The final collision between the accretionary belt of northern margin of the North China craton and northern massifs took place during the Late Permian to Middle Triassic. The scissor type closure of the Paleo-Asian Ocean finally happened in the Middle Triassic. The southward subduction of the Mongol-Okhotsk oceanic plate happened during the late stage of Late Paleozoic to Early Jurassic, which controlled the magmatic activities in the Great Xing'an Range and northern Hebei-western Liaoning provinces in this period. The closure of the Mongol-Okhotsk Ocean took place in the Middle Jurassic, and the post-closure extensional environment occurred in the Late Jurassic to Early Cretaceous. The onset of subduction of the Paleo-Pacific plate beneath the Eurasia continent took place in the Early Jurassic. The stike-slip tectonic nature in continental margin of northeastern Asia occurred in the Late Jurassic to early Early Cretaceous, resulting in the tectonic emplacement of accretionary complexes in continental margin from low latitude to high latitude. The eastward shrinking of extents of magmatic activities from the late Early Cretaceous to Paleogene reveals the subduction and subsequent roll-back processes of the Paleo-Pacific plate. The opening of the Japan Sea in the Late Paleogene marks the transformation from active continental margin to trench-arc-basin system and the formation of large mantle wedge in eastern Asia.

Key words: Xing'an-Mongolian Orogenic Belt; microcontinental massif; crustal accretion and reworking; the Paleo-Asian Oceanic tectonic regime; the Mongol-Okhotsk tectonic regime; the circum-Pacific tectonic regime; tectonics.

中亚造山带是全球最大的增生型造山带，它的形成与演化以及后期的构造叠加与演化历史一直是地学领域研究的热点问题之一.中亚造山带东段（国内通常称为兴蒙造山带）是全球多个构造体系叠加与演化的经典地区.Şengör *et al*.(1993)和 Şengör and Natal'in(1996)将该区划分为阿尔泰和满洲两个构造拼合体，并认为这些地区都是不断向洋迁移岛弧的系统.本文所指的兴蒙造山带只包括受到古生代构造作用影响的东北地区，在构造上包括额尔古纳地块、兴安地块、松嫩地块、佳木斯地块和兴凯地块以及地块间的构造带和华北克拉通北缘陆缘增生杂岩带.中生代期间，这一地区又遭受了蒙古－鄂霍茨克构造体系和环太平洋构造体系的叠加与改造(Wu *et al*., 2011).21 世纪以来，随着锆石原位微区定年技术的广泛应用，兴蒙造山带中微陆块的基底属性、地质体的时代构成(Wu *et al*., 2011)、不同构造体系的形成与演化及其叠加历史等(Ge *et al*., 2005; Li, 2006; Meng *et al*., 2010; Xu *et al*., 2013;裴福萍等，2014;Wang *et al*., 2014, 2017a;徐备等，2014; Tang *et al*., 2015, 2016, 2018)研究已经取得了突出进展，例如，微陆块中传统上认为的前寒武纪基底（吉林省地质矿产局，1988;内蒙古自治区地质矿产局，1991;黑龙江省地质矿产局，1993）基本上已经解体，除少数新元古代地质体外，主体由古生代和少量早中生代地质体构成(Wilde *et al*., 2000;Pei *et al*., 2006;Miao *et al*., 2007;Wang *et al*., 2012;Wu *et al*., 2012;Xu *et al*., 2012;郝文丽等，2014;Zhao *et al*., 2016)；传统上认为的海西期花岗岩其主体形成于中生代(Wu *et al*., 2011)；兴蒙造山带显生宙地壳增生已经被绝大多数学者所接受(Jahn *et al*., 2000, 2004;Wu *et al*., 2000;Chen and Arakawa, 2005;Xiao *et al*., 2009)等.然而，兴蒙造山带微陆块中是否存在前寒武纪结晶基底？该区地壳增生是否只发生在显生宙？不同构造体系演化过程及其影响的时空范围如何？这些问题一直存在争论.针对这些问题，本文系统总结了近年来对兴蒙造山带基础地质研究取得的最新研究成果与新发现，探讨了兴蒙造山带中微陆块的基底属性、地壳增生的时间与方式及其再造过程、多构造体系的叠加与演化历史，进而构建了中亚造山带东段多构造体系古生代－中生代的演化与叠加历史.

1 兴蒙造山带：古生代－中生代基本构造格局

兴蒙造山带，南有西拉木伦－长春－延吉缝合线与华北克拉通相邻，北有中生代蒙古－鄂霍茨克缝合带与北亚克拉通相连，东侧为环太平洋构造体系(图 1a).按微陆块及构造带的属性，区内主要构造

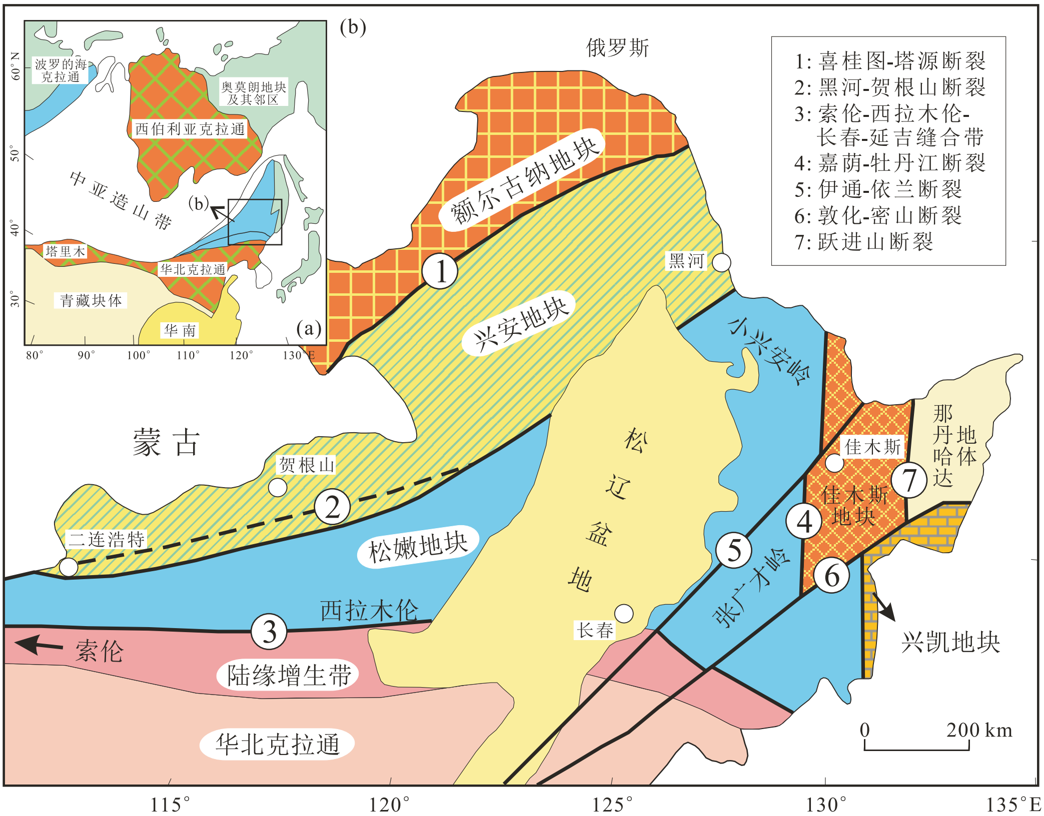

图1 兴蒙造山带构造单元划分

Fig.1 Simplified geological map of main tectonic subdivisions in the Xing'an-Mongolian Orogenic Belt

据 Wu *et al*.(2007b)改

单元包括:微陆块和显生宙造山带,后者包括显生宙岛弧(如多宝山岛弧)、增生或碰撞杂岩(如跃进山杂岩和那丹哈达地体)(Li, 2006;图1b).微陆块自西向东包括额尔古纳地块、兴安地块、松嫩地块、佳木斯地块和兴凯地块;陆块间的造山带包括位于兴安地块与松嫩地块之间的多宝山古生代(早古生代—晚古生代早期)岛弧带(Li, 2006)和华北克拉通北缘的古生代陆缘增生杂岩带(Wu *et al*., 2007b);中生代地体为位于佳木斯地块东侧的那丹哈达地体(张兴洲等,2006;Zhou *et al*., 2014);在佳木斯地块与那丹哈达地体之间为跃进山杂岩,它是二叠纪构造就位的增生杂岩(Sun *et al*., 2015;Bi *et al*., 2016, 2017)(图1b).兴蒙造山带,在古生代(尤其是晚古生代)—中生代期间叠加有蒙古—鄂霍茨克构造体系的改造,该大洋板块晚古生代晚期发生的南向俯冲作用(Tang *et al*., 2014, 2016;Li *et al*., 2017a)、大洋的闭合(李宇等,2015)以及闭合后的伸展作用(Tang *et al*., 2015)对兴蒙造山带进行了强烈改造.同时,兴蒙造山带在中生代期间也经历了古太平洋板块西向俯冲作用的叠加与改造(Xu *et al*., 2013).

2 兴蒙造山带:微陆块中前寒武纪基底是否存在?

兴蒙造山带主要由多个微陆块和其间的造山带组成.对于微陆块中前寒武纪基底是否存在一直存在争论.这里所说的兴蒙造山带基底是指显生宙之前的基底.传统上认为这些微陆块中均存在前寒武纪地质体,如额尔古纳地块中的兴华渡口群、佳疙疸组,兴安地块上的风水沟河群,松嫩地块中的东风山群、兴东群、张广才岭群和一面坡群,佳木斯地块中的麻山群和马家街群以及兴凯地块中的Nakhimovka组、伊曼群等(吉林省地质矿产局,1988;内蒙古自治区地质矿产局,1991;黑龙江省地质矿产局,1993).自从20世纪90年代中期以来,锆石原位微区定年技术的广泛应用,对这些传统上认为的前寒武纪地质体进行了系统定年,结果表明,这些所谓的前寒武纪地质体,除少数形成于新元古代外,主体形成于古生代和早中生代(那福超等,2014; Luan *et al*., 2017b; Wang *et al*., 2017c),比如,额尔古纳地块中原定为古元古代的兴华渡口群,主体形成于古

生代，并有少量新元古代地质体（Miao *et al.*，2007；葛梦春等，2011；Zhou *et al.*，2011a；Wu *et al.*，2012；Ge *et al.*，2015；邵军等，2015）；兴安地块中原定为新元古代的风水沟河群，主体形成于晚古生代—早中生代（Xu *et al.*，2012）；松嫩地块中原定为古元古代的东风山群，除少量新元古代地质体外，主体形成于古生代（Wang *et al.*，2006，2014），而原定为新元古代的张广才岭群、黄松群、一面坡群主要形成于古生代—早中生代（Wang *et al.*，2012；郝文丽等，2014；郝文丽，2018）；佳木斯地块中原定为太古代的麻山群形成于古生代（Wilde *et al.*，2000；吴福元等，2001）；兴凯地块西缘原定为古元古代的麻山群，实际形成时代为早古生代（Zhou *et al.*，2010）。从上述研究结果可以看出，传统上认为的前寒武纪地质体主体均已解体，那么，兴蒙造山带这些微陆块中是否存在前寒武纪基底？

近年来，随着研究的深入，在不同的微陆块中均发现了新元古代侵入体，这些侵入体均显示片麻状构造，变形强烈，如额尔古纳地块中已经发现多期新元古代（时代为 737～927 Ma）花岗岩和少量的辉长岩（约 790 Ma）（Wu *et al.*，2011，2012；Zhou *et al.*，2011b；Gou *et al.*，2013；Tang *et al.*，2013；Zhao *et al.*，2016；赵硕等，2016a，2016b）；在兴安地块的北部已鉴别出新元古代侵入体（Zhou *et al.*，2011b）；在松嫩地块东部的小兴安岭—张广才岭也相继发现了形成于 726～929 Ma 的新元古代花岗质侵入体（权京玉等，2013；Wang *et al.*，2014；Luan *et al.*，2017a，2019）；在佳木斯地块上不仅发现了新元古代花岗质侵入体（Yang *et al.*，2017，2018），同时也鉴别出新元古代形成的沉积建造（Luan *et al.*，2017a）；在兴凯地块同样发现了年龄约为 750 Ma 的花岗质侵入体（Khanchuk *et al.*，2010）（图 2）。兴蒙造山带古生代沉积建造中碎屑锆石 U-Pb 定年结果，对这些新元古代地质体的存在也给予了很好的佐证，如佳木斯地块和松嫩地块东缘晚古生代早期沉积建造中发现有大量的新元古代碎屑锆石（Meng *et al.*，2010），在大兴安岭北段奥陶纪—泥盆纪沉积建造中碎屑锆石的定年结果同样证明了大量新元古代岩浆锆石的存在（Han *et al.*，2011，2017；王利民，2015；Yang *et al.*，2018）。

在上述沉积建造碎屑锆石 U-Pb 年代学研究中，除了古生代和新元古代碎屑锆石外，还存在一部分古元古代碎屑锆石（Meng *et al.*，2010；Han *et al.*，2011，2012；Wang *et al.*，2012，2014），这就给

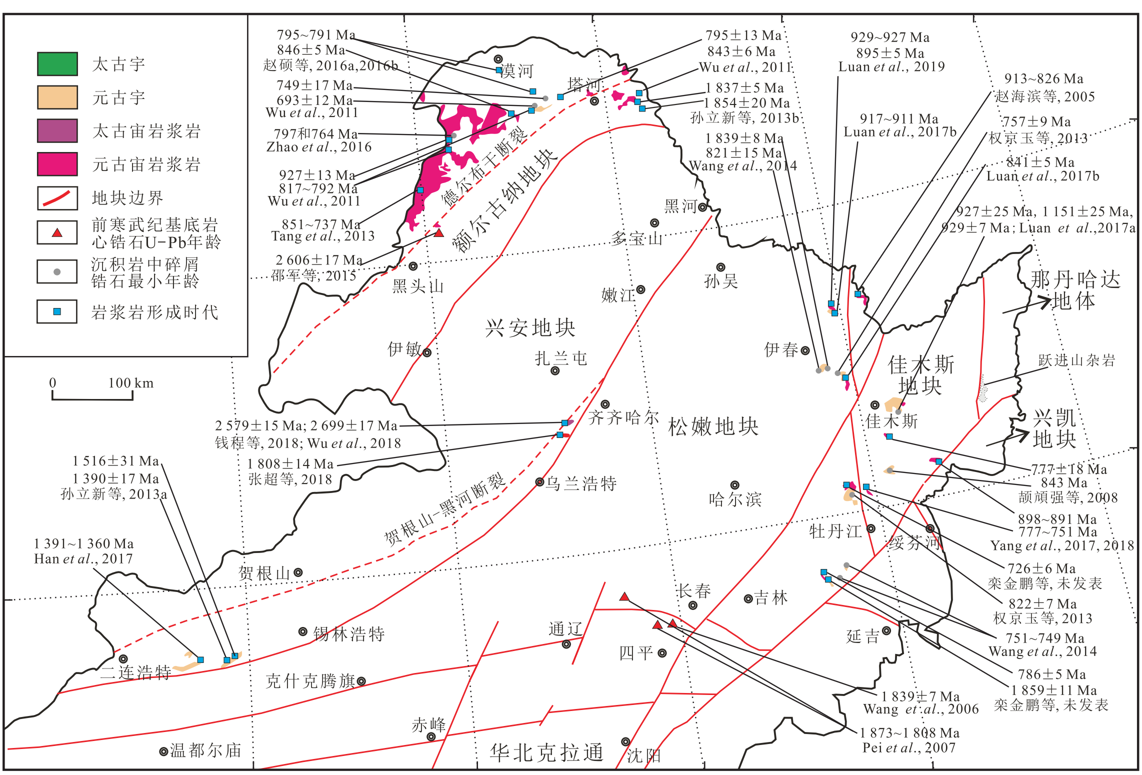

图 2　兴蒙造山带微陆块中前寒武纪地质体分布

Fig.2　Distribution map of Precambrian terranes within microcontinental massifs in the Xing'an-Mongolian Orogenic Belt

我们提出了这样一个问题,在兴蒙造山带这些微陆块中是否还存在古元古代地质体?古生代和新元古代花岗质岩石中锆石的Hf同位素模式年龄也暗示该区应存在古元古代甚至更为古老的陆壳物质(Tang *et al*., 2013; Wang *et al*., 2016, 2017c; Luan *et al*., 2017b; Yang *et al*., 2017).虽然Pei *et al*.(2007)报道了松辽盆地南部基底钻孔中存在1 873±13 Ma和1 808±21 Ma的变质岩,但由于该钻孔位置靠近华北克拉通,因此对其成因还存在争论,即它是代表松嫩地块的基底?还是来自南部华北克拉通的推覆体?由此还不能作为判定松嫩地块存在古元古代地质体的直接证据.然而,随着研究的深入,在不同的微陆块中相继发现了出露于地表的古元古代和新太古代地质体,如孙立新等(2013a, 2013b)报道了额尔古纳地块北段存在1 837±5 Ma和1 741±30 Ma的花岗质片麻岩,张超等(2018)报道了兴安地块东侧18亿年的花岗岩,钱程等(2018)同样在兴安地块东侧发现了2 579±15 Ma的花岗岩,本研究组在松嫩地块东缘的张广才岭南段也发现了18亿年的地质体(Luan *et al*., 2019),这些古元古代和新太古代地质体的发现,与古生代和新元古代沉积建造中古元古代和新太古代碎屑锆石的存在以及古生代和新元古代花岗岩中锆石的古元古代和新太古代Hf同位素模式年龄一起,表明兴蒙造山带这些微陆块中存在古元古代和新太古代基底.然而,由于新元古代－古生代－中生代岩浆作用的多期改造及其花岗岩形成过程中的多期再造,造成目前只有极少数保存在晚期的花岗岩中.兴蒙造山带微陆块中存在古元古代基底物质也得到了近年来岩石圈地幔研究的证实,如Zhang *et al*.(2011b)报道了兴安地块和松嫩地块新生代玄武岩中存在古元古代Re亏损模式年龄的地幔橄榄岩捕虏体,Wang *et al*.(2015b)和Guo *et al*.(2017a)分别报道了兴凯地块新生代玄武岩中存在古元古代Re亏损模式年龄的地幔橄榄岩捕虏体,这些结果都暗示在这些微陆块的岩石圈地幔中存在古老岩石圈地幔物质,并且地壳和岩石圈地幔在时代上是耦合的,它们共同揭示兴蒙造山带的这些微陆块曾经具有古老的陆壳和古老的岩石圈地幔物质,这些古老的地壳与岩石圈地幔物质已经被后期的新元古代、古生代和中生代构造岩浆作用所再造、改造或被新增生的地幔或地壳物质所置换(Guo *et al*., 2017a; Sun *et al*., 2017).

