

蒙古-鄂霍茨克洋东段关闭对松辽盆地形成与演化的影响

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摘要:松辽盆地是位于中国东北的大型白垩系陆相含油气盆地,前人普遍认为其形成和演化主要受西太平洋板块向西俯冲作用的影响和控制。那么,环西太平洋构造带仅在中国东北形成大型拗陷盆地的动力机制是什么,松辽盆地在拗陷阶段之前发育火石岭组和营城组2套断陷期火山岩的诱因是什么,中国东北地区大规模发育中生代岩浆岩的主控因素是什么。显然,这些现象很难单纯用古太平洋板块活动控制来解释。本文在充分吸收已有科研成果的基础上,从区域动力学背景、火山岩时空分布特征以及沉积盆地构造演化的角度,分析了蒙古-鄂霍茨克洋东段的闭合对松辽盆地形成与演化的影响,指出蒙古-鄂霍茨克洋关闭是中生代东北亚最重要的一次大地构造事件,板块的俯冲、碰撞、挤压、拉张以及岩浆活动等作用对该区盆-山格局的形成和演化都具有重要的影响;并提出了松辽盆地可能存在的蒙古-鄂霍茨克洋和西太平洋板块双向俯冲成因模式,厘定了两者对中国东北地区多期次挤压和拉张作用的转换时间,从全新的角度认识了松辽盆地的形成和演化过程,合理地诠释了中国东北部晚侏罗世-早白垩世有别于西太平洋南部地区的岩浆岩发育特征。

关键词:构造演化;双向俯冲模式;岩浆岩;缝合带;松辽盆地;蒙古-鄂霍茨克洋;东北亚地区

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Impacts of the closure of eastern Mongolia-Okhotsk Ocean on formation and evolution of Songliao Basin

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Abstract: Songliao Basin is a large non-marine petroliferous basin of the Cretaceous in Northeast China. It is generally believed that its tectonic evolution is mainly controlled by the westward subduction of the Western Pacific Plate. What is the dynamic mechanism in forming a large depression basin only in Northeast China within the Western Pacific tectonic belt? Why are there two stages of volcanism (Huoshiling Formation and Yingcheng Formation) developed in the rifting stage of Songliao Basin? Why are the Mesozoic magmatic rocks prone to get developed in Northeast China? Obviously, it's difficult to explain these questions merely by Pacific Plate activities. The closure of Mongolia-Okhotsk Ocean is the most important tectonic event in Northeast Asia in the Mesozoic. There is no doubt that the plate subduction, collision, subsequent compression, extension and magmatic activity would have significant effects on the formation and evolution of the basins and mountains in Northeast Asia. Based on existing research results, this paper analyzes the influence of the closure of the eastern Mongolia-Okhotsk Ocean on the formation and evolution of Songliao Basin from the perspectives of regional dynamics, temporal and spatial distribution characteristics of volcanic rocks and tectonic evolution of sedimentary basins. Besides, a genetic model of bidirectional subduction between the Mongolia-Okhotsk Ocean and the West Pacific

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Plate is proposed for the formation of Songliao Basin, under the effect of which multiple transitions between compression and extension mechanisms in Northeast China are delineated. In all, the formation and evolution of Songliao Basin are re-recognized from brand-new perspectives, while reasonably interpreting the differential magmatic activities between Northeast China and southern West Pacific during the Late Jurassic and Early Cretaceous.

Key words: tectonic evolution, bidirectional subduction pattern, magmatic rock, suture zone, Songliao Basin, Mongolia-Okhotsk Ocean, Northeast Asia