3　兴蒙造山带:地壳的增生与再造过程

中亚造山带是全球最大的增生型造山带之一,这一认识已经得到了共识(Şengör *et al*., 1993; Windley *et al*., 2007; Xiao *et al*., 2009),并且基于其中大量岛弧组合和蛇绿岩的存在以及花岗岩全岩Sm-Nd同位素资料得出,中亚造山带是地球上显生宙地壳增生的主要场所(Şengör *et al*., 1993; Jahn *et al*., 2000).上述研究主要集中在岛弧地体组合和其中的花岗质岩石的Sm-Nd同位素组成方面(Jahn *et al*., 2000; Wu *et al*., 2000; Hong *et al*., 2004).然而,中亚造山带,尤其是中亚造山带东段——兴蒙造山带,其中不仅有岛弧地体组合和陆缘增生杂岩带的存在,更为重要的是其主体由多个微陆块组成,仅用少量岛弧地体中花岗质岩石Sm-Nd同位素组成得到的认识并不能代表整个造山带的地壳增生历史,也就是说以往的认识过高地估算了中亚造山带显生宙的地壳增生量(Kröner *et al*., 2014, 2017; Sun *et al*., 2017).

近年来,对兴蒙造山带微陆块中不同时代花岗质岩石进行了广泛的锆石Hf同位素组成分析,以额尔古纳地块为例,该地块中发育古元古代、新元古代、古生代和中生代花岗质岩浆作用(图3),不同时代花岗岩中锆石Hf同位素的二阶段模式年龄统计结果表明,该微陆块中地壳增生发生的主要时期是

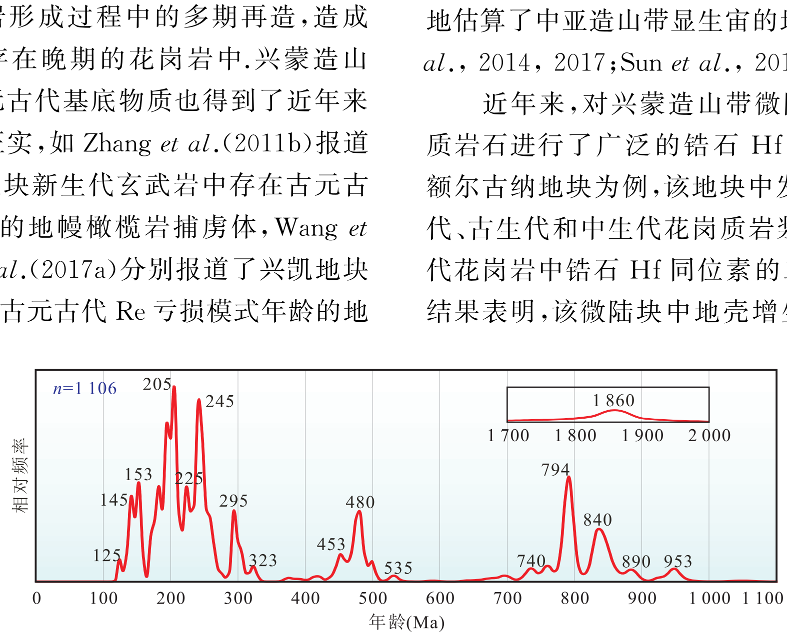

图3　额尔古纳地块中花岗质岩浆作用的期次

Fig.3　Probability plot of granitoid magmatic event ages within the Erguna massif

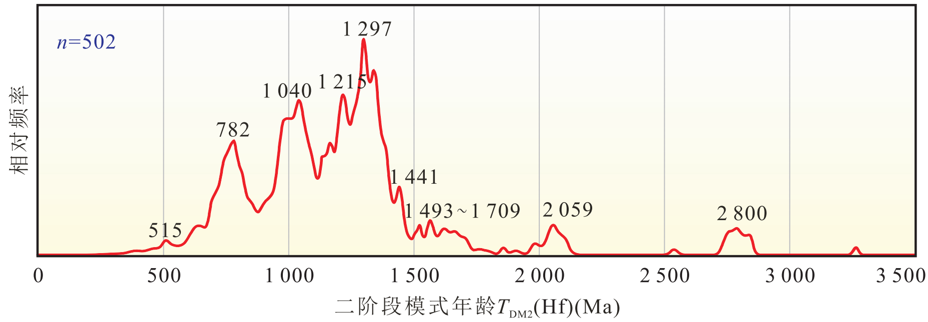

图 4　额尔古纳地块花岗岩锆石 Hf 同位素二阶段模式年龄频谱与地壳增生

Fig.4　Probability plot of zircon T_{DM2} (Hf) ages from granitoids and crustal accretion within the Erguna massif

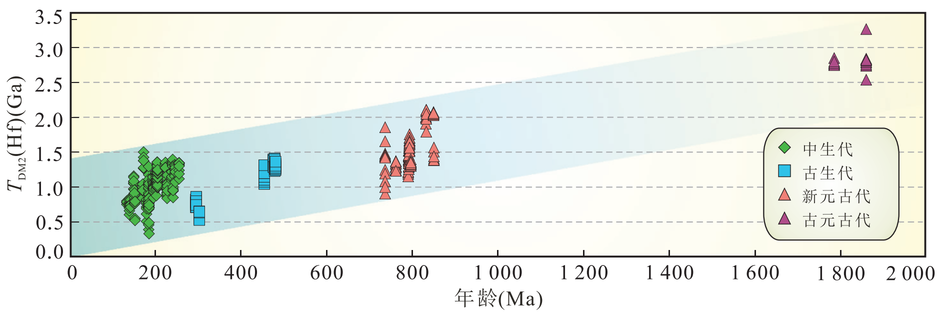

图 5　额尔古纳地块花岗岩年龄与锆石 Hf 同位素二阶段模式年龄变异图

Fig.5　Plot of zircon T_{DM2} (Hf) ages against granitoid ages within the Erguna massif

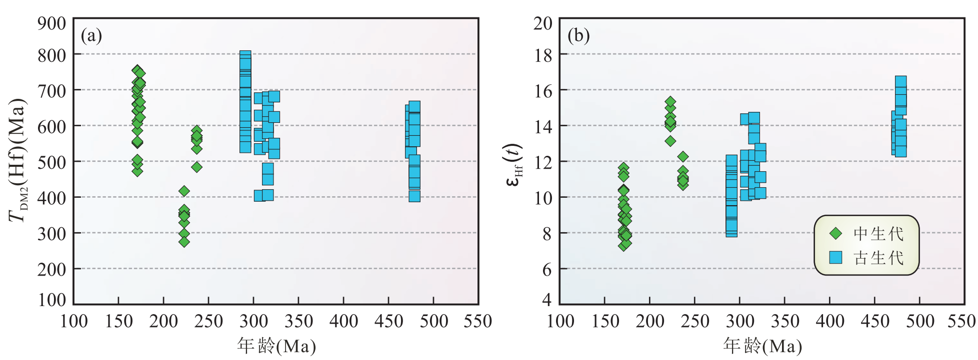

图 6　多宝山岛弧地体古生代—中生代花岗岩年龄与锆石 Hf 同位素组成变异图

Fig.6　Plots of zircon Hf compositions (T_{DM2} (Hf) ages and ε_{Hf} values) against the ages of Paleozoic-Mesozoic granitoids from Duobaoshan island arc terrane

中元古代和新元古代，新太古代次之，古生代更微弱（图 4）. 然而，花岗质岩浆作用时代与锆石 Hf 两阶段模式年龄图解表明，随着花岗岩形成时代变新，锆石 Hf 同位素模式年龄逐渐变年轻，这很好地揭示了不同时代花岗质岩石的形成是不同时代源岩再造的结果（Sun *et al.*, 2017）（图 5）. 对兴凯地块古生代—中生代花岗岩中锆石 Hf 同位素组成的研究结果同样给出了类似的认识：地壳增生主要发生在新元古代和中元古代，其次为古元古代，而不同时代花岗岩的形成同样显示出不同时代源岩分别再造的产物（Zhang *et al.*, 2018）.

在兴蒙造山带中，与微陆块相比，岛弧地体组合出露的面积很少，主要有多宝山古生代岛弧地体和华北克拉通北缘古生代陆缘增生杂岩带. 对多宝山岛弧地体中发育的古生代和中生代花岗岩锆石 Hf 同位素统计结果表明，这些花岗质岩石所揭示的地壳增生事件主要发生在新元古代和古生代，新元古代和古生代早期岛弧地体物质的再造为古生代和中生代花岗质岩浆的产生提供了物源（图 6）.

综上所述，可以看出兴蒙造山带的地壳增生可

以划分成2个构造阶段,即微陆块形成演化阶段的陆壳增生和古生代造山带形成演化阶段的陆壳增生,其中微陆块的地壳增生主要发生在新元古代和中元古代,新太古代和古元古代次之,显生宙地壳增生量很少,地壳的增生方式可能以垂向增生为主.相反,古生代造山带(或岛弧地体)的地壳增生主要发生在古生代和新元古代,地壳的增生方式以侧向增生为主.

4　微陆块间的拼合历史

4.1　额尔古纳地块与兴安地块的拼合

4.1.1　缝合线的位置　额尔古纳地块与兴安地块之间缝合线的位置一直是一个争论的问题.传统上将德尔布干断裂作为二者间的缝合线(黄汲清等,1977;黑龙江省地质矿产局,1993;任纪舜等,1999;Wu *et al.*,2003).然而,近年来的工作表明德尔布干断裂是一个晚中生代(115～130 Ma)形成的伸展断裂(郑常青等,2009).此外,德尔布干断裂作为一个地块间的缝合带也缺乏地球物理资料的支持(孙晓猛等,2011).因此,德尔布干断裂不可能作为陆块间的缝合带.相反,新林蛇绿岩的发现(李瑞山,1991)、塔河地区早古生代同碰撞型花岗岩的发现(Ge *et al.*,2005;Wu *et al.*,2011)和头道桥早古生代高压蓝片岩的发现(Zhou *et al.*,2015)均暗示新林—喜桂图—头道桥构造带应是额尔古纳地块与兴安地块之间的构造缝合线(图7).

4.1.2　块体的拼合时间　额尔古纳地块与兴安地块的拼合时间可以从蓝片岩的变质时间、缝合带中同碰撞岩浆作用发生的时间以及2个陆块上岩浆作用的时间与性质等方面得到回答.(1)对头道桥蓝片岩的锆石U-Pb年代学研究表明,蓝片岩相变质作用发生的时间为510～490 Ma(Miao *et al.*,2015;Zhou *et al.*,2015);(2)塔河地区同碰撞型花岗岩的形成时代为500 Ma(Ge *et al.*,2005);(3)额尔古纳地块与兴安地块均发育480 Ma和460 Ma的岩浆

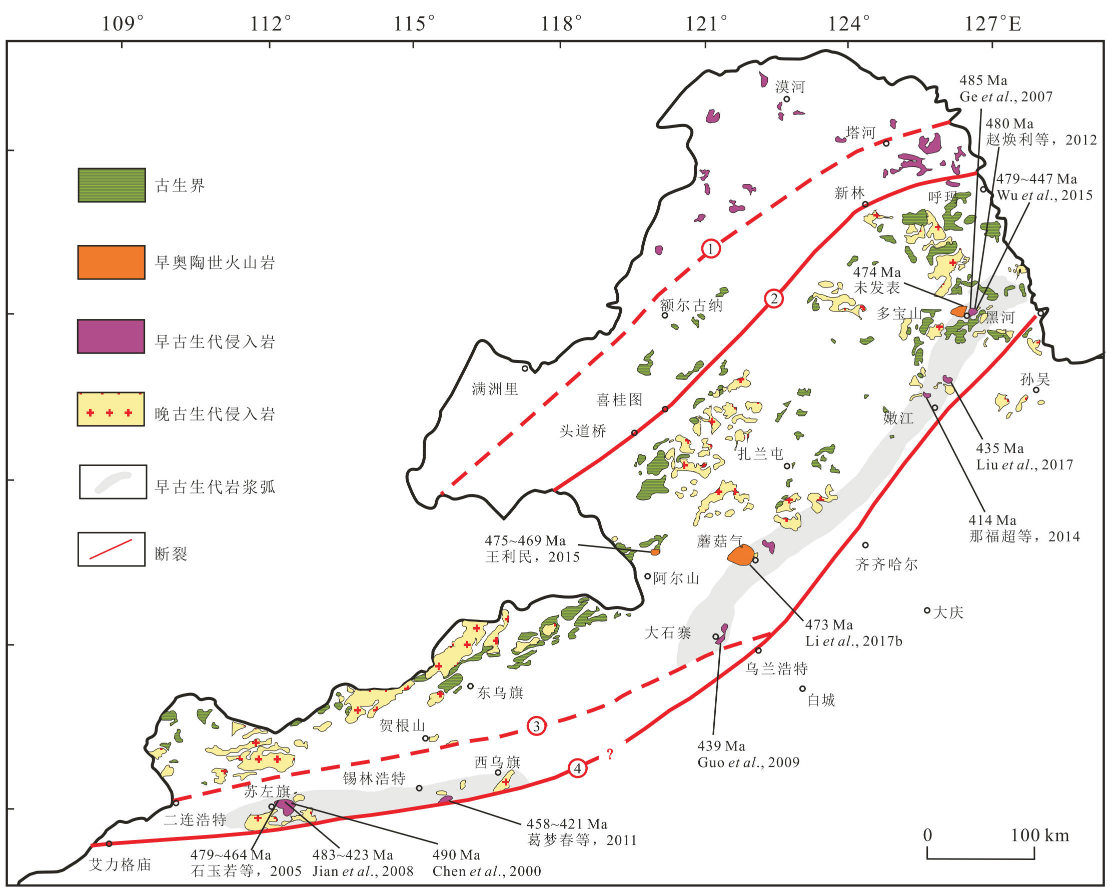

图7　额尔古纳地块、兴安地块和松嫩地块间的缝合线位置

Fig.7　Locations of the suture zones between the Erguna and Xing'an massifs as well as the Xing'an and Songnen massifs

据Li *et al.*,2017b;①德尔布干断裂;②喜桂图—塔源缝合带;③黑河—嫩江—贺根山断裂;④黑河—嫩江缝合带

作用，并且显示双峰式火成岩组合，暗示区域伸展环境的存在（Ge *et al*.，2005；Zhao *et al*.，2014）；(4)在额尔古纳地块北段兴华渡口群发生的麻粒岩相变质作用约发生在 500 Ma（Zhou *et al*.，2011a，2011b）.综合上述特征，我们可以得出额尔古纳地块与兴安地块的拼合时间应是早古生代早期.

4.2　兴安地块与松嫩地块的拼合

4.2.1　缝合线的位置　兴安地块与松嫩地块之间缝合线的位置一直存在争论，争论的焦点集中在缝合线从扎兰屯向南如何延伸.基于兴安地块北段早古生代多宝山岛弧的存在以及地块南侧贺根山蛇绿岩的发现，多数学者认为黑河－嫩江－贺根山构造带作为兴安地块与松嫩地块间的缝合线（图 7；Wu *et al*.，2011；Liu *et al*.，2017）.然而，徐备等（2014）和 Xu *et al*.(2015)根据晚古生代早期沉积建造组合和前寒武纪地质体的出露位置，将黑河－嫩江－乌兰浩特－锡林浩特南－艾力格庙构造带作为 2 个地块间的缝合线.Li *et al*.(2017a)根据兴安地块东缘和东南缘早古生代弧型火成岩的发现，这包括北部的多宝山弧型火成岩及其斑岩型铜－钼矿床（Li，2006；Ge *et al*.，2007；Zeng *et al*.，2014；Wu *et al*.，2015，2018）、扎兰屯南部蘑菇气地区早古生代钙碱性火山岩（Guo *et al*.，2009；Li *et al*.，2017b）和南部苏尼特左旗－锡林浩特地区早古生代弧型火成岩（Chen *et al*.，2000；石玉若等，2005；Jian *et al*.，2008），将 2 个地块间的缝合线确定在该早古生代火成岩带的东侧，即黑河－嫩江－乌兰浩特－锡林浩特南一线，该构造线也是重要的生物群界线，其北以分布图瓦贝（Tuvaella）动物群为特色，见于多宝山、额尔古纳西、伊尔施和东乌珠穆沁旗等地（内蒙古自治区地质矿产局，1991；徐备等，2014）.此外，结合对贺根山蛇绿岩的最新定年结果显示其形成时代应在 350 Ma 左右（Zhang *et al*.，2015），这表明贺根山洋盆打开的时间应是石炭纪早期，它是陆内裂开的一个洋盆.综上所述，本文认为黑河－嫩江－乌兰浩特－锡林浩特南一线应是兴安地块与松嫩地块之间的缝合线（图 7）.

4.2.2　块体的拼合时间　兴安地块与松嫩地块之间的拼合时间具有多种观点，包括晚志留世－泥盆纪（Şengör and Natal'in，1996）、晚泥盆世－早石炭世（邵济安，1991；Hong *et al*.，1995）、早石炭世晚期（赵芝等，2010）、二叠纪之前（Shi *et al*.，2004；Sun *et al*.，2001；童英等，2010）和三叠纪（Chen *et al*.，2000；Miao *et al*.，2004）.目前多数学者支持二者的拼合发生在晚古生代.Li *et al*.(2013)基于黑河－嫩江缝合带两侧晚石炭世早期“S 型”火成岩的发现，并结合小兴安岭西北侧从早石炭世海相沉积到晚石炭世陆相沉积的转变（黑龙江省地质矿产局，1993），认为兴安地块与松嫩地块之间的拼合发生在早石炭世晚期（约 320 Ma），这与研究区普遍缺失早石炭世晚期（Serpukhovian 期）－晚石炭世早期（Bashkirian and Moscovian 期）沉积是相吻合的（黑龙江省地质矿产局，1993；内蒙古自治区地质矿产局，1991）.

4.3　松嫩地块与佳木斯地块的拼合

4.3.1　缝合线的位置　牡丹江断裂，与沿该断裂分布的黑龙江杂岩（包括磨刀石、依兰和萝北 3 个出露区）一起，通常被认为是松嫩地块与佳木斯地块间的缝合线，这已经被绝大多数学者所认可（张兴洲，1992；黑龙江省地质矿产局，1993；李锦轶等，1999；赵焕利等，2012）.但是对其南延却有不同认识，多数学者将该缝合带南延到磨刀石蓝片岩出露地，而周建波等（2013）将该带向南与华北克拉通北缘吉中地区出露的红帘石片岩带相连（为长春－延吉缝合带的位置），并统称为吉黑高压变质带.周建波等（2013）认为吉黑高压变质带是由于松嫩地块与佳木斯地块的碰撞拼合以及佳木斯地块与华北克拉通的碰撞拼合所致，其碰撞拼合的时间为晚三叠世－早侏罗世.本文的认识是：由于华北克拉通北缘长春－延吉缝合带的变质时间（约 250 Ma；Wu *et al*.，2007b）明显早于黑龙江杂岩的构造就位时间（175～186 Ma；Wu *et al*.，2007a；Zhou *et al*.，2009；Aouizerat *et al*.，2018；Dong *et al*.，2018），同时结合华北克拉通北缘近东西向晚三叠世碱性火成岩和双峰式火成岩带的存在（Xu *et al*.，2013；Tang *et al*.，2018），可以判定华北克拉通北缘吉中－延吉的中高压变质带应是西拉木伦－长春－延吉缝合带的一部分，应与古亚洲洋的最终闭合有关（Liu *et al*.，2017），而与松嫩地块和佳木斯地块的拼合无关，沿嘉荫－牡丹江断裂分布的黑龙江杂岩应代表了该缝合线的位置.

4.3.2　块体的拼合时间　松嫩地块与佳木斯地块间的拼合时间一直是个争论的问题，目前主要有 2 种看法，一是认为 2 个陆块之间的拼合发生在早古生代晚期，这主要是基于松嫩地块东缘早古生代火成岩的研究（李锦轶等，1999；Wang *et al*.，2012）以及早期对黑龙江杂岩的研究（张兴洲，1992）；另一种观点认为 2 个陆块间的拼合发生在早侏罗世，这种

观点的提出主要是基于对黑龙江杂岩变形时代的研究得出的(Wu *et al*., 2007a; Zhou *et al*., 2009; Aouizerat *et al*., 2018; Dong *et al*., 2018).上述认识的差异主要是由于对黑龙江杂岩形成时代认识的不同(见4.3.3).许文良等(2012)基于对牡丹江断裂两侧岩浆事件的对比研究,结合佳木斯地块中三叠纪岩浆事件的缺乏以及区域二叠纪沉积建造组合属性,认为松嫩地块与佳木斯地块之间的块体拼合曾经发生过2次,早期拼合发生在早古生代末期(约425 Ma),晚期拼合发生在早侏罗世.由于后期构造作用的改造,早期拼合位置较难恢复,而两地块再次裂开的时间可以通过黑龙江杂岩中沉积建造形成的最早时间给出限定,约235～180 Ma沉积作用发生(见4.3.3).

4.3.3　牡丹江洋——中生代早期的一个短命洋

牡丹江洋的提出主要是基于2个陆块间出露的黑龙江杂岩,尤其是依兰地区黑龙江杂岩中MORB型玄武岩和纯橄岩/蛇纹岩的存在(Wu *et al*., 2007a; Zhou *et al*., 2009).然而,由于对黑龙江杂岩中构造块体形成时代的认识不一和牡丹江断裂两侧晚古生代弧型火成岩的存在,导致了牡丹江洋形成时代的2种不同认识,一种观点认为古生代期间,牡丹江洋一直存在,并且双向俯冲于松嫩地块和佳木斯地块之下(Dong *et al*., 2017, 2018),另一种观点认为牡丹江洋形成于早中生代,是在原来已经拼合的松嫩地块与佳木斯地块之上重新裂开的(许文良等,2012).最近,孙晨阳等(2018)系统总结了黑龙江杂岩中沉积单元碎屑锆石的构成,发现出露于磨刀石、依兰和萝北3处黑龙江杂岩中的沉积单元最年轻的碎屑锆石年龄为235～180 Ma,而黑龙江杂岩中白云母的Ar-Ar年龄和变辉长岩中金红石的U-Pb年龄为171～177 Ma(Aouizerat *et al*., 2018; Dong *et al*., 2018),这说明黑龙江杂岩中沉积岩的形成时代应为235～177 Ma,即牡丹江洋的形成时代应是中三叠世—早侏罗世,由此可以看出位于2个陆块间的牡丹江洋是一个早中生代的短命洋(图8).

4.4　兴凯地块与佳木斯地块和松嫩地块的关系

4.4.1　兴凯地块与佳木斯地块的关系　在中亚造山带东段,传统上将布列亚地块、佳木斯地块和兴凯地块作为一个整体称为布列亚—佳木斯—兴凯地块,并且认为它们具有类似的构造属性(Zhou *et al*., 2010; Sorokin *et al*., 2017).Zhou *et al*.(2010)对兴凯地块西北缘虎头地区出露的麻粒岩相变质岩研究表明,该区存在泛非期的变质作用,并以此认为兴凯地块与佳木斯地块具有类似的属性.然而,王枫等(2016)和Xu *et al*.(2018)对比了佳木斯地块和兴凯地块中发育的古生代和中生代岩浆作用,结果发现兴凯地块中普遍发育早古生代晚期和早中生代岩

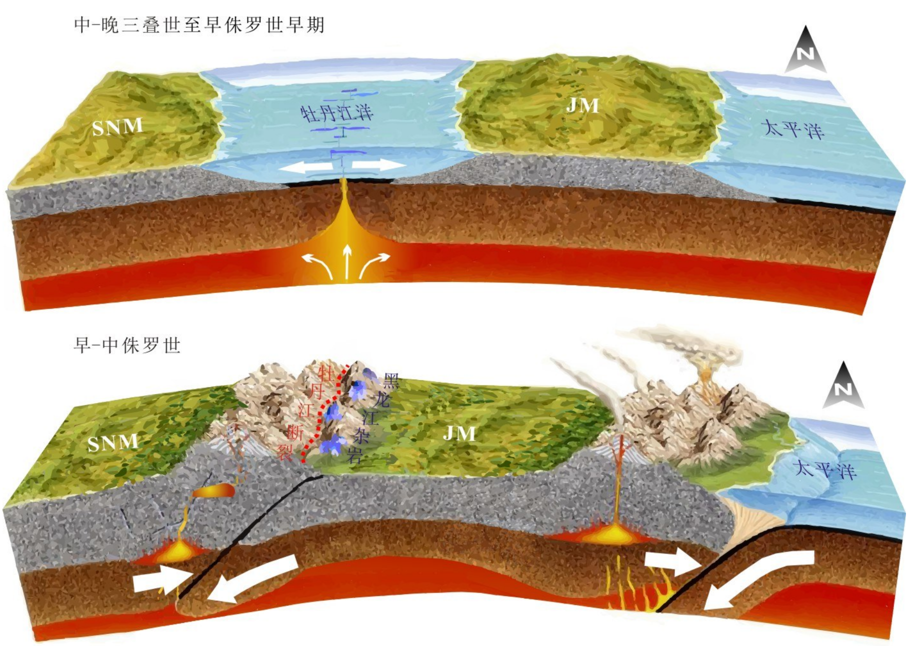

图8　牡丹江洋的形成与黑龙江杂岩构造就位模式

Fig.8　A model for the formation of the Mudanjiang Ocean and tectonic emplacement of the Heilongjiang complex

据孙晨阳等(2018);SNM.松嫩地块;JM.佳木斯地块

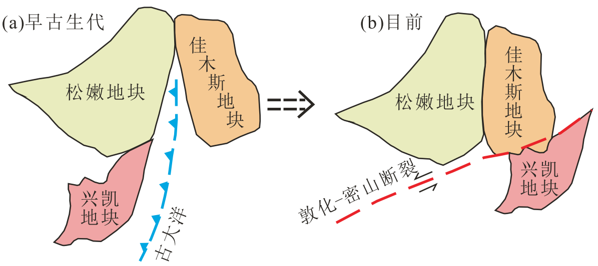

图 9　兴凯地块、松嫩地块和佳木斯地块构造关系

Fig.9　Tectonic relation map for the Khanka, Songnen and Jiamusi massifs

据 Xu *et al*.(2018)

浆事件，而佳木斯地块缺乏这些岩浆事件，为此判定 2 个陆块可能不具有类似的构造演化历史，并且认为兴凯地块西北缘虎头地区出露的麻粒岩相变质岩可能属于佳木斯地块上的麻山群在敦化—密山断裂左行平移过程中切割过去的佳木斯地块物质(图 9).上述认识也得到了 2 个陆块上具有不同的早古生代沉积建造组合的支持(吉林省地质矿产局，1988；邵济安和唐克东，1995).

4.4.2　兴凯地块与松嫩地块的关系　正如 4.4.1 节所说，兴凯地块与佳木斯地块至少在早古生代晚期和中生代早期不具有类似的岩浆作用历史.相反，古生代和中生代岩浆事件对比表明，松嫩地块与兴凯地块具有类似的岩浆作用历史，暗示二者具有相似的构造属性(图 9；王枫等，2016；Xu *et al*., 2018).上述认识也得到了 2 个陆块上均发育约 750 Ma 的岩浆事件的证实(Khanchuk *et al*., 2010；Wang *et al*., 2015b).王枫等(2016)系统总结对比了松嫩地块与兴凯地块古生代和早中生代岩浆作用，认为敦化—密山断裂至少发生过 2 次走滑事件，一次发生在中—晚二叠世—早三叠世，另一次发生在晚侏罗世—早白垩世早期，由于上述走滑事件的发生，造成了目前微陆块的分布(图 9b).

5　古亚洲洋最终闭合的时间与方式

古亚洲洋最终闭合的位置通常是指沿西拉木伦—长春—延吉缝合线发生的古亚洲洋闭合.对其闭合的时间一直存在争论，主要观点有：(1)基于东北地区泥盆纪稳定陆缘沉积建造的形成，认为古亚洲洋的最终闭合在早古生代晚期已经完成(徐备等，2014；Xu *et al*., 2015)；(2)根据二叠纪磨拉石沉积建造组合的形成或变质作用发生的时间，认为古亚洲洋的最终闭合发生在中—晚二叠世(吉林省地质矿产局，1988；Shi, 2006；Wu *et al*., 2007b；李锦轶等，2009)；(3)根据内蒙古东南部和辽北—吉中地区

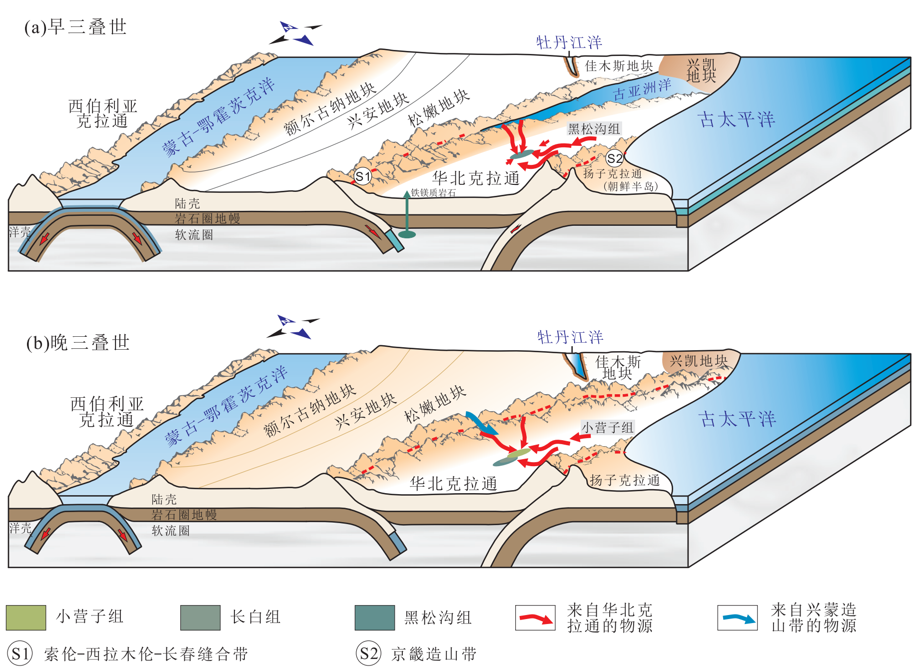

图 10　华北克拉通北缘早中生代地层物源变化与古亚洲洋最终闭合过程

Fig.10　Provenance variation of the Early Mesozoic strata in the northern margin of the North China craton and the final closure process of the Paleo-Asian Ocean

据 Wang *et al*.(2018)

碰撞型花岗岩的形成时间，认为古亚洲洋的最终闭合发生在晚二叠世－中三叠世(Cao *et al.*, 2013; Wang *et al.*, 2015d)或早－中三叠世(孙德有等，2004).上述争论之所以存在，追其根本原因就是不同学者研究对象的不同或研究地区的不同.根据沿西拉木伦－长春－延吉缝合线晚古生代晚期－早中生代同碰撞型花岗岩的研究表明，自西向东同碰撞型花岗岩形成时代具有逐渐变新的趋势(Wang *et al.*, 2015d)，二叠纪沉积建造的空间变化也反映了类似的特征——自西向东二叠纪海相地层具有逐渐变年轻的趋势(吉林省地质矿产局，1988)，这表明古亚洲洋最终闭合的时间具有自西向东逐渐变年轻的趋势，东部最终闭合的时间为中三叠世(Wang *et al.*, 2015d; Wang *et al.*, 2018).上述认识也得到了华北克拉通北缘早中生代地层和物源分析的支持——在华北克拉通北缘燕辽地区缺失早三叠世地层(Meng *et al.*, 待发表)，而在华北克拉通东北缘缺失中三叠世地层，同时早三叠世地层的物源均来自华北克拉通内部，而晚三叠世地层中已经存在来自中亚造山带的物源，这说明晚三叠世期间古亚洲洋已经最终闭合(Wang *et al.*, 2018).结合华北克拉通北缘早中生代地层的缺失及其物源变化和同碰撞花岗岩的空间变异，本文认为古亚洲洋最终闭合的时间发生在中三叠世，并且表现为自西向东逐渐闭合的剪刀式闭合方式(图10).

6　蒙古－鄂霍茨克构造体系的叠加与演化：大洋板块的南向俯冲与演化历史

蒙古－鄂霍茨克缝合带是蒙古－鄂霍茨克洋闭合后的产物，主要分布在东经96°～130°，北纬46°～58°的俄罗斯和蒙古境内，西起蒙古中部的杭爱山脉，东至鄂霍茨克海的乌达海湾，总体呈北东－南西走向，长约为3 000 km，宽约为300 km，北部为西伯利亚克拉通及其增生边缘，南部为中朝－蒙古板块及其以北的造山带与地块镶嵌构造区，东部为太平洋板块(黄始琪等，2014).它是东亚北部一条具有较长地质历史的造山带，并在东亚大陆形成演化的历史过程中占有极其重要的位置(李锦轶等，2009).蒙古－鄂霍茨克洋普遍被认为是古太平洋的巨型海湾(Zonenshain *et al.*, 1990; Gordienko, 1994; Tang *et al.*, 1995; Zorin, 1999; Parfenov *et al.*, 2001; Shi, 2006)，在晚古生代－早中生代期间分隔西伯利亚克拉通和中朝－蒙古板块.目前对蒙古－鄂霍茨克大洋形成的时间(Tomurtogoo *et al.*, 2005; Donskaya *et al.*, 2013)、俯冲演化历史(Şengör *et al.*, 1993; Zorin, 1999; Parfenov *et al.*, 2003; Bussien *et al.*, 2011; Donskaya *et al.*, 2013)以及大洋闭合的时间(Zonenshain *et al.*, 1990; Enkin *et al.*, 1992; Zorin, 1999; Parfenov *et al.*, 2001)还有诸多争论，但是该大洋板块北向俯冲于西伯利亚板块之下(Zorin, 1999)和自西向东剪刀式闭合方式(Kravchinsky *et al.*, 2002; Metelkin *et al.*, 2007)得到了绝大多数地质学家认可.蒙古－鄂霍茨克大洋板块是否存在南向俯冲作用？如果存在，它的演化历史及其影响的时空范围如何？这些问题至今没有得到很好的解决.鉴于此，本文基于近年来在我国境内火成岩和区域成矿作用的研究成果，主要讨论该构造体系对我国东北乃至华北的影响，这对于揭示区域成矿背景和指导找矿具有重要的现实意义.