松辽盆地位于中国东北部,是中国最大的白垩系陆相含油气盆地,在全球占有重要地位。前人研究普遍认为包括松辽盆地在内的中国东北地区中、新生代沉积盆地的构造演化、岩浆作用和沉积建造与中国华南、华北地区的沉积盆地一样,受西太平洋板块向西俯冲作用的影响和控制^[1-3]。然而,中国东北部与中国东部其他中、新生代沉积盆地特征以及火山岩发育情况有着明显的不同^[4-7]。华南地区中、新生代盆地规模小,且数量少,多以小型山间盆地为主,中生代岩浆岩发育,呈现自东向西逐渐减少的特点^[8-9];华北地区中、新生代盆地比较发育,多以拉分断陷盆地为主^[7],中、新生代岩浆岩相对较少,且主要分布在东部地区^[10-12];而在东北地区侏罗纪和白垩纪的岩浆岩,特别是火山岩,明显较其以南的其他滨太平洋地区更加发育^[13-17],在其中心部位发育了中国东部唯一的大型陆相拗陷盆地,且其下部断陷群发育了两期厚度较大的火山岩层系。显然,这些现象很难单纯用古太平洋板块活动控制来解释。造成这种差别的原因,除了西太平洋板块的俯冲外,可能还与其所处的独特大地构造位置有关。

松辽盆地处于东北亚多向汇聚的构造背景下,围陷于南部索伦克缝合带、北部蒙古-鄂霍茨克缝合带以及东部古太平洋缝合带之间^[17-20](图1)。南部的索伦克缝合带最终形成于二叠纪-三叠纪^[17,20-24],是松辽盆地基底发育时期^[25-26]。东部的古太平洋是从前寒武纪到现今一直存在的泛大洋,蒙古-鄂霍茨克洋作为古太平洋的一部分,其南北两侧的西伯利亚板块和华北板块在三叠纪以前均为古太平洋的同一边缘^[4,27-28]。古生代至中生代早期,这两个板块边缘陆壳不断增生,古太平洋板块不断后退,额尔古纳地块、松嫩地块和佳木斯地块等陆续拼合到华北地台上,形成了中国东北地区的基底,即阿穆尔地块(也有学者称之为兴蒙地块)^[17,24,27,29]。已有证据表明,蒙古-鄂霍茨克洋是自西向东“剪刀式”逐步闭合,其东段在中国东北地区的西北部,大洋闭合作用发生于晚侏罗世一早白垩世^[24,28,30-31]。早期的研究更多关注于蒙古-鄂霍茨克洋对其北部西伯利亚克拉通的俯冲^[32]。近

年来随着相关研究工作的开展,一些学者逐渐认识到蒙古-鄂霍茨克洋东段的闭合作用对中国东北地区的构造变形与沉积建造有着广泛的影响^[16,27,33-35]。基于深地震反射资料以及岩浆岩地球化学资料,很多学者已认识到蒙古-鄂霍茨克洋曾向南(南东)俯冲^[16,27,35-48],也有学者关注到其闭合过程对中国东北地区乃至华北克拉通产生了挤压作用^[39,41,44-46,49-51]。Feng等^[15]提出了松辽盆地的形成和演化受古太平洋和蒙古-鄂霍茨克洋双向俯冲控制的可能性。本文将依据板块构造理论、盆地动力学、盆山耦合机制、沉积学原理、古地磁以及同位素年代学,从区域动力学背景、地球深部构造、火山岩时空分布特征以及沉积盆地构造演化的角度入手,结合中国东部盆地的空间分布及其演化特征、岩浆岩的分布特征,进一步探讨蒙古-鄂霍茨克洋东段关闭对松辽盆地形成和演化的影响,从一个全新的角度探讨松辽盆地的成因。

1 蒙古-鄂霍茨克缝合带

蒙古-鄂霍茨克缝合带(或称之为杭盖-鄂霍茨克带),自西向东由蒙古中部的杭盖山开始,经外贝加尔地区,一直延伸到鄂霍茨克海的乌达海湾,长约3 000 km,南北宽几十公里到几百公里,呈略向西北凸出的巨大勺状弧型构造带(图1)。古生代末期古亚洲洋关闭后,西伯利亚板块和其南侧的兴蒙地块均为古太平洋西缘,属于同一个活动大陆边缘^[4,18,29,33]。因兴蒙地块随华北板块逆时针旋转,在西伯利亚地台和华北板块之间形成了西窄东宽的喇叭形大洋——蒙古-鄂霍茨克洋(杭盖-肯特洋)^[27-28,52]。从三叠纪到白垩纪早期,蒙古-鄂霍茨克洋自西向东逐步关闭,形成了现今的蒙古-鄂霍茨克缝合带^[50,53-55]。蒙古-鄂霍茨克缝合带自西向东大致可以分为3段,西段位于蒙古中部(杭盖山地区),中段位于外贝加尔及以南地区(Trans-Baikal),东段位于阿穆尔(Amur)及以北地区。