6.1　蒙古－鄂霍茨克大洋板块南向俯冲作用的起始时间

以往的研究多数集中在蒙古－鄂霍茨克大洋板块北向俯冲作用过程，这主要是因为蒙古－鄂霍茨克缝合带的主体位于俄罗斯和蒙古境内.与之相比，对于蒙古－鄂霍茨克大洋板块南向俯冲过程的研究较少.Zorin(1999)认为蒙古－鄂霍茨克大洋板块在早石炭世向南俯冲于中朝－蒙古板块之下.然而，随着近年来对蒙古国地质研究程度的提高，刘翼飞等(2010)认为蒙古国阿林诺尔钼矿赋矿岩体的成岩成矿作用是蒙古－鄂霍茨克大洋板块于中三叠世(约229 Ma)向其南侧大陆俯冲构造体制下地壳伸展作用的产物；位于中蒙古地块的晚二叠世－三叠纪(260～235 Ma)Hangay岩基以I型含角闪石花岗闪长岩为主(Jahn *et al.*, 2004; Li *et al.*, 2013)，研究表明该岩基形成于安第斯型大陆边缘弧环境(Tomurtogoo *et al.*, 2005; Orolmaa *et al.*, 2008).而对于我国来说，额尔古纳地块与蒙古－鄂霍茨克缝合带相邻，位于缝合带的东南侧，前人认为该地块以元古宙和古生代岩浆事件为主，中生代岩浆作用微弱(内蒙古自治区地质矿产局，1991)，因而忽略了蒙古－鄂霍茨克缝合带对我国东北地区的影响.随着现代同位素测年技术的发展和精度的提高，在额尔古纳地块乃至整个东北地区鉴别出大量中生代岩浆事件(Wu *et al.*, 2011; Xu *et al.*, 2013; Tang *et al.*, 2014, 2015, 2016)，认识到蒙古－鄂霍茨克缝合带对我国东北地区存在重要影响，如太平川斑岩

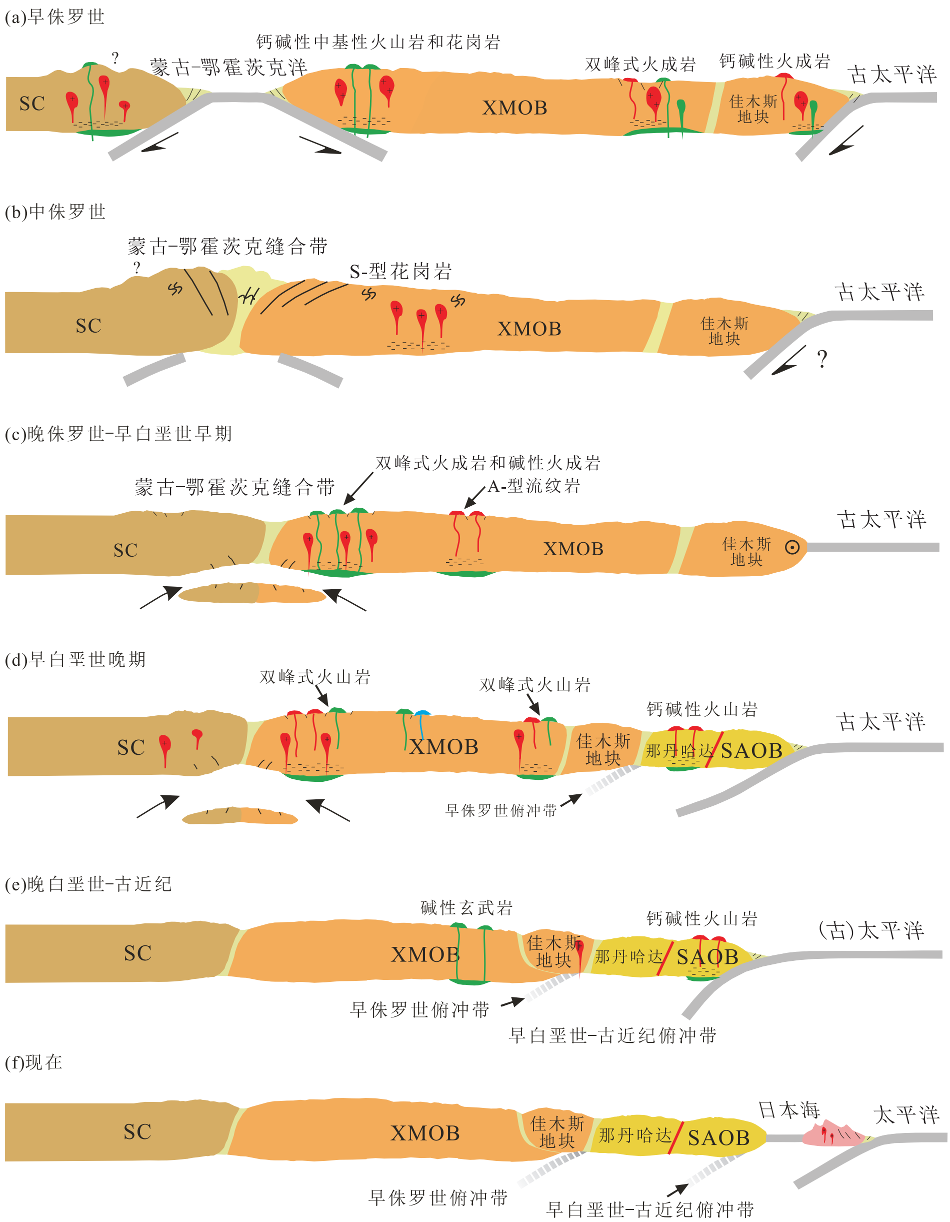

图 11　蒙古—鄂霍茨克构造体制与环太平洋构造体制早侏罗世—新生代演化模式

Fig.11　The evolutionary model for the Mongol-Okhotsk and circum-Pacific tectonic regimes during the Early Jurassic-Cenozoic

据 Tang *et al*.(2018)修改；SC.西伯利亚克拉通；XMOB.兴蒙造山带；SAOB.锡霍特—阿林造山带

型铜钼矿床被认为是形成于晚三叠世蒙古—鄂霍茨克洋向其南侧的额尔古纳地块俯冲形成的陆缘弧环境(陈志广等，2010)；大兴安岭地区早中生代花岗岩、火山岩形成于与蒙古—鄂霍茨克大洋板块俯冲有关的活动大陆边缘环境(Wu *et al*., 2011；佘宏全等，2012；王伟等，2012；Xu *et al*., 2013；Wang *et al*., 2015c；Tang *et al*., 2016)．上述研究已经表明，蒙古—鄂霍茨克大洋板块存在南向俯冲作用，根据对额尔古纳地块上晚古生代岩浆作用的研究，认为南向俯冲作用的起始时间在额尔古纳地块西北侧至少发生在晚二叠世(Li *et al*., 2017a)．

6.2　蒙古—鄂霍茨克大洋板块早中生代(T-J_1)持续南向俯冲

近年来，随着对我国东北地区中生代岩浆作用研究的深入，尤其是大量高精度锆石 U-Pb 年代学资料的获得，使传统上认为东北地区广泛存在的海西期岩浆作用(吉林省地质矿产局，1988；内蒙古自治区地质矿产局，1991；黑龙江省地质矿产局，1993)得以修正，东北地区所谓的海西期花岗岩主体形成于中生代(Wu *et al*., 2011)．中蒙古地块和额尔古

纳地块上大量早中生代(早三叠世—早侏罗世)钙碱性火成岩(尤其是早侏罗世钙碱性火山岩组合)和同期斑岩型矿床的发现以及它们呈南西—北东向的带状展布特征均揭示了蒙古—鄂霍茨克大洋板块南向俯冲作用的发生(图10和11a;Tang *et al*., 2014, 2016;Wang *et al*., 2015c);兴安地块东缘早中生代钙碱性火山岩的发现进一步揭示蒙古—鄂霍茨克大洋板块南向俯冲作用影响的空间范围至少到达松辽盆地以西地区(Li *et al*., 2017c).

6.3　蒙古—鄂霍茨克大洋闭合的时间:中侏罗世

对于蒙古—鄂霍茨克洋的剪刀式闭合方式几乎得到了绝大多数学者的认可.但是,就其最终闭合的时间还存在较多争论,Zorin(1999)和Parfenov *et al*.(2001)认为该洋是在早—中侏罗世闭合;根据古地磁数据,Kravchinsky *et al*.(2002)和Cogné *et al*.(2005)认为蒙古—鄂霍茨克洋主要是在侏罗纪期间闭合,东部的闭合时间可持续到晚侏罗世—早白垩世;Zonenshain *et al*.(1990)和Şengör and Natal'in(1996)认为蒙古—鄂霍茨克洋西部于三叠纪闭合,东部于晚侏罗世闭合;而Enkin *et al*.(1992)和Scotese(2001)通过解析古地磁数据,认为蒙古—鄂霍茨克洋在晚侏罗世并没有闭合,而是于早白垩世闭合.Guo *et al*.(2017b)对我国境内漠河盆地和俄罗斯境内上阿莫尔盆地沉积相的时空变异研究,认为蒙古—鄂霍茨克洋的最终闭合应发生在晚侏罗世最晚期—早白垩世早期.本研究组在大兴安岭北段发现了具有S型花岗岩地球化学属性的中侏罗世(约168 Ma)白云母二长花岗岩,该区同期花岗岩具有类似的地球化学属性,暗示该期花岗岩形成于陆壳加厚背景(赵海滨等,2005;李宇等,2015).结合燕辽地区海房沟组之下广泛发育的一个区域不整合(即燕山运动A幕)以及自北向南的构造推覆作用(张岳桥等,2007;Zhang *et al*., 2011a),本文认为蒙古—鄂霍茨克大洋闭合发生在中侏罗世(图11b).上述认识也得到了俄罗斯学者对蒙古—鄂霍茨克带研究结果的支持,即中侏罗世地层以区域不整合的形式覆盖在之前的地层之上,这一地质现象在该带东西两端均是如此,并且他认为自中侏罗世之后,该带不存在洋盆,但存在海盆.因此,沿该带仍存在晚侏罗世—早白垩世的海相沉积(Sorokin, 未发表).

6.4　蒙古—鄂霍茨克大洋闭合后晚中生代的演化历史——区域伸展

进入到晚侏罗世—早白垩世早期阶段,在大兴安岭和冀北—辽西地区广泛产出碱性—亚碱性过渡性质的火山岩和碱性流纹岩,前者以大兴安岭北部的塔木兰沟组为代表(约162 Ma;孟恩等,2011),南部以满克头鄂博组为代表(王建国等,2013),在冀北—辽西地区则以髫髻山组和蓝旗组为代表(165～157 Ma;赵越等,2004;胡健民等,2007);后者以大兴安岭北部的吉祥峰组(约142 Ma)和南部的玛尼吐组(约142 Ma)碱性流纹岩(王建国等,2013)以及冀北—辽西地区的张家口组为代表(约135 Ma;张宏等,2005).这2套(晚侏罗世和早白垩世早期)火山岩主要发育在断陷盆地中,结合其碱性火山岩组合,它们共同揭示了区域伸展环境的存在,并分别与燕山运动A幕和B幕之后的伸展环境相对应.与这2期岩浆事件密切相关的成矿作用主要表现为浅成低温热液成矿(135～155 Ma; Ouyang *et al*., 2013).此外,这2期岩浆事件形成的时间具有自北向南逐渐变新的趋势(Zhang *et al*., 2008, 2010),暗示这2期岩浆事件的形成应与蒙古—鄂霍茨克构造体系的演化有关,我国松辽盆地以东地区以及韩国、日本均缺失这些岩浆事件进一步证实它们的形成与蒙古—鄂霍茨克构造体系演化有关,而与环太平洋体系无关(图11c;Xu *et al*., 2013;Tang *et al*., 2018).

7　环太平洋构造体系的叠加与演化:中生代俯冲起始时间与中—新生代俯冲演化历史

7.1　古太平洋板块中生代在欧亚大陆下俯冲的起始时间:早侏罗世

古太平洋板块在欧亚大陆下俯冲的起始时间一直存在争论,包括二叠纪(Li and Li, 2007;Sun *et al*., 2015;Yang *et al*., 2015)、三叠纪(Zhou *et al*., 2014)、早侏罗世(Wu *et al*., 2007a;Xu *et al*., 2009, 2013)和白垩纪(Chen *et al*., 2008)不同观点.由于二叠纪期间在我国东北仍然存在古亚洲洋板块的俯冲作用(如华北克拉通北缘东段;Guo *et al*., 2016;Wang *et al*., 2018),如何鉴别二叠纪期间古大洋板块的性质,它是古亚洲洋还是古太平洋目前并没有得到解决.因此,本文在讨论古太平洋板块在欧亚大陆下俯冲起始时间时,只涉及中生代.

东北亚陆缘三叠纪火成岩主要分布在华北克拉通北缘和苏鲁—朝鲜京畿造山带的北西侧,前者主要由碱性火成岩和双峰式火成岩构成,并呈近东西向带状展布,反映其形成应与古亚洲洋最终闭合后

的伸展环境相对应（Xu *et al*.，2013；Tang *et al*.，2018），后者主要由碱性岩（如石岛岩体；Yang *et al*.，2007）和双峰式火成岩（如蚂蚁河岩体；裴福萍等，2008）构成，并呈平行于苏鲁造山带的北东－南西向带状展布，其形成应与苏鲁造山带快速折返过程相对应.此外，在我国吉黑东部和俄罗斯远东地区，晚三叠世地层是一套被动陆缘沉积建造组合（Zhang *et al*.，2014），它们与晚三叠世的 A 型流纹岩（Xu *et al*.，2009）和双峰式侵入岩（Wang *et al*.，2015a）一起共同揭示了三叠纪期间东北亚陆缘是一个被动陆缘的构造属性.相反，进入到早侏罗世，佳木斯地块东缘早侏罗世钙碱性火山岩的发现（Wang *et al*.，2017b）以及早侏罗世火成岩自陆缘向陆内火成岩成分的极性变化（Yu *et al*.，2012；Guo *et al*.，2016；Wang *et al*.，2017a），很好地揭示了古太平洋板块俯冲作用的开始（图 11a），这也得到了东北亚陆缘早侏罗世增生杂岩（如日本的美浓地体、我国黑龙江杂岩）的支持（Xu *et al*.，2013；Tang *et al*.，2018）.基于韩国南部大量早－中侏罗世火成岩的存在和我国黑龙江杂岩中最新金红石 U-Pb 和云母 Ar-Ar 定年结果（172～175 Ma；Dong *et al*.，2017；Aouizerat *et al*.，2018），可以判定古太平洋板块在欧亚大陆下的俯冲作用可能持续到中侏罗世（Tang *et al*.，2018）.

7.2　晚侏罗世－早白垩世早期：东北亚陆缘走滑的构造属性与古太平洋板块斜向俯冲

晚侏罗世－早白垩世早期东北亚陆缘的构造属性一直存在争论.传统上认为古太平洋板块俯冲仍然控制了东北亚陆缘的构造演化，该区仍处于活动陆缘的构造属性（Maruyama *et al*.，1997；Seton *et al*.，2012；Zhu *et al*.，2017）.然而，近年来对东北亚中生代岩浆作用的研究结果表明，除少数增生地体（如饶河杂岩）外，中国东北的东部（松辽盆地以东地区）、俄罗斯远东、日本和韩国普遍缺失 160～135 Ma的岩浆作用（Xu *et al*.，2013），这似乎与板块俯冲的活动陆缘背景相矛盾.此外，从陆缘增生地体的生物学证据和碎屑锆石物源分析结果均显示，目前位于东北亚陆缘的这些增生地体其原始位置是位于低纬度地区（邵济安和唐克东，1995；Zhou *et al*.，2015），日本美浓地体到达海沟的时间约是 190 Ma，地体最终构造就位时间约是 175 Ma（Isozaki，1997），这与早－中侏罗世古太平洋板块的俯冲作用相吻合.那么，这些陆缘增生杂岩是何时从低纬度走滑到高纬度地区的？由于后期构造的叠加改造，目前很难鉴别地体从低纬度到高纬度的走滑构造，然而分布在陆缘的郯庐断裂带是我国东部重要的走滑断裂带，近年来，对该断裂带北部的研究表明，约 160 Ma 是该断裂带重要的走滑时期（孙晓猛等，2016；Zhu *et al*.，2018），除此之外，断裂带南部和北部还存在约 139 Ma 的走滑事件（Zhang *et al*.，2018）.上述走滑事件的定年结果与日本中生代地体所发生的变质作用时间（160 Ma 和 140 Ma；Isozaki，1997）是相吻合的.结合饶河增生杂岩的最终构造就位时间（137～130 Ma；Zhou *et al*.，2014），可以判定东北亚陆缘地体从低纬度到高纬度的走滑事件发生在 160～140 Ma.这与东北亚陆缘普遍缺乏晚侏罗世－早白垩世早期岩浆事件相一致.综上所述，可以得出在晚侏罗世－早白垩世期间，东北亚陆缘与古太平洋板块之间处于一种走滑的构造属性，并与古太平洋板块以小角度斜向俯冲作用相联系（图 11c）.

7.3　早白垩世晚期－古近纪：古太平洋板块俯冲－后撤过程

进入到早白垩世晚期（约 130 Ma），东亚陆缘早白垩世晚期（130～110 Ma）岩浆作用广泛分布，在陆缘区形成一套钙碱性火山岩组合（如华北克拉通东北部分布的二股砬子组和果松组以及佳木斯地块东部产出的皮克山组），陆内为双峰式火成岩组合（如松辽盆地中的营城子组和大兴安岭分布的上库力组和伊列克得组），火成岩组合的空间变异揭示了古太平洋板块在欧亚大陆下俯冲作用的发生（图 11d）（Xu *et al*.，2013；Tang *et al*.，2018），这也得到了俄罗斯远东哈巴杂岩和黑龙江省东部饶河增生杂岩早白垩世构造就位的支持（Zyabrev and Matsuoka，1999；Zhou *et al*.，2014；Wang *et al*.，2017b）.与早白垩世晚期相比，早白垩世最晚期（110～100 Ma）－晚白垩世岩浆作用的空间分布范围逐渐向东收缩，此时陆缘主要由一套钙碱性火成岩组合构成（如延边地区分布的部分屯田营组火山岩；Xu *et al*.，2013），而陆内主要为一套碱性玄武岩（如阜新碱锅玄武岩、辽南曲家屯玄武岩和胶东大西庄玄武岩；Xu *et al*.，2013）.进入到古近纪，东北亚陆缘岩浆作用范围进一步向东收缩，该期岩浆作用主要分布在中国东北的最东部（如三江盆地和珲春地区；王智慧等，2016）、俄罗斯远东的东锡霍特－阿林和萨哈林岛（44～40 Ma；Liao *et al*.，2018）.从早白垩世晚期到晚白垩世－古近纪，东北亚陆缘岩浆作用的空间范围逐渐向东收缩（图 12；孙明道，2016），这揭示了大洋板片俯冲角度逐渐变陡，即板

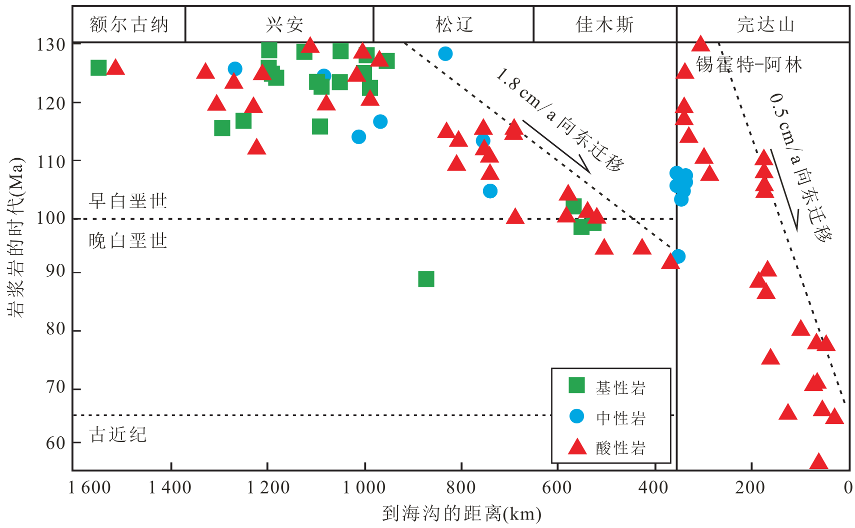

图 12　中国东北及俄罗斯滨海边疆区白垩纪—古近纪岩浆活动时空变异

Fig.12　Spatial-temporal variations of the Cretaceous-Paleocene magmatisms in NE China and Russian Far East

据孙明道(2016)

片逐渐后撤(roll-back)的过程(图 11e).