一些学者基于大量古地磁测试结果,定量地刻画了蒙古-鄂霍茨克洋存在自西向东“剪刀式”关闭模式^[23-24,56-58]。最近,Ren等学者^[24]报道阿穆尔地块

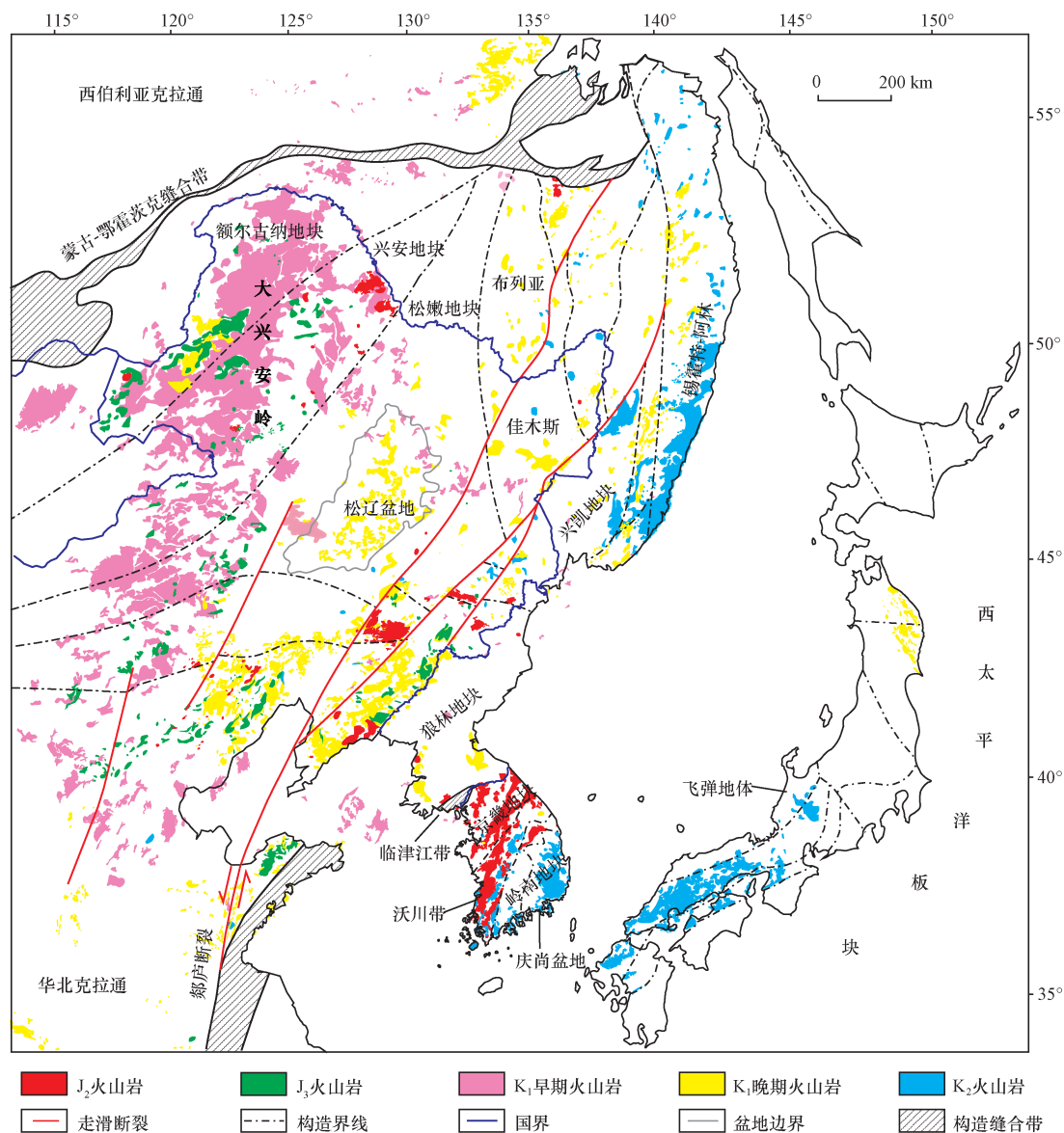


图1 蒙古-鄂霍茨克缝合带与松辽盆地构造位置及中-晚侏罗世—早白垩世火山岩分布特征(据参考文献[31,67]修编)