7.4　日本海打开标志着从活动陆缘到沟—弧—盆体系的开始

虽然目前对日本海形成的时间还存在争论(最大的时间跨度达到侏罗纪—新第三纪;Fukuma *et al*., 1998;Baba *et al*., 2007),但多数学者认为日本海的扩张开始于 20 Ma 之前(Lallemand and Jolivet, 1986; Tamaki, 1995).海沟后撤已成为日本海形成的主要构造模式(Seno and Maruyama, 1984).日本海的打开,标志着东北亚陆缘已经从早白垩世—古近纪的活动大陆边缘环境转变成沟—弧—盆体系.同时,俯冲带的快速后撤,导致俯冲板片在地幔过渡带的滞留,进而标志着东亚大地幔楔的形成(图 11f).

8　结论

(1)兴蒙造山带主要由微陆块和其间的造山带组成,微陆块中存在前寒武纪结晶基底,并具有壳幔耦合特征.这些前寒武纪地质体已经被后期构造—岩浆热事件多期改造与再造.

(2)兴蒙造山带微陆块中的陆壳增生主要发生在中元古代和新元古代以及次要的新太古代和古生代,且以垂向增生为主;而陆块间的造山带或岛弧地体陆壳增生发生在新元古代和古生代,且以横向增生为主.

(3)兴蒙造山带中微陆块间的拼合主要发生在古生代,古亚洲洋的最终闭合时间为中三叠世,且为剪刀式闭合过程.

(4)蒙古—鄂霍茨克构造体系对我国境内的影响至少始于晚二叠世,南向俯冲作用发生于晚二叠世—早侏罗世,大洋闭合于中侏罗世,晚侏罗世—白垩纪主要表现为造山后的伸展环境.该构造体系影响的空间范围主要在松辽盆地以西和华北克拉通北缘地区.

(5)古太平洋板块中生代期间在欧亚大陆下俯冲起始的时间为早—中侏罗世,晚侏罗世—早白垩世早期东北亚陆缘处于走滑的构造属性,早白垩世晚期—古近纪岩浆作用的向东收缩揭示俯冲板片的后撤过程,日本海的打开标志着东北亚陆缘已经从活动陆缘转换成沟—弧—盆体系,并且标志着东亚大地幔楔的形成.

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References

Aouizerat, A., Xiao, W. J., Schulmann, K., et al., 2018. Structures, Strain Analyses, and ^{40}Ar/^{39}Ar Ages of Blueschist-Bearing Heilongjiang Complex (NE China): Implications for the Mesozoic Tectonic Evolution of NE China. *Geological Journal*, 160(5): 1—30. https://doi.org/10.1002/gj.3323

Baba, A. K., Matsuda, T., Itaya, T., et al., 2007. New Age Constraints on Counter-Clockwise Rotation of NE Japan. *Geophysical Journal International*, 171(3): 1325－1341. https://doi.org/10.1111/j.1365-246x.2007.03513.x

Bi,J.H.,Ge,W.C.,Yang,H.,et al.,2016.Geochronology and Geochemistry of Late Carboniferous-Middle Permian I- and A-Type Granites and Gabbro-Diorites in the Eastern Jiamusi Massif,NE China:Implications for Petrogenesis and Tectonic Setting. *Lithos*, 266－267: 213－232.https://doi.org/10.1016/j.lithos.2016.10.001

Bi,J.H.,Ge,W.C.,Yang,H.,et al.,2017.Geochemistry of MORB and OIB in the Yuejinshan Complex,NE China: Implications for Petrogenesis and Tectonic Setting. *Journal of Asian Earth Sciences*, 145: 475－493. https://doi.org/10.1016/j.jseaes.2017.06.025

Bussien,D.,Gombojav,N.,Winkler,W.,et al.,2011.The Mongol-Okhotsk Belt in Mongolia—An Appraisal of the Geodynamic Development by the Study of Sandstone Provenance and Detrital Zircons. *Tectonophysics*, 510(1－2):132－150.https://doi.org/10.1016/j.tecto.2011.06.024

Cao,H.H.,Xu,W.L.,Pei,F.P.,et al.,2013.Zircon U-Pb Geochronology and Petrogenesis of the Late Paleozoic-Early Mesozoic Intrusive Rocks in the Eastern Segment of the Northern Margin of the North China Block. *Lithos*,170－171:191－207.https://doi.org/10.1016/j.lithos.2013.03.006

Chen,B.,Arakawa,Y.,2005.Elemental and Nd-Sr Isotopic Geochemistry of Granitoids from the West Junggar Foldbelt (NW China),with Implications for Phanerozoic Continental Growth. *Geochimica et Cosmochimica Acta*,69(5):1307－1320.https://doi.org/10.1016/j.gca.2004.09.019

Chen,B.,Jahn,B.M.,Wilde,S.,et al.,2000.Two Contrasting Paleozoic Magmatic Belts in Northern Inner Mongolia, China:Petrogenesis and Tectonic Implications. *Tectonophysics*,328(1－2):157－182.https://doi.org/10.1016/s0040-1951(00)00182-7

Chen,C.H.,Lee,C.Y.,Shinjo,R.,2008.Was There Jurassic Paleo-Pacific Subduction in South China?:Constraints from $^{40}Ar/^{39}Ar$ Dating,Elemental and Sr-Nd-Pb Isotopic Geochemistry of the Mesozoic Basalts. *Lithos*,106(1－2):83－92.https://doi.org/10.1016/j.lithos.2008.06.009

Chen,Z.G.,Zhang,L.C.,Lu,B.Z.,et al.,2010.Geochronology and Geochemistry of the Taipingchuan Copper-Molybdenum Deposit in Inner Mongolia,and Its Geological Significances. *Acta Petrologica Sinica*,26(5):1437－1449 (in Chinese with English abstract).

Cogné,J.P.,Kravchinsky,V.A.,Halim,N.,et al.,2005.Late Jurassic-Early Cretaceous Closure of the Mongol-Okhotsk Ocean Demonstrated by New Mesozoic Palaeomagnetic Results from the Trans-Baïkal Area (SE Siberia). *Geophysical Journal International*,163(2):813－832.https://doi.org/10.1111/j.1365-246x.2005.02782.x

Dong,Y.,Ge,W.C.,Yang,H.,et al.,2017.Geochemistry and Geochronology of the Late Permian Mafic Intrusions along the Boundary Area of Jiamusi and Songnen-Zhangguangcai Range Massifs and Adjacent Regions, Northeastern China:Petrogenesis and Implications for the Tectonic Evolution of the Mudanjiang Ocean. *Tectonophysics*,694:356－367.https://doi.org/10.1016/j.tecto.2016.11.017

Dong,Y.,Ge,W.C.,Yang,H.,et al.,2018.Convergence History of the Jiamusi and Songnen-Zhangguangcai Range Massifs:Insights from Detrital Zircon U-Pb Geochronology of the Yilan Heilongjiang Complex,NE China. *Gondwana Research*,56:51－68.https://doi.org/10.1016/j.gr.2017.12.008

Donskaya,T.V.,Gladkochub,D.P.,Mazukabzov,A.M.,et al.,2013.Late Paleozoic-Mesozoic Subduction-Related Magmatism at the Southern Margin of the Siberian Continent and the 150 Million-Year History of the Mongol-Okhotsk Ocean. *Journal of Asian Earth Sciences*,62:79－97.https://doi.org/10.1016/j.jseaes.2012.07.023

Enkin,R.J.,Yang,Z.Y.,Chen,Y.,et al.,1992.Paleomagnetic Constraints on the Geodynamic History of the Major Blocks of China from the Permian to the Present. *Journal of Geophysical Research (Solid Earth)*,97(B10):13953－13989.https://doi.org/10.1029/92jb00648

Fukuma,K.,Shinjoe,H.,Hamano,Y.,1998.Origin of the Absence of Magnetic Lineations in the Yamato Basin of the Japan Sea:Magnetic Properties of Mafic Rocks from Ocean Drilling Program Hole 794D. *Journal of Geophysical Research (Solid Earth)*,103(B8):17791－17805.https://doi.org/10.1029/98jb01486

Ge,M.C.,Zhou,W.X.,Yu,Y.,et al.,2011.Dissolution and Supracrustal Rocks Dating of Xilin Gol Complex,Inner Mongolia,China. *Earth Science Frontiers*,18(5):182－195 (in Chinese with English abstract).

Ge,W.C.,Chen,J.S.,Yang,H.,et al.,2015.Tectonic Implications of New Zircon U-Pb Ages for the Xinghuadukou Complex, Erguna Massif,Northern Great Xing'an Range,NE China. *Journal of Asian Earth Sciences*,106:169－185.https://doi.org/10.1016/j.jseaes.2015.03.011

Ge,W.C.,Wu,F.Y.,Zhou,C.Y.,et al.,2005.Emplacement Age of the Tahe Granite and Its Constraints on the Tectonic Nature of the Ergun Block in the Northern Part of the Da Hinggan Range. *Chinese Science Bulletin*, 50 (18): 2097−2105. https://doi.org/10.1007/bf03322807

Ge, W. C., Wu, F. Y., Zhou, C. Y., et al., 2007. Porphyry Cu-Mo Deposits in the Eastern Xing'an-Mongolian Orogenic Belt: Mineralization Ages and Their Geodynamic Implications. *Chinese Science Bulletin*, 52 (24): 3416−3427. https://doi.org/10.1007/s11434-007-0466-8

Gordienko, I. V., 1994. Paleozoic Geodynamic Evolution of the Mongol-Okhotsk Fold Belt. *Journal of Southeast Asian Earth Sciences*, 9 (4): 429−433. https://doi.org/10.1016/0743-9547(94)90054-x

Gou, J., Sun, D. Y., Ren, Y. S., et al., 2013. Petrogenesis and Geodynamic Setting of Neoproterozoic and Late Paleozoic Magmatism in the Manzhouli-Erguna Area of Inner Mongolia, China: Geochronological, Geochemical and Hf Isotopic Evidence. *Journal of Asian Earth Sciences*, 67−68: 114−137. https://doi.org/10.1016/j.jseaes.2013.02.016

Guo, F., Fan, W. M., Li, C. W., et al., 2009. Early Paleozoic Subduction of the Paleo-Asian Ocean: Geochronological and Geochemical Evidence from the Dashizhai Basalts, Inner Mongolia. *Science in China* (*Series D*: *Earth Sciences*), 52 (7): 940−951. https://doi.org/10.1007/s11430-009-0083-2

Guo, P., Xu, W. L., Wang, C. G., et al., 2017a. Age and Evolution of the Lithospheric Mantle beneath the Khanka Massif: Geochemical and Re-Os Isotopic Evidence from Sviyagino Mantle Xenoliths. *Lithos*, 282−283: 326−338. https://doi.org/10.1016/j.lithos.2017.03.015

Guo, Z. X., Yang, Y. T., Zyabrev, S., et al., 2017b. Tectonostratigraphic Evolution of the Mohe-Upper Amur Basin Reflects the Final Closure of the Mongol-Okhotsk Ocean in the Latest Jurassic-Earliest Cretaceous. *Journal of Asian Earth Sciences*, 145: 494−511. https://doi.org/10.1016/j.jseaes.2017.06.020

Guo, P., Xu, W. L., Yu, J. J., et al., 2016. Geochronology and Geochemistry of Late Triassic Bimodal Igneous Rocks at the Eastern Margin of the Songnen-Zhangguangcai Range Massif, Northeast China: Petrogenesis and Tectonic Implications. *International Geology Review*, 58 (2): 196−215. https://doi.org/10.1080/00206814.2015.1059295

Han, G. Q., Liu, Y. J., Neubauer, F., et al., 2011. Origin of Terranes in the Eastern Central Asian Orogenic Belt, NE China: U-Pb Ages of Detrital Zircons from Ordovician-Devonian Sandstones, North Da Xing'an Mts.. *Tectonophysics*, 511 (3−4): 109−124. https://doi.org/10.1016/j.tecto.2011.09.002

Han, G. Q., Liu, Y. J., Neubauer, F., et al., 2012. Provenance Analysis of Permian Sandstones in the Central and Southern Da Xing'an Mountains, China: Constraints on the Evolution of the Eastern Segment of the Central Asian Orogenic Belt. *Tectonophysics*, 580: 100−113. https://doi.org/10.1016/j.tecto.2012.08.041

Han, J., Zhou, J. B., Li, L., et al., 2017. Mesoproterozoic (~1.4 Ga) A-Type Gneissic Granites in the Xilinhot Terrane, NE China: First Evidence for the Break-up of Columbia in the Eastern CAOB. *Precambrian Research*, 296: 20−38. https://doi.org/10.1016/j.precamres.2017.04.043

Hao, W. L., 2018. Rock Assemblage and Geochronology of "Neoproterozoic" Yimianpo and Huangsong Groups in Eastern Heilongjiang Province: Implications for Regional Tectonic Evolution (Dissertation). Jilin University, Changchun (in Chinese with English abstract).

Hao, W. L., Xu, W. L., Wang, F., et al., 2014. Geochronology of the "Neoproterozoic" Yimianpo Group in the Zhangguangcai Range, NE China: Constraints from U-Pb Ages of Detrial and Magmatic Zicons. *Acta Petrologica Sinica*, 30(7): 1867−1878 (in Chinese with English abstract).

Heilongjiang Bureau of Geology and Mineral Resources, 1993. Regional Geology of Heilongjiang Province. Geological Publishing House, Beijing, 734 (in Chinese).

Hong, D. W., Huang, H. Z., Xiao, Y. J., et al., 1995. The Permian Alkaline Granites in Central Inner Mongolia and Their Geodynamic Significance. *Acta Geologica Sinica* (*English Edition*), 8 (1): 27−39. https://doi.org/10.1111/j.1755-6724.1995.mp8001003.x

Hong, D. W., Zhang, J. S., Wang, T., et al., 2004. Continental Crustal Growth and the Supercontinental Cycle: Evidence from the Central Asian Orogenic Belt. *Journal of Asian Earth Sciences*, 23 (5): 799−813. https://doi.org/10.1016/s1367-9120(03)00134-2

Hu, J. M., Liu, X. W., Yang, Z. Q., 2007. Geochronological Constrains for the Early Mesozoic Tectonic Deformation of Yanshan Intraplate Orogen in Northeastern China. *Acta Petrologica Sinica*, 23(3): 605−616 (in Chinese with English abstract).

Huang, J. Q., Ren, J. S., Jiang, C. F., 1977. An Outline of the Tectonic Characteristics of China. *Acta Geologica Sinica*, 51(2): 117−135 (in Chinese with English abstract).

Huang, S. Q., Dong, S. W., Zhang, F. Q., et al., 2014. Tectonic Deformation and Dynamic Characteristics of the Middle Part of the Mongolia-Okhotsk Collisional Belt, Mongolia. *Acta Geoscientica Sinica*, 35(4): 415−424 (in Chinese with English abstract).

Inner Mongolian Bureau of Geology and Mineral Resources, 1991. Regional Geology of Inner Mongolian Autonomous Region. Geological Publishing House, Beijing (in Chinese).

Isozaki, Y., 1997. Jurassic Accretion Tectonics of Japan. *The Island Arc*, 6(1): 25－51. https://doi.org/10.1111/j.1440-1738.1997.tb00039.x

Jahn, B.M., Windley, B., Natal'in, B., et al., 2004. Phanerozoic Continental Growth in Central Asia. *Journal of Asian Earth Sciences*, 23(5): 599－603. https://doi.org/10.1016/s1367-9120(03)00124-x

Jahn, B.M., Wu, F.Y., Chen, B., 2000. Granitoids of the Central Asian Orogenic Belt and Continental Growth in the Phanerozoic. *Transactions of the Royal Society of Edinburgh (Earth Sciences)*, 91(1－2): 181－193. https://doi.org/10.1017/s0263593300007367

Jian, P., Liu, D.Y., Kröner, A., et al., 2008. Time Scale of an Early to Mid-Paleozoic Orogenic Cycle of the Long-Lived Central Asian Orogenic Belt, Inner Mongolia of China: Implications for Continental Growth. *Lithos*, 101(3－4): 233－259. https://doi.org/10.1016/j.lithos.2007.07.005

Jilin Bureau of Geology and Mineral Resources, 1988. Regional Geology of Jilin Province. Geological Publishing House, Beijing, 698 (in Chinese).

Khanchuk, A.I., Vovna, G.M., Kiselev, V.I., et al., 2010. First Results of Zircon LA-ICP-MS U-Pb Dating of the Rocks from the Granulite Complex of Khanka Massif in the Primorye Region. *Doklady Earth Sciences*, 434(1): 1164－1167. https://doi.org/10.1134/s1028334x10090059

Kravchinsky, V.A., Cogne, J.P., Harbert, W.P., et al., 2002. Evolution of the Mongol-Okhotsk Ocean as Constrained by New Palaeomagnetic Data from the Mongol-Okhotsk Suture Zone, Siberia. *Geophysical Journal International*, 148(1): 34－57. https://doi.org/10.1046/j.1365-246x.2002.01557.x

Kröner, A., Kovach, V., Alexeiev, D., et al., 2017. No Excessive Crustal Growth in the Central Asian Orogenic Belt: Further Evidence from Field Relationships and Isotopic Data. *Gondwana Research*, 50: 135－166. https://doi.org/10.1016/j.gr.2017.04.006

Kröner, A., Kovach, V., Belousova, E., et al., 2014. Reassessment of Continental Growth during the Accretionary History of the Central Asian Orogenic Belt. *Gondwana Research*, 25(1): 103－125. https://doi.org/10.1016/j.gr.2012.12.023

Lallemand, S., Jolivet, L., 1986. Japan Sea: A Pull-Apart Basin?. *Earth and Planetary Science Letters*, 76(3－4): 375－389. https://doi.org/10.1016/0012-821x(86)90088-9

Li, J.Y., 2006. Permian Geodynamic Setting of Northeast China and Adjacent Regions: Closure of the Paleo-Asian Ocean and Subduction of the Paleo-Pacific Plate. *Journal of Asian Earth Sciences*, 26(3－4): 207－224. https://doi.org/10.1016/j.jseaes.2005.09.001

Li, J.Y., Niu, B.G., Song, B., 1999. Crustal Formation and Evolution of Northern Changbai Mountains, Northeast China. Geological Publishing House, Beijing (in Chinese).