Fig. 1 Locations of the Mongolia-Okhotsk suture zone and the Songliao Basin, as well as the volcanic rock distribution pattern of the Middle-to-Late Jurassic and Early Cretaceous (modified after references[31,67])

和华北地块晚中生代高质量的古地磁测试结果,研究表明晚侏罗世(~ 155 Ma)之后西伯利亚地块和阿穆尔-华北地块之间存在 $14.3^\circ \pm 6.9^\circ$ (约 1587 ± 766 km)的纬向汇聚运动和 $0 \sim 19^\circ$ 的相对旋转运动;这样大规模的纬向汇聚运动可能直到 ~ 130 Ma才完全停止,指示蒙古-鄂霍茨克洋盆至此已完全关闭,然而其间一定程度的旋转运动可能要到100 Ma才结束。另外,沿着蒙古-鄂霍茨克缝合带两侧分布的一系列晚中生代火山-侵入岩,具有自西向东逐渐变年轻的趋势^[28,30],进而也支持西伯利亚板块与蒙古-华北板块存在自西向东的穿时性碰撞^[55,59-61]。因此,综合已有的地质事件和古地磁数据,蒙古-鄂霍茨克洋是自西向东的、呈“剪刀状”的、长期的、分阶段(或持续)关闭的,不同区段其关

闭时间不一,东端最终闭合于早白垩世中期(~ 130 Ma)之前^[24,28,30,44,62-64]。

2 中国东北部岩浆岩分布特征

蒙古-鄂霍茨克缝合带及其两侧火山岩-侵入岩规模宏大^[65],侵入体与火山岩的地表出露面积占全区总面积的70%以上,如果考虑到区内各中生代盆地内也分布大量火山岩,则岩浆岩将占有统治地位^[3,31,35,51,66-68]。在中国东北地区,除了在北部的额尔古纳和佳木斯地区存在一些古生代的花岗岩外^[40],大面积分布的岩浆岩主要形成于中生代^[5,27,35,51,67-68]。大致以大兴安岭为中轴,火山岩年龄整体表现出中间老(侏罗纪为

主)、两侧新(白垩纪为主)的特点^[27,28,35,66,69-70]。宏观上火山岩展布具有明显的条带性(图1),以松辽盆地为界,盆地以西的火山岩带分布方向基本平行于兴安-蒙古裂谷盆地群排列方向,即与蒙古-鄂霍茨克带具有一致性,时间上主要是晚侏罗世-早白垩世^[21,28,31,35,67];松辽盆地以东的火山岩带的展布方向基本平行于环太平洋裂谷盆地群排列方向,即与古太平洋缝合带具有一致性,同时也发育大量的晚侏罗纪-早白垩世火山岩^[7,21,35,67,71]。

近年来大量的高精度同位素测年数据显示,位于松辽盆地以西的大兴安岭,火山岩喷发高峰期是在早白垩世早期,而不是前人所说的晚侏罗世^[31,35,67,69],表明早白垩世早期存在一次重要的火山岩喷发事件^[71-73],这与蒙古-鄂霍茨克缝合带的中、东段发育的火山岩和侵入岩的形成时代具有一致性^[35,38,74-81]。此时,在松辽盆地基底之上发育了断陷早期的火石岭组,有大量的火山岩喷发。而到了早白垩世中晚期,松辽盆地内部(尤其以徐家围子断陷营城组为代表)以及其东部地区,同样有强烈的火山岩喷发活动,但其西部却相对较少,而在整个中国东部则大规模发育这个时代的侵入岩和火山岩,空间展布则呈北北东向,显示出与西太平洋板块向西俯冲引起的弧后拉张作用导致的岩浆上涌相匹配^[21]。