Li, J.Y., Zhang, J., Yang, T.N., et al., 2009. Crustal Tectonic Division and Evolution of the Southern Part of the North Asian Orogenic Region and Its Adjacent Areas. *Journal of Jilin University (Earth Science Edition)*, 39(4): 584－605 (in Chinese with English abstract).

Li, R.S., 1991. Xinlin Ophiolite. *Heilongjiang Geology*, 2(1): 19－31 (in Chinese with English abstract).

Li, S., Wang, T., Wilde, S.A., et al., 2013. Evolution, Source and Tectonic Significance of Early Mesozoic Granitoid Magmatism in the Central Asian Orogenic Belt (Central Segment). *Earth-Science Reviews*, 126: 206－234. https://doi.org/10.1016/j.earscirev.2013.06.001

Li, Y., Ding, L.L., Xu, W.L., et al., 2015. Geochronology and Geochemistry of Muscovite Granite in Sunwu Area, NE China: Implications for the Timing of Closure of the Mongol-Okhotsk Ocean. *Acta Petrologica Sinica*, 31(1): 56－66 (in Chinese with English abstract).

Li, Y., Xu, W.L., Wang, F., et al., 2017a. Early-Middle Ordovician Volcanism along the Eastern Margin of the Xing'an Massif, Northeast China: Constraints on the Suture Location between the Xing'an and Songnen-Zhangguangcai Range Massifs. *International Geology Review*, 60(16): 2046－2062. https://doi.org/10.1080/00206814.2017.1402378

Li, Y., Xu, W.L., Wang, F., et al., 2017b. Geochronology and Geochemistry of Late Paleozoic-Early Mesozoic Igneous Rocks of the Erguna Massif, NE China: Implications for the Early Evolution of the Mongol-Okhotsk Tectonic Regime. *Journal of Asian Earth Sciences*, 144: 205－224. https://doi.org/10.1016/j.jseaes.2016.12.005

Li, Y., Xu, W.L., Wang, F., et al., 2017c. Triassic Volcanism along the Eastern Margin of the Xing'an Massif, NE China: Constraints on the Spatial-Temporal Extent of the Mongol-Okhotsk Tectonic Regime. *Gondwana Research*, 48: 205－223. https://doi.org/10.1016/j.gr.2017.05.002

Li, Z.X., Li, X.H., 2007. Formation of the 1 300-km-Wide Intracontinental Orogen and Postorogenic Magmatic Province in Mesozoic South China: A Flat-Slab Subduction Model. *Geology*, 35(2): 179－182. https://doi.org/

10.1130/g23193a.1

Liao,J.P.,Jahn,B.M.,Alexandrov,I.,et al.,2018.Petrogenesis of Mid-Eocene Granites in South Sakhalin,Russian Far East:Juvenile Crustal Growth and Comparison with Granitic Magmatism in Hokkaido and Sikhote-Alin. *Journal of Asian Earth Sciences*, 167: 103－129. https://doi.org/10.1016/j.jseaes.2018.05.020

Liu,Y.F.,Nie,F.J.,Jiang,S.H.,et al.,2010.The Geochronology and Geochemical Features of Ore-Hosting Granite in the Aryn nuur Molybdenum Deposit,Mongolia.*Acta Geoscientica Sinica*,31(3):343－349 (in Chinese with English abstract).

Liu,Y.J.,Li,W.M.,Feng,Z.Q.,et al.,2017.A Review of the Paleozoic Tectonics in the Eastern Part of Central Asian Orogenic Belt. *Gondwana Research*, 43: 123－148. https://doi.org/10.1016/j.gr.2016.03.013

Luan,J.P.,Wang,F.,Xu,W.L.,et al.,2017a.Provenance,Age,and Tectonic Implications of Neoproterozoic Strata in the Jiamusi Massif:Evidence from U-Pb Ages and Hf Isotope Compositions of Detrital and Magmatic Zircons.*Precambrian Research*,297:19－32.https://doi.org/10.1016/j.precamres.2017.05.012

Luan,J.P.,Xu,W.L.,Wang,F.,et al.,2017b.Age and Geochemistry of Neoproterozoic Granitoids in the Songnen-Zhangguangcai Range Massif,NE China:Petrogenesis and Tectonic Implications.*Journal of Asian Earth Sciences*,148:265－276.https://doi.org/10.1016/j.jseaes.2017.09.011

Luan,J.P.,Yu,J.J.,Yu,J.L.,et al.,2019.Early Neoproterozoic Magmatism and Associated Metamorphism in the Songnen Massif,NE China:Petrogenesis and Tectonic Implications. *Precambrian Research*. https://doi.org/10.1016/j.precamres.2019.04.004

Maruyama,S.,Isozaki,Y.,Kimura,G.,et al.,1997.Paleogeographic Maps of the Japanese Islands:Plate Tectonic Synthesis from 750 Ma to the Present.*The Island Arc*,6(1):121－142.https://doi.org/10.1111/j.1440-1738.1997.tb00043.x

Meng,E.,Xu,W.L.,Pei,F.P.,et al.,2010.Detrital-Zircon Geochronology of Late Paleozoic Sedimentary Rocks in Eastern Heilongjiang Province,NE China:Implications for the Tectonic Evolution of the Eastern Segment of the Central Asian Orogenic Belt. *Tectonophysics*, 485(1－4): 42－51. https://doi.org/10.1016/j.tecto.2009.11.015

Meng,E.,Xu,W.L.,Yang,D.B.,et al.,2011.Zircon U-Pb Chronology,Geochemistry of Mesozoic Volcanic Rocks from the Lingquan Basin in Manzhouli Area,and Its Tectonic Implications.*Acta Petrologica Sinica*,27(4):1209－1226 (in Chinese with English abstract).

Metelkin,D.V.,Gordienko,I.V.,Klimuk,V.S.,2007.Paleomagnetism of Upper Jurassic Basalts from Transbaikalia:New Data on the Time of Closure of the Mongol-Okhotsk Ocean and Mesozoic Intraplate Tectonics of Central Asia.*Russian Geology and Geophysics*,48(10):825－834.https://doi.org/10.1016/j.rgg.2007.09.004

Miao,L.C.,Fan,W.M.,Zhang,F.Q.,et al.,2004.Zircon SHRIMP Geochronology of the Xinkailing-Kele Complex in the Northwestern Lesser Xing'an Range,and Its Geological Implications. *Chinese Science Bulletin*, 49(2):201－209.https://doi.org/10.1360/03wd0316

Miao,L.C.,Liu,D.Y.,Zhang,F.Q.,et al.,2007.Zircon SHRIMP U-Pb Ages of the "Xinghuadukou Group" in Hanjiayuanzi and Xinlin Areas and the "Zhalantun Group" in Inner Mongolia,Da Hinggan Mountains.*Chinese Science Bulletin*,52(8):1112－1124.https://doi.org/10.1007/s11434-007-0131-2

Miao,L.C.,Zhang,F.,Jiao,S.J.,2015.Age,Protoliths and Tectonic Implications of the Toudaoqiao Blueschist,Inner Mongolia,China.*Journal of Asian Earth Sciences*,105:360－373.https://doi.org/10.1016/j.jseaes.2015.01.028

Na,F.C.,Fu,J.Y.,Wang,Y.,et al.,2014.LA-ICP-MS Zircon U-Pb Age of the Chlorite-Muscovite Tectonic Schist in Hadayang,Morin Dawa Banner,Inner Mongolia,and Its Tectonic Significance.*Geological Bulletin of China*,33(9):1326－1332 (in Chinese with English abstract).

Orolmaa,D.,Erdenesaihan,G.,Borisenko,A.S.,et al.,2008.Permian-Triassic Granitoid Magmatism and Metallogeny of the Hangayn (Central Mongolia).*Russian Geology and Geophysics*,49(7):534－544.https://doi.org/10.1016/j.rgg.2008.06.008

Ouyang,H.G.,Mao,J.W.,Santosh,M.,et al.,2013.Geodynamic Setting of Mesozoic Magmatism in NE China and Surrounding Regions:Perspectives from Spatio-Temporal Distribution Patterns of Ore Deposits.*Journal of Asian Earth Sciences*, 78(12): 222－236. https://doi.org/10.1016/j.jseaes.2013.07.011

Parfenov,L.M.,Berzin,N.A.,Khanchuk,A.I.,et al.,2003.A Model for the Formation of Orogenic Belts in Central and Northeast Asia. *Tikhookeanskaya Geologiya*, 22(6):7－41 (in Russian).

Parfenov,L.M.,Popeko,L.I.,Tomurtogoo,O.,2001.Problems of Tectonics of the Mongol-Okhotsk Orogenic Belt.*Geology of the Pacific Ocean*,16(5):797－830.

Pei,F.P.,Wang,Z.W.,Cao,H.H.,et al.,2014.Petrogenesis of the Early Paleozoic Tonalite in the Central Jilin Province:Evidence from Zircon U-Pb Chronology and Geochemistry. *Acta Petrologica Sinica*, 30(7): 2009－2019 (in Chinese with English abstract).

Pei, F.P., Xu, W.L., Yang, D.B., et al., 2006. SHRIMP Zircon U-Pb Dating and Its Geological Significance of Chibaisong Gabbro in Tonghua Area, Jilin Province, China. *Science in China (Series D: Earth Sciences)*, 49(4): 368－374. https://doi.org/10.1007/s11430-006-0368-7

Pei, F.P., Xu, W.L., Yang, D.B., et al., 2007. Zircon U-Pb Geochronology of Basement Metamorphic Rocks in the Songliao Basin. *Chinese Science Bulletin*, 52(7): 942－948. https://doi.org/10.1007/s11434-007-0107-2

Pei, F.P., Xu, W.L., Yu, Y., et al., 2008. Petrogenesis of the Late Triassic Mayihe Pluton in Southern Jilin Province: Evidence from Zircon U-Pb Geochronology and Geochemistry. *Journal of Jilin University (Earth Science Edition)*, 38(3): 351－362 (in Chinese with English abstract).

Qian, C., Chen, H.J., Lu, L., et al., 2018. The Discovery of Neoarchean Granite in Longjiang Area, Heilongjiang Province. *Acta Geoscientica Sinica*, 39(1): 27－36 (in Chinese with English abstract).

Quan, J.Y., Chi, X.G., Zhang, R., et al., 2013. LA-ICP-MS U-Pb Geochronology of Detrital Zircon from the Neoproterozoic Dongfengshan Group in Songnen Masiff and Its Geological Significance. *Geological Bulletin of China*, 32(2－3): 353－364 (in Chinese with English abstract).

Ren, J.S., Niu, B.G., Liu, Z.G., 1999. Soft Collision, Superposition Orogeny and Polycyclic Suturing. *Earth Science Frontiers*, 6(3): 85－93 (in Chinese with English abstract).

Scotese, C.R., 2001. Atlas of Earth History. PALEOMAP Project, Arlington.

Şengör, A.M.C., Natal'in, B.A., 1996. Paleotectonics of Asia: Fragments of a Synthesis. Cambridge University Press, Cambridge, 486－640.

Şengör, A.M.C., Natal'in, B.A., Burtman, V.S., 1993. Evolution of the Altaid Tectonic Collage and Palaeozoic Crustal Growth in Eurasia. *Nature*, 364(6435): 299－307. https://doi.org/10.1038/364299a0

Seno, T., Maruyama, S., 1984. Paleogeographic Reconstruction and Origin of the Philippine Sea. *Tectonophysics*, 102(1－4): 53－84. https://doi.org/10.1016/0040-1951(84)90008-8

Seton, M., Müller, R.D., Zahirovic, S., et al., 2012. Global Continental and Ocean Basin Reconstructions since 200 Ma. *Earth-Science Reviews*, 113(3－4): 212－270. https://doi.org/10.1016/j.earscirev.2012.03.002

Shao, J., Li, Y.F., Zhou, Y.H., et al., 2015. Neo-Archaean Magmatic Event in Erguna Massif of Northeast China: Evidence from the Zircon LA-ICP-MS Dating of the Gneissic Monzogranite from the Drill. *Journal of Jilin University (Earth Science Edition)*, 45(2): 364－373 (in Chinese with English abstract).

Shao, J.A., 1991. Crustal Evolution in the Middle Part of the Northern Margin of the Sino-Korean Plate. Peking University Press, Beijing (in Chinese).

Shao, J.A., Tang, K.D., 1995. Terranes in Northeast China and Evolution of Northeast Asia Continental Margin. Seismological Press, Beijing (in Chinese).

She, H.Q., Li, J.W., Xiang, A.P., et al., 2012. U-Pb Ages of the Zircons from Primary Rocks in Middle-Northern Daxinganling and Its Implications to Geotectonic Evolution. *Acta Petrologica Sinica*, 28(2): 571－594 (in Chinese with English abstract).

Shi, G.H., Miao, L.C., Zhang, F.Q., et al., 2004. Emplacement Age and Tectonic Implications of the Xilinhot A-Type Granite in Inner Mongolia, China. *Chinese Science Bulletin*, 49(7): 723－729. https://doi.org/10.1007/bf03184272

Shi, G.R., 2006. The Marine Permian of East and Northeast Asia: An Overview of Biostratigraphy, Palaeobiogeography and Palaeogeographical Implications. *Journal of Asian Earth Sciences*, 26(3－4): 175－206. https://doi.org/10.1016/j.jseaes.2005.11.004

Shi, Y.R., Liu, D.Y., Zhang, Q., et al., 2005. The Petrogenesis and SHRIMP Dating of the Baiyinbaolidao Adakitic Rocks in Southern Suzuoqi, Inner Mongolia. *Acta Petrologica Sinica*, 21(1): 143－150 (in Chinese with English abstract).

Sorokin, A.A., Ovchinnikov, R.O., Kudryashov, N.M., et al., 2017. Two Stages of Neoproterozoic Magmatism in the Evolution of the Bureya Continental Massif of the Central Asian Fold Belt. *Russian Geology and Geophysics*, 58(10): 1171－1187. https://doi.org/10.1016/j.rgg.2016.12.009

Sun, C.Y., Long, X.Y., Xu, W.L., et al., 2018. Zircon U-Pb Ages and Hf Isotopic Compositions of the Heilongjiang Complex from Jiayin, Heilongjiang Province and Kundur, Russian Far East and Their Geological Implications. *Acta Petrologica Sinica*, 34(10): 2901－2916 (in Chinese with English abstract).

Sun, C.Y., Tang, J., Xu, W.L., et al., 2017. Crustal Accretion and Reworking Processes of Micro-Continental Massifs within Orogenic Belt: A Case Study of the Erguna Massif, NE China. *Science China Earth Sciences*, 60(7): 1256－1267. https://doi.org/10.1007/s11430-016-9033-5

Sun, D.Y., Wu, F.Y., Li, H.M., et al., 2001. Emplacement Age of the Postorogenic A-Type Granites in Northwestern Lesser Xing'an Ranges, and Its Relationship to the Eastward Extension of Suolushan-Hegenshan-Zhalaite Collisional Suture Zone. *Chinese Science Bulletin*, 46(5): 427-432. https://doi.org/10.1007/bf03183282

Sun, D. Y., Wu, F. Y., Zhang, Y. B., et al., 2004. The Final Closing Time of the West Lamulun River-Changchun-Yanji Plate Suture Zone—Evidence from the Dayushan Granitic Pluton, Jilin Province. *Journal of Jilin University (Earth Science Edition)*, 34(2): 174-181 (in Chinese with English abstract).

Sun, L. X., Ren, B. F., Zhao, F. Q., et al., 2013a. Late Paleoproterozoic Magmatic Records in the Eerguna Massif: Evidences from the Zircon U-Pb Dating of Granitic Gneisses. *Geological Bulletin of China*, 32(2-3): 341-352 (in Chinese with English abstract).

Sun, L. X., Ren, B. F., Zhao, F. Q., et al., 2013b. Zircon U-Pb Dating and Hf Isotopic Compositions of the Mesoporterozoic Granitic Gneiss in Xilinhot Block, Inner Mongolia. *Geological Bulletin of China*, 32(2-3): 327-340 (in Chinese with English abstract).

Sun, M. D., 2016. Cretaceous Magmatism in NE China and Adjacent Areas and Its Relationship with the Paleo-Pacific Plate Subduction. *Bulletin of Mineralogy, Petrology and Geochemistry*, 35(6): 1090-1097, 1071 (in Chinese with English abstract).

Sun, M. D., Xu, Y. G., Wilde, S. A., et al., 2015. The Permian Dongfanghong Island-Arc Gabbro of the Wandashan Orogen, NE China: Implications for Paleo-Pacific Subduction. *Tectonophysics*, 659: 122-136. https://doi.org/10.1016/j.tecto.2015.07.034

Sun, X. M., Liu, C., Zhu, D. F., et al., 2011. Geophysical Features and Tectonic Attribute of the Derbugan Fault Belts in the Western Slope of Da Hinggan Ling Mountains. *Chinese Journal of Geophysics*, 54(2): 433-440 (in Chinese with English abstract).

Sun, X. M., Zhang, X. Q., He, S., et al., 2016. Two Important Cretaceous Deformation Events of the Dunhua-Mishan Fault Zone, NE China. *Acta Petrologica Sinica*, 32(4): 1114-1128 (in Chinese with English abstract).

Tamaki, K., 1995. Opening Tectonics of the Japan Sea. In: Taylor, B., ed., Backarc Basins. Springer, Boston, 407-420. https://doi.org/10.1007/978-1-4615-1843-3_11

Tang, J., Xu, W. L., Wang, F., et al., 2013. Geochronology and Geochemistry of Neoproterozoic Magmatism in the Erguna Massif, NE China: Petrogenesis and Implications for the Breakup of the Rodinia Supercontinent. *Precambrian Research*, 224: 597-611. https://doi.org/10.1016/j.precamres.2012.10.019

Tang, J., Xu, W. L., Wang, F., et al., 2014. Geochronology and Geochemistry of Early-Middle Triassic Magmatism in the Erguna Massif, NE China: Constraints on the Tectonic Evolution of the Mongol-Okhotsk Ocean. *Lithos*, 184-187: 1-16. https://doi.org/10.1016/j.lithos.2013.10.024

Tang, J., Xu, W. L., Wang, F., et al., 2015. Geochronology, Geochemistry, and Deformation History of Late Jurassic-Early Cretaceous Intrusive Rocks in the Erguna Massif, NE China: Constraints on the Late Mesozoic Tectonic Evolution of the Mongol-Okhotsk Orogenic Belt. *Tectonophysics*, 658: 91-110. https://doi.org/10.1016/j.tecto.2015.07.012

Tang, J., Xu, W. L., Wang, F., et al., 2016. Early Mesozoic Southward Subduction History of the Mongol-Okhotsk Oceanic Plate: Evidence from Geochronology and Geochemistry of Early Mesozoic Intrusive Rocks in the Erguna Massif, NE China. *Gondwana Research*, 31: 218-240. https://doi.org/10.1016/j.gr.2014.12.010

Tang, J., Xu, W. L., Wang, F., et al., 2018. Subduction History of the Paleo-Pacific Slab beneath Eurasian Continent: Mesozoic-Paleogene Magmatic Records in Northeast Asia. *Science China Earth Sciences*, 61(5): 527-559. https://doi.org/10.1007/s11430-017-9174-1

Tang, K. D., Wang, Y., He, G. Q., et al., 1995. Continental-Margin Structure of Northeast China and Its Adjacent Areas. *Acta Geologica Sinica (English Edition)*, 8(3): 241-258. https://doi.org/10.1111/j.1755-6724.1995.mp8003002.x

Tomurtogoo, O., Windley, B. F., Kröner, A., et al., 2005. Zircon Age and Occurrence of the Adaatsag Ophiolite and Muron Shear Zone, Central Mongolia: Constraints on the Evolution of the Mongol-Okhotsk Ocean, Suture and Orogen. *Journal of the Geological Society*, 162(1): 125-134. https://doi.org/10.1144/0016-764903-146

Tong, Y., Hong, D. W., Wang, T., et al., 2010. Spatial and Temporal Distribution of Granitoids in the Middle Segment of the Sino-Mongolian Border and Its Tectonic and Metallogenic Implications. *Acta Geoscientica Sinica*, 31(3): 395-412 (in Chinese with English abstract).

Wang, F., Xu, W. L., Gao, F. H., et al., 2012. Tectonic History of the Zhangguangcailing Group in Eastern Heilongjiang Province, NE China: Constraints from U-Pb Geochronology of Detrital and Magmatic Zircons. *Tectonophysics*, 566-567: 105-122. https://doi.org/10.1016/j.tecto.2012.07.018

Wang, F., Xu, W. L., Gao, F. H., et al., 2014. Precambrian

Terrane within the Songnen-Zhangguangcai Range Massif, NE China: Evidence from U-Pb Ages of Detrital Zircons from the Dongfengshan and Tadong Groups. *Gondwana Research*, 26(1): 402−413. https://doi.org/10.1016/j.gr.2013.06.017

Wang, F., Xu, W. L., Ge, W. C., et al., 2016. The Offset Distance of the Dunhua-Mishan Fault: Constraints from Paleozoic-Mesozoic Magmatism within the Songnen-Zhangguangcai Range, Jiamusi, and Khanka Massifs. *Acta Petrologica Sinica*, 32(4): 1129−1140 (in Chinese with English abstract).

Wang, F., Xu, W. L., Xu, Y. G., et al., 2015a. Late Triassic Bimodal Igneous Rocks in Eastern Heilongjiang Province, NE China: Implications for the Initiation of Subduction of the Paleo-Pacific Plate beneath Eurasia. *Journal of Asian Earth Sciences*, 97: 406−423. https://doi.org/10.1016/j.jseaes.2014.05.025

Wang, K., Vladimir, P., O'Reilly, S. Y., et al., 2015b. Ancient Mantle Lithosphere beneath the Khanka Massif in the Russian Far East: In Situ Re-Os Evidence. *Terra Nova*, 27(4): 277−284. https://doi.org/10.1111/ter.12157

Wang, W., Tang, J., Xu, W. L., et al., 2015c. Geochronology and Geochemistry of Early Jurassic Volcanic Rocks in the Erguna Massif, Northeast China: Petrogenesis and Implications for the Tectonic Evolution of the Mongol-Okhotsk Suture Belt. *Lithos*, 218−219: 73−86. https://doi.org/10.1016/j.lithos.2015.01.012

Wang, Z. J., Xu, W. L., Pei, F. P., et al., 2015d. Geochronology and Geochemistry of Middle Permian-Middle Triassic Intrusive Rocks from Central-Eastern Jilin Province, NE China: Constraints on the Tectonic Evolution of the Eastern Segment of the Paleo-Asian Ocean. *Lithos*, 238: 13−25. https://doi.org/10.1016/j.lithos.2015.09.019

Wang, F., Xu, Y. G., Xu, W. L., et al., 2017a. Early Jurassic Calc-Alkaline Magmatism in Northeast China: Magmatic Response to Subduction of the Paleo-Pacific Plate beneath the Eurasian Continent. *Journal of Asian Earth Sciences*, 143: 249−268. https://doi.org/10.1016/j.jseaes.2017.04.018

Wang, Z. H., Ge, W. C., Yang, H., et al., 2017b. Petrogenesis and Tectonic Implications of Early Jurassic Volcanic Rocks of the Raohe Accretionary Complex, NE China. *Journal of Asian Earth Sciences*, 134: 262−280. https://doi.org/10.1016/j.jseaes.2016.09.021

Wang, Z. W., Xu, W. L., Pei, F. P., et al., 2017c. Geochronology and Geochemistry of Early Paleozoic Igneous Rocks from the Zhangguangcai Range, Northeastern China: Constraints on Tectonic Evolution of the Eastern Central Asian Orogenic Belt. *Lithosphere*, 9(5): 803−827. https://doi.org/10.1130/l639.1

Wang, J. G., He, Z. H., Xu, W. L., 2013. Petrogenesis of Riebeckite Rhyolites in the Southern Da Hinggan Mts.: Geohronological and Geochemical Evidence. *Acta Petrologica Sinica*, 29(3): 853−863 (in Chinese with English abstract).

Wang, L. M., 2015. Geochemistry of the Ordovician Volcanic Rocks in Aershan, Inner Mongolia and Its Tectonic Significance (Dissertation). Jilin University, Changchun (in Chinese with English abstract).

Wang, W., Xu, W. L., Wang, F., et al., 2012. Zircon U-Pb Chronology and Assemblages of Mesozoic Granitoids in the Manzhouli-Erguna Area, NE China: Constraints on the Regional Tectonic Evolution. *Geological Journal of China Universities*, 18(1): 88−105 (in Chinese with English abstract).

Wang, Y., Zhang, F. Q., Zhang, D. W., et al., 2006. Zircon SHRIMP U-Pb Dating of Meta-Diorite from the Basement of the Songliao Basin and Its Geological Significance. *Chinese Science Bulletin*, 51(15): 1877−1883. https://doi.org/10.1007/s11434-006-2035-y

Wang, Y. N., Xu, W. L., Wang, F., et al., 2018. New Insights on the Early Mesozoic Evolution of Multiple Tectonic Regimes in the Northeastern North China Craton from the Detrital Zircon Provenance of Sedimentary Strata. *Solid Earth*, 9(6): 1375−1397. https://doi.org/10.5194/se-9-1375-2018

Wang, Z. H., Yang, H., Ge, W. C., et al., 2016. Discovery and Geological Significance of the Eocene Granodiorites in the Sanjiang Basin, NE China: Evidence from Zircon U-Pb Chronology, Geochemistry and Sr-Nd-Hf Isotopes. *Acta Petrologica Sinica*, 32(6): 1823−1838 (in Chinese with English abstract).

Wang, Z. W., Xu, W. L., Pei, F. P., et al., 2016. Geochronology and Geochemistry of Early Paleozoic Igneous Rocks of the Lesser Xing'an Range, NE China: Implications for the Tectonic Evolution of the Eastern Central Asian Orogenic Belt. *Lithos*, 261: 144−163. https://doi.org/10.1016/j.lithos.2015.11.006

Wilde, S. A., Zhang, X. Z., Wu, F. Y., 2000. Extension of a Newly Identified 500 Ma Metamorphic Terrane in North East China: Further U-Pb SHRIMP Dating of the Mashan Complex, Heilongjiang Province, China. *Tectonophysics*, 328(1−2): 115−130. https://doi.org/10.1016/s0040-1951(00)00180-3

Windley, B. F., Alexeiev, D., Xiao, W. J., et al., 2007. Tectonic Models for Accretion of the Central Asian Orogenic

Belt. *Journal of the Geological Society*, 164(1): 31-47. https://doi.org/10.1144/0016-76492006-022

Wu, F. Y., Jahn, B. M., Wilde, S., et al., 2000. Phanerozoic Crustal Growth: U-Pb and Sr-Nd Isotopic Evidence from the Granites in Northeastern China. *Tectonophysics*, 328(1-2): 89-113. https://doi.org/10.1016/s0040-1951(00)00179-7

Wu, F.Y., Jahn, B.M., Wilde, S.A., et al., 2003. Highly Fractionated I-Type Granites in NE China (I): Geochronology and Petrogenesis. *Lithos*, 67(3-4): 241-273. https://doi.org/10.1016/s0024-4937(02)00222-0

Wu, F.Y., Sun, D.Y., Ge, W.C., et al., 2011. Geochronology of the Phanerozoic Granitoids in Northeastern China. *Journal of Asian Earth Sciences*, 41(1): 1-30. https://doi.org/10.1016/j.jseaes.2010.11.014

Wu, F.Y., Wilde, S., Sun, D.Y., 2001. Zircon SHRIMP U-Pb Ages of Gneissic Granites in Jiamusi Massif, Northeastern China. *Acta Petrologica Sinica*, 17(3): 443-452 (in Chinese with English abstract).

Wu, F. Y., Yang, J. H., Lo, C. H., et al., 2007a. The Heilongjiang Group: A Jurassic Accretionary Complex in the Jiamusi Massif at the Western Pacific Margin of Northeastern China. *Island Arc*, 16(1): 156-172. https://doi.org/10.1111/j.1440-1738.2007.00564.x

Wu, F. Y., Zhao, G. C., Sun, D. Y., et al., 2007b. The Hulan Group: Its Role in the Evolution of the Central Asian Orogenic Belt of NE China. *Journal of Asian Earth Sciences*, 30(3-4): 542-556. https://doi.org/10.1016/j.jseaes.2007.01.003

Wu, G., Chen, Y. C., Chen, Y. J., et al., 2012. Zircon U-Pb Ages of the Metamorphic Supracrustal Rocks of the Xinghuadukou Group and Granitic Complexes in the Argun Massif of the Northern Great Hinggan Range, NE China, and Their Tectonic Implications. *Journal of Asian Earth Sciences*, 49: 214-233. https://doi.org/10.1016/j.jseaes.2011.11.023

Wu, G., Chen, Y.C., Sun, F.Y., et al., 2015. Geochronology, Geochemistry, and Sr-Nd-Hf Isotopes of the Early Paleozoic Igneous Rocks in the Duobaoshan Area, NE China, and Their Geological Significance. *Journal of Asian Earth Sciences*, 97: 229-250. https://doi.org/10.1016/j.jseaes.2014.07.031

Wu, X. W., Zhang, C., Zhang, Y. J., et al., 2018. 2.7 Ga Monzogranite on the Songnen Massif and Its Geological Implications. *Acta Geologica Sinica (English Edition)*, 92(3): 1265-1266. https://doi.org/10.1111/1755-6724.13609

Xiao, W. J., Windley, B. F., Huang, B. C., et al., 2009. End-Permian to Mid-Triassic Termination of the Accretionary Processes of the Southern Altaids: Implications for the Geodynamic Evolution, Phanerozoic Continental Growth, and Metallogeny of Central Asia. *International Journal of Earth Sciences*, 98(6): 1189-1217. https://doi.org/10.1007/s00531-008-0407-z

Xie, H.Q., Miao, L.C., Chen, F.K., et al., 2008. Characteristics of the "Mashan Group" and Zircon SHRIMP U-Pb Dating of Granite in Muling Area, Southeastern Heilongjiang Province, China: Constraint on Crustal Evolution of the South-Ernmost of Jiamusi Massif. *Geological Bulletin of China*, 27(12): 2127-2137 (in Chinese with English abstract).

Xu, B., Zhao, P., Bao, Q.Z., et al., 2014. Preliminary Study on the Pre-Mesozoic Tectonic Unit Division of the Xing-Meng Orogenic Belt (XMOB). *Acta Petrologica Sinica*, 30(7): 1841-1857 (in Chinese with English abstract).

Xu, B., Zhao, P., Wang, Y. Y., et al., 2015. The Pre-Devonian Tectonic Framework of Xing'an-Mongolia Orogenic Belt (XMOB) in North China. *Journal of Asian Earth Sciences*, 97: 183-196. https://doi.org/10.1016/j.jseaes.2014.07.020

Xu, M. J., Xu, W. L., Wang, F., et al., 2012. Age, Association and Provenance of the "Neoproterozoic" Fengshuigouhe Group in the Northwestern Lesser Xing'an Range, NE China: Constraints from Zircon U-Pb Geochronology. *Journal of Earth Science*, 23(6): 786-801. https://doi.org/10.1007/s12583-012-0291-0

Xu, T., Xu, W. L., Wang, F., et al., 2018. Geochronology and Geochemistry of Early Paleozoic Intrusive Rocks from the Khanka Massif in the Russian Far East: Petrogenesis and Tectonic Implications. *Lithos*, 300-301: 105-120. https://doi.org/10.1016/j.lithos.2017.12.004

Xu, W.L., Ji, W.Q., Pei, F.P., et al., 2009. Triassic Volcanism in Eastern Heilongjiang and Jilin Provinces, NE China: Chronology, Geochemistry, and Tectonic Implications. *Journal of Asian Earth Sciences*, 34(3): 392-402. https://doi.org/10.1016/j.jseaes.2008.07.001

Xu, W.L., Pei, F.P., Wang, F., et al., 2013. Spatial-Temporal Relationships of Mesozoic Volcanic Rocks in NE China: Constraints on Tectonic Overprinting and Transformations between Multiple Tectonic Regimes. *Journal of Asian Earth Sciences*, 74(18): 167-193. https://doi.org/10.1016/j.jseaes.2013.04.003

Xu, W.L., Wang, F., Meng, E., et al., 2012. Paleozoic-Early Mesozoic Tectonic Evolution in the Eastern Heilongjiang Province, NE China: Evidence from Igneous Rock Association and U-Pb Geochronology of Detrital Zircons. *Journal of Jilin University (Earth Science Edition)*, 42(5): 1378－1389 (in Chinese with English abstract).

Yang, H., Ge, W. C., Bi, J. H., et al., 2018. The Neoproterozoic-Early Paleozoic Evolution of the Jiamusi Block, NE China and Its East Gondwana Connection: Geochemical and Zircon U-Pb-Hf Isotopic Constraints from the Mashan Complex. *Gondwana Research*, 54: 102－121. https://doi.org/10.1016/j.gr.2017.10.002

Yang, H., Ge, W. C., Zhao, G. C., et al., 2017. Zircon U-Pb Ages and Geochemistry of Newly Discovered Neoproterozoic Orthogneisses in the Mishan Region, NE China: Constraints on the High-Grade Metamorphism and Tectonic Affinity of the Jiamusi-Khanka Block. *Lithos*, 268－271: 16－31. https://doi.org/10.1016/j.lithos.2016.10.017

Yang, J. H., Wu, F. Y., Chung, S. L., et al., 2007. Rapid Exhumation and Cooling of the Liaonan Metamorphic Core Complex: Inferences from $^{40}Ar/^{39}Ar$ Thermochronology and Implications for Late Mesozoic Extension in the Eastern North China Craton. *Geological Society of America Bulletin*, 119(11－12): 1405－1414. https://doi.org/10.1130/b26085.1

Yang, Y. T., Guo, Z. X., Song, C. C., et al., 2015. A Short-Lived but Significant Mongol-Okhotsk Collisional Orogeny in Latest Jurassic-Earliest Cretaceous. *Gondwana Research*, 28(3): 1096－1116. https://doi.org/10.1016/j.gr.2014.09.010

Yu, J. J., Wang, F., Xu, W. L., et al., 2012. Early Jurassic Mafic Magmatism in the Lesser Xing'an-Zhangguangcai Range, NE China, and Its Tectonic Implications: Constraints from Zircon U-Pb Chronology and Geochemistry. *Lithos*, 142－143: 256－266. https://doi.org/10.1016/j.lithos.2012.03.016

Zeng, Q. D., Liu, J. M., Chu, S. X., et al., 2014. Re-Os and U-Pb Geochronology of the Duobaoshan Porphyry Cu-Mo-(Au) Deposit, Northeast China, and Its Geological Significance. *Journal of Asian Earth Sciences*, 79: 895－909. https://doi.org/10.1016/j.jseaes.2013.02.007

Zhang, C., Wu, X. W., Liu, Z. H., et al., 2018. Precambrian Geological Events on the Western Margin of Songnen Massif: Evidence from LA-ICP-MS U-Pb Geochronology of Zircons from Paleoproterozoic Granite in the Longjiang Area. *Acta Petrologica Sinica*, 34(10): 3137－3152 (in Chinese with English abstract).

Zhang, C. H., Li, C. M., Deng, H. L., et al., 2011a. Mesozoic Contraction Deformation in the Yanshan and Northern Taihang Mountains and Its Implications to the Destruction of the North China Craton. *Science China Earth Sciences*, 54(6): 798－822. https://doi.org/10.1007/s11430-011-4180-7

Zhang, Y. L., Liu, C. Z., Ge, W. C., et al., 2011b. Ancient Sub-Continental Lithospheric Mantle (SCLM) beneath the Eastern Part of the Central Asian Orogenic Belt (CAOB): Implications for Crust-Mantle Decoupling. *Lithos*, 126(3－4): 233－247. https://doi.org/10.1016/j.lithos.2011.07.022

Zhang, H., Yuan, H. L., Hu, Z. C., et al., 2005. U-Pb Zircon Dating of the Mesozoic Volcanic Strata in Luanping of North Hebei and Its Significance. *Earth Science*, 30(6): 707－720 (in Chinese with English abstract).

Zhang, J. H., Gao, S., Ge, W. C., et al., 2010. Geochronology of the Mesozoic Volcanic Rocks in the Great Xing'an Range, Northeastern China: Implications for Subduction-Induced Delamination. *Chemical Geology*, 276(3－4): 144－165. https://doi.org/10.1016/j.chemgeo.2010.05.013

Zhang, J. H., Ge, W. C., Wu, F. Y., et al., 2008. Large-Scale Early Cretaceous Volcanic Events in the Northern Great Xing'an Range, Northeastern China. *Lithos*, 102(1－2): 138－157. https://doi.org/10.1016/j.lithos.2007.08.011

Zhang, S., Zhu, G., Liu, C., et al., 2018. Strike-Slip Motion within the Yalu River Fault Zone, NE Asia: The Development of a Shear Continental Margin. *Tectonics*, 37(6): 1771－1796. https://doi.org/10.1029/2018tc004968

Zhang, S. H., Zhao, Y., Davis, G. A., et al., 2014. Temporal and Spatial Variations of Mesozoic Magmatism and Deformation in the North China Craton: Implications for Lithospheric Thinning and Decratonization. *Earth-Science Reviews*, 131(4): 49－87. https://doi.org/10.1016/j.earscirev.2013.12.004

Zhang, X. M., Xu, W. L., Sun, C. Y., et al., 2018. Crustal Accretion and Reworking within the Khanka Massif: Evidence from Hf Isotopes of Zircons in Phanerozoic Granitoids. *Journal of Earth Science*, 29(2): 255－264. https://doi.org/10.1007/s12583-017-0950-2

Zhang, X. Z., 1992. The Evidence of Suture of Heilongjiang Rock Series-Jiamusi Massif Ancient Caledonian. *Journal of Changchun University of Earth Science*, 22(Suppl.): 94－101 (in Chinese with English abstract).

Zhang, X. Z., Yang, B. J., Wu, F. Y., et al., 2006. The Lithosphere Structure in the Hingmong-Jihei (Hinggan-Mongolia-Jilin-Heilongjiang) Region, Northeastern China. *Geology in China*, 33(4): 816－823 (in Chinese with English abstract).

Zhang, Y. Q., Dong, S. W., Zhao, Y., et al., 2007. Jurassic Tectonics of North China: A Synthetic View. *Acta Geologica Sinica*, 81(11): 1462－1480 (in Chinese with English abstract).

Zhang, Z.C., Li, K., Li, J.F., et al., 2015. Geochronology and Geochemistry of the Eastern Erenhot Ophiolitic Complex: Implications for the Tectonic Evolution of the Inner Mongolia-Daxinganling Orogenic Belt. *Journal of Asian Earth Sciences*, 97: 279－293. https://doi.org/10.1016/j.jseaes.2014.06.008

Zhao, H.B., Han, Z.Z., Liu, X.G., 2005. Isotopic Ages of the Granitic Gneisses in Alongshan Area of Daxinganling and Its Implication for Global Continental Reconstructions. *Journal of East China Institute of Technology*, 28(4): 313－316 (in Chinese with English abstract).

Zhao, H. L., Zhu, C. Y., Liu, H. Y., et al., 2012. Zircon SHRIMP U-Pb Dating and Its Tectonic Implications of the Granodiorite in Duobaoshan Copper Deposit, Heilongjiang Province. *Geology and Resources*, 21(5): 421－424 (in Chinese with English abstract).

Zhao, S., Xu, W.L., Tang, J., et al., 2016a. Neoproterozoic Magmatic Events and Tectonic Attribution of the Erguna Massif: Constraints from Geochronological, Geochemical and Hf Isotopic Data of Intrusive Rocks. *Earth Science*, 41(11): 1803－1829 (in Chinese with English abstract).

Zhao, S., Xu, W.L., Wang, F., et al., 2016b. Neoproterozoic Magmatisms in the Erguna Massif, NE China: Evidence from Zircon U-Pb Geochronology. *Geotectonica et Metallogenia*, 40(3): 559－573 (in Chinese with English abstract).

Zhao, S., Xu, W.L., Tang, J., et al., 2016. Timing of Formation and Tectonic Nature of the Purportedly Neoproterozoic Jiageda Formation of the Erguna Massif, NE China: Constraints from Field Geology and U-Pb Geochronology of Detrital and Magmatic Zircons. *Precambrian Research*, 281: 585－601. https://doi.org/10.1016/j.precamres.2016.06.014

Zhao, S., Xu, W.L., Wang, W., et al., 2014. Geochronology and Geochemistry of Middle-Late Ordovician Granites and Gabbros in the Erguna Region, NE China: Implications for the Tectonic Evolution of the Erguna Massif. *Journal of Earth Science*, 25(5): 841－853. https://doi.org/10.1007/s12583-014-0476-9

Zhao, Y., Zhang, S.H., Xu, G., et al., 2004. The Jurassic Major Tectonic Event in the Yanshanian Intraplate Deformation Belt. *Geological Bulletin of China*, 23(9－10): 854－863 (in Chinese with English abstract).

Zhao, Z., Chi, X.G., Pan, S.Y., et al., 2010. Zircon U-Pb LA-ICP-MS Dating of Carboniferous Volcanics and Its Geological Significance in the Northwestern Lesser Xing' an Range. *Acta Petrologica Sinica*, 26(8): 2452－2464 (in Chinese with English abstract).

Zheng, C.Q., Zhou, J.B., Jin, W., et al., 2009. Geochronology in the North Segment of the Derbugan Fault Zone, Great Xing' an Range, NE China. *Acta Petrologica Sinica*, 25(8): 1989－2000 (in Chinese with English abstract).

Zhou, J.B., Cao, J.L., Wilde, S.A., et al., 2014. Paleo-Pacific Subduction-Accretion: Evidence from Geochemical and U-Pb Zircon Dating of the Nadanhada Accretionary Complex, NE China. *Tectonics*, 33: 2444－2466. https://doi.org/10.1016/10.1002/2014tc003637

Zhou, J.B., Han, J., Wilde, S.A., et al., 2013. A Primary Study of the Jilin-Heilongjiang High-Pressure Metamorphic Belt: Evidence and Tectonic Implications. *Acta Petrologica Sinica*, 29(2): 386－398 (in Chinese with English abstract).

Zhou, J.B., Wang, B., Wilde, S.A., et al., 2015. Geochemistry and U-Pb Zircon Dating of the Toudaoqiao Blueschists in the Great Xing' an Range, Northeast China, and Tectonic Implications. *Journal of Asian Earth Sciences*, 97: 197－210. https://doi.org/10.1016/j.jseaes.2014.07.011

Zhou, J.B., Wilde, S.A., Zhang, X.Z., et al., 2009. The Onset of Pacific Margin Accretion in NE China: Evidence from the Heilongjiang High-Pressure Metamorphic Belt. *Tectonophysics*, 478(3－4): 230－246. https://doi.org/10.1016/j.tecto.2009.08.009

Zhou, J.B., Wilde, S.A., Zhang, X.Z., et al., 2011a. Early Paleozoic Metamorphic Rocks of the Erguna Block in the Great Xing'an Range, NE China: Evidence for the Timing of Magmatic and Metamorphic Events and Their Tectonic Implications. *Tectonophysics*, 499(1－4): 105－117. https://doi.org/10.1016/j.tecto.2010.12.009

Zhou, J.B., Wilde, S.A., Zhang, X.Z., et al., 2011b. A＞1 300 km Late Pan-African Metamorphic Belt in NE China: New Evidence from the Xing'an Block and Its Tectonic Implications. *Tectonophysics*, 509(3－4): 280－292. https://doi.org/10.1016/j.tecto.2011.06.018

Zhou, J.B., Wilde, S.A., Zhao, G.C., et al., 2010. Pan-African Metamorphic and Magmatic Rocks of the Khanka Massif, NE China: Further Evidence Regarding Their Affinity. *Geological Magazine*, 147: 737－749. https://doi.org/10.1017/s0016756810000063

Zhu, G., Liu, C., Gu, C.C., et al., 2018. Oceanic Plate Subduction History in the Western Pacific Ocean: Constraint from Late Mesozoic Evolution of the Tan-Lu Fault Zone. *Science China Earth Sciences*, 61(4): 386－405. https://doi.org/10.1007/s11430-017-9136-4

Zhu, R.X., Zhang, H.F., Zhu, G., et al., 2017. Craton Destruc-

tion and Related Resources. *International Journal of Earth Sciences*, 106: 2233－2257. https://doi.org/10.1007/s00531-016-1441-x
Zonenshain, L.P., Kuzmin, M.L., Natapov, L.M., et al., 1990. Geology of USSR: A Plate-Tectonic Synthesis. *Amer. Geophys. Union Geodynamics Series*, 21: 242. https://doi.org/10.1029/gd021
Zorin, Y. A., 1999. Geodynamics of the Western Part of the Mongolia-Okhotsk Collisional Belt, Trans-Baikal Region (Russia) and Mongolia. *Tectonophysics*, 306(1): 33－56. https://doi.org/c10.1016/s0040-1951(99)00042-6
Zyabrev, S., Matsuoka, A., 1999. Late Jurassic (Tithonian) Radiolarians from a Clastic Unit of the Khabarovsk Complex (Russian Far East): Significance for Subduction Accretion Timing and Terrane Correlation. *The Island Arc*, 8: 30－37. https://doi.org/10.1046/j.1440-1738.1999.00220.x

附中文参考文献

陈志广，张连昌，卢百志，等，2010.内蒙古太平川铜钼矿成矿斑岩时代、地球化学及地质意义.岩石学报，26(5)：1437－1449.
葛梦春，周文孝，于洋，等，2011.内蒙古锡林郭勒杂岩解体及表壳岩系年代确定.地学前缘，18(5)：182－195.
郝文丽，2018.黑龙江省东部"新元古界"一面坡群和黄松群的岩石组合与时代：对区域构造演化的意义(博士学位论文).长春：吉林大学.
郝文丽，许文良，王枫，等，2014.张广才岭"新元古代"一面坡群的形成时代：来自岩浆锆石和碎屑锆石U-Pb年龄的制约.岩石学报，30(7)：1867－1878.
黑龙江省地质矿产局，1993.黑龙江省区域地质志.北京：地质出版社.
胡健民，刘晓文，杨之青，2007.辽西地区燕山板内造山带早中生代构造变形的年代学限定.岩石学报，23(3)：605－616.
黄汲清，任纪舜，姜春发，等，1977.中国大地构造基本轮廓.地质学报，51(2)：117－135.
黄始琪，董树文，张福勤，等，2014.蒙古－鄂霍茨克构造带中段构造变形及动力学特征.地球学报，35(4)：415－424.
内蒙古自治区地质矿产局，1991.内蒙古自治区区域地质志.北京：地质出版社.
吉林省地质矿产局，1988.吉林省区域地质志.北京：地质出版社，698.
李锦轶，牛宝贵，宋彪，1999.长白山北段地壳的形成与演化.北京：地质出版社.
李锦轶，张进，杨天南，等，2009.北亚造山区南部及其毗邻地区地壳构造分区与构造演化.吉林大学学报(地球科学版)，39(4)：584－605.
李瑞山，1991.新林蛇绿岩.黑龙江地质，2(1)：19－31.
李宇，丁磊磊，许文良，等，2015.孙吴地区中侏罗世白云母花岗岩的年代学与地球化学：对蒙古－鄂霍茨克洋闭合时间的限定.岩石学报，31(1)：56－66.
刘翼飞，聂凤军，江思宏，等，2010.蒙古国阿林诺尔钼矿床赋矿花岗岩年代学及地球化学特征.地球学报，31(3)：343－349.
孟恩，许文良，杨德彬，等，2011.满洲里地区灵泉盆地中生代火山岩的锆石U-Pb年代学、地球化学及其地质意义.岩石学报，27(4)：1209－1226.
那福超，付俊彧，汪岩，等，2014.内蒙古莫力达瓦旗哈达阳绿泥石白云母构造片岩LA-ICP-MS锆石U-Pb年龄及其地质意义.地质通报，33(9)：1326－1332.
裴福萍，王志伟，曹花花，等，2014.吉林省中部地区早古生代英云闪长岩的成因：锆石U-Pb年代学和地球化学证据.岩石学报，30(7)：2009－2019.
裴福萍，许文良，于洋，等，2008.吉林南部晚三叠世蚂蚁河岩体的成因：锆石U-Pb年代学和地球化学证据.吉林大学学报(地球科学版)，38(3)：351－362.
钱程，陈会军，陆露，等，2018.黑龙江省龙江地区新太古代花岗岩的发现.地球学报，39(1)：27－36.
权京玉，迟效国，张蕊，等，2013.松嫩地块东部新元古代东风山群碎屑锆石LA-ICP-MS U-Pb年龄及其地质意义.地质通报，32(2－3)：353－364.
任纪舜，牛宝贵，刘志刚，1999.软碰撞、叠覆造山和多旋回缝合作用.地学前缘，6(3)：85－93.
邵军，李永飞，周永恒，等，2015.中国东北额尔古纳地块新太古代岩浆事件：钻孔片麻状二长花岗岩锆石LA-ICP-MS测年证据.吉林大学学报(地球科学版)，45(2)：364－373.
邵济安，1991.中朝板块北缘中段地壳演化.北京：北京大学出版社.
邵济安，唐克东，1995.中国东北地体与东北亚大陆边缘演化.北京：地震出版社.
佘宏全，李进文，向安平，等，2012.大兴安岭中北段原岩锆石U-Pb测年及其与区域构造演化关系.岩石学报，28(2)：571－594.
石玉若，刘敦一，张旗，等，2005.内蒙古苏左旗白音宝力道Adakite质岩类成因探讨及其SHRIMP年代学研究.岩石学报，21(1)：143－150.
孙晨阳，龙欣雨，许文良，等，2018.黑龙江嘉荫与俄罗斯远东Kundur地区黑龙江杂岩锆石U-Pb年代学、Hf同位素组成及其地质意义.岩石学报，34(10)：2901－2916.
孙德有，吴福元，张艳斌，等，2004.西拉木伦河－长春－延吉板块缝合带的最后闭合时间——来自吉林大玉山花岗岩体的证据.吉林大学学报(地球科学版)，34(2)：174－181.
孙立新，任邦方，赵凤清，等，2013a.内蒙古额尔古纳地块古

元古代末期的岩浆记录——来自花岗片麻岩的锆石U-Pb年龄证据.地质通报,32(2-3):341-352.
孙立新,任邦方,赵凤清,等,2013b.内蒙古锡林浩特地块中元古代花岗片麻岩的锆石U-Pb年龄和Hf同位素特征.地质通报,32(2-3):327-340.
孙明道,2016.中国东北及邻区白垩纪岩浆活动与古太平洋板块俯冲的关系.矿物岩石地球化学通报,35(6):1090-1097,1071.
孙晓猛,刘财,朱德丰,等,2011.大兴安岭西坡德尔布干断裂地球物理特征与构造属性.地球物理学报,54(2):433-440.
孙晓猛,张旭庆,何松,等,2016.敦密断裂带白垩纪两期重要的变形事件.岩石学报,32(4):1114-1128.
童英,洪大卫,王涛,等,2010.中蒙边境中段花岗岩时空分布特征及构造和找矿意义.地球学报,31(3):395-412.
王枫,许文良,葛文春,2016.敦化-密山断裂带的平移距离:来自松嫩-张广才岭-佳木斯-兴凯地块古生代-中生代岩浆作用的制约.岩石学报,32(4):1129-1140.
王建国,和钟铧,许文良,2013.大兴安岭南部钠闪石流纹岩的岩石成因:年代学和地球化学证据.岩石学报,29(3):853-863.
王利民,2015.内蒙古阿尔山地区奥陶纪火山岩地球化学特征及其构造意义(博士学位论文).长春:吉林大学.
王伟,许文良,王枫,等,2012.满洲里-额尔古纳地区中生代花岗岩的锆石U-Pb年代学与岩石组合:对区域构造演化的制约.高校地质学报,18(1):88-105.
王智慧,杨浩,葛文春,等,2016.东北三江盆地始新世花岗闪长岩的发现及其地质意义:锆石U-Pb年代学、地球化学和Sr-Nd-Hf同位素证据.岩石学报,32(6):1823-1838.
吴福元,Wilde, S.,孙德有,2001.佳木斯地块片麻状花岗岩的锆石离子探针U-Pb年龄.岩石学报,17(3):443-452.
颉颃强,苗来成,陈福坤,等,2008.黑龙江东南部穆棱地区"麻山群"的特征及花岗岩锆石SHRIMP U-Pb定年——对佳木斯地块最南缘地壳演化的制约.地质通报,27(12):2127-2137.
徐备,赵盼,鲍庆中,等,2014.兴蒙造山带前中生代构造单元划分初探.岩石学报,30(7):1841-1857.
许文良,王枫,孟恩,等,2012.黑龙江省东部古生代-早中生代的构造演化:火成岩组合与碎屑锆石U-Pb年代学证据.吉林大学学报(地球科学版),42(5):1378-1389.
张超,吴新伟,刘正宏,等,2018.松嫩地块西缘前寒武岩浆事件——来自龙江地区古元古代花岗岩锆石LA-ICP-MS U-Pb年代学证据.岩石学报,34(10):3137-3152.
张宏,袁洪林,胡兆初,等,2005.冀北滦平地区中生代火山岩地层锆石U-Pb测年及启示.地球科学,30(6):707-720.
张兴洲,1992.黑龙江岩系-古佳木斯地块加里东缝合带的证据.长春地质学院学报,22(增刊):94-101.
张兴洲,杨宝俊,吴福元,等,2006.中国兴蒙-吉黑地区岩石圈结构基本特征.中国地质,33(4):816-823.
张岳桥,董树文,赵越,等,2007.华北侏罗纪大地构造:综评与新认识.地质学报,81(11):1462-1480.
赵海滨,韩振哲,刘旭光,2005.大兴安岭阿龙山地区花岗片麻岩的同位素年龄与超大陆.华东理工大学学报(自然科学版),28(4):313-316.
赵焕利,朱春艳,刘海洋,等,2012.黑龙江多宝山铜矿床中花岗闪长岩锆石SHRIMP U-Pb测年及其构造意义.地质与资源,21(5):421-424.
赵硕,许文良,唐杰,等,2016a.额尔古纳地块新元古代岩浆作用与微陆块构造属性:来自侵入岩锆石U-Pb年代学、地球化学和Hf同位素的制约.地球科学,41(11):1803-1829.
赵硕,许文良,王枫,等,2016b.额尔古纳地块新元古代岩浆作用:锆石U-Pb年代学证据.大地构造与成矿学,40(3):559-573.
赵越,张拴宏,徐刚,等,2004.燕山板内变形带侏罗纪主要构造事件.地质通报,23(9-10):854-863.
赵芝,迟效国,潘世语,等,2010.小兴安岭西北部石炭纪地层火山岩的锆石LA-ICP-MS U-Pb年代学及其地质意义.岩石学报,26(8):2452-2464.
郑常青,周建波,金巍,等,2009.大兴安岭地区德尔布干断裂带北段构造年代学研究.岩石学报,25(8):1989-2000.
周建波,韩杰,Wilde, S.A.,等,2013.吉林-黑龙江高压变质带的初步厘定:证据和意义.岩石学报,29(2):386-398.