3 中国东北部以及东部中、新生代盆地特征

从蒙古国到中国东部以及俄罗斯远东等广大地区发育大量的中、新生代伸展盆地(图2)。自1959年以来,随着大庆油田的发现,陆续在中国东部众多的中、新生代沉积盆地中采集了大量的地震资料,使得沉积盆地的地质结构越来越明晰。这些盆地在空间展布上大体上可以分两组。第一组为兴安-蒙古裂谷盆地群,走向大致平行于蒙古-鄂霍茨克缝合带,属于晚侏罗纪-早白垩世断陷盆地群,如海拉尔-塔木察格盆地、二连盆地和银根-额济纳旗盆地(简称银额盆地),以及蒙古国境内大量中生代裂谷盆地等;第二组为环西太平洋断陷盆地群,走向近平行于古太平洋缝合带或现今西太平洋板块俯冲带,如渤海湾盆地、南华北盆地、苏北-南黄海盆地、北黄海盆地以及中国东南沿海等新生代盆地或中、新生代叠合盆地。第一组裂谷盆地群和第二组裂谷盆地群宏观上组成了一个“人”字,松辽盆地恰巧位于“人”字的交汇处(图2)。另外在盆地结构上也展示出了明显的规律性。兴安-

蒙古裂谷盆地群内的断陷多呈西断东超的特征^[7,46],如海拉尔-塔木察格盆地;而环西太平洋裂谷盆地群恰好相反,多数断陷呈现出东断西超的特征^[7],如东海盆地、黄海盆地、渤海湾盆地和辽河盆地等,其中东海盆地为典型的弧后断陷盆地群,其中各控陷断层几乎都位于断陷的东侧^[7]。

4 松辽盆地沉积与构造特征

松辽盆地是世界上最大的陆相含油气盆地之一,地球物理和钻井等资料丰富,研究相对深入^[15,21-22,25-26,82-90]。松辽盆地整体呈NNE-SSW向展布,长度近750 km,宽度为330~370 km,面积约为 $26 \times 10^4 \text{ km}^2$ 。松辽盆地位于阿穆尔地块的核心区域,中生代夹于蒙古-鄂霍茨克洋构造域(缝合带)和古太平洋构造域(缝合带)之间,距离这两个构造域(缝合带)均约600~800 km(图2)。盆地基底主要由晚古生界的变质砂岩、大理岩、板岩和千枚岩等组成,钻探揭露有大量中生代花岗岩,显示盆地形成之前该区遭受了大规模的隆(抬)升。基底之上的沉积盖层主要是中生代-新生代的沉积岩,在盆地中心位置最大累计厚度可以达到上千米。

松辽盆地具有下部断陷和上部拗陷组成的二元结构,且晚白垩世晚期在拗陷基础上叠加了“前陆”盆地发育过程^[87]。盆地拗陷期为一套富含油的河流-湖泊相碎屑岩沉积,自下而上主要包括白垩系的登娄库组、泉头组、青山口组、姚家组、嫩江组、四方台组和明水组(图3)。断陷期发育火山岩与含煤碎屑岩交互、以含气为主的沉积地层,自下而上包括下白垩统的火石岭组、沙河子组和营城组。火石岭组以火山岩沉积为主,其上覆的沙河子组主要为湖相碎屑岩和含煤层系。火石岭组火山岩类型包括安山岩、粗面岩、粗面安山岩、玄武质安山岩、玄武质粗面安山岩和流纹岩,以中性为主,形成时代为早白垩世早期(145~120 Ma)^[14]。营城组是目前松辽盆地北部火山岩气藏的主要储集层^[83-86,91],地层厚度一般为200~800 m,最厚处可达2 000 m^[43,91]。营城组下部以火山岩为主,上部为湖相碎屑岩沉积,总体为从泥岩到砾岩的反旋回地层组合。营城组火山岩以酸性和中酸性为主,也发育基性火山岩,主要包括流纹岩、英安岩、安山岩、粗面岩、粗面安山岩、玄武粗面安山岩、玄武安山岩以及碧玄岩。松科二井获得营城组的年龄值为 $(112.078 \pm 0.067) \text{ Ma}$ (3 266 m)^[43],形成时代为早白垩世中晚期(120~100 Ma);大量同位素年龄数据显示营城组火山岩发育大致有两个峰期,即118~120 Ma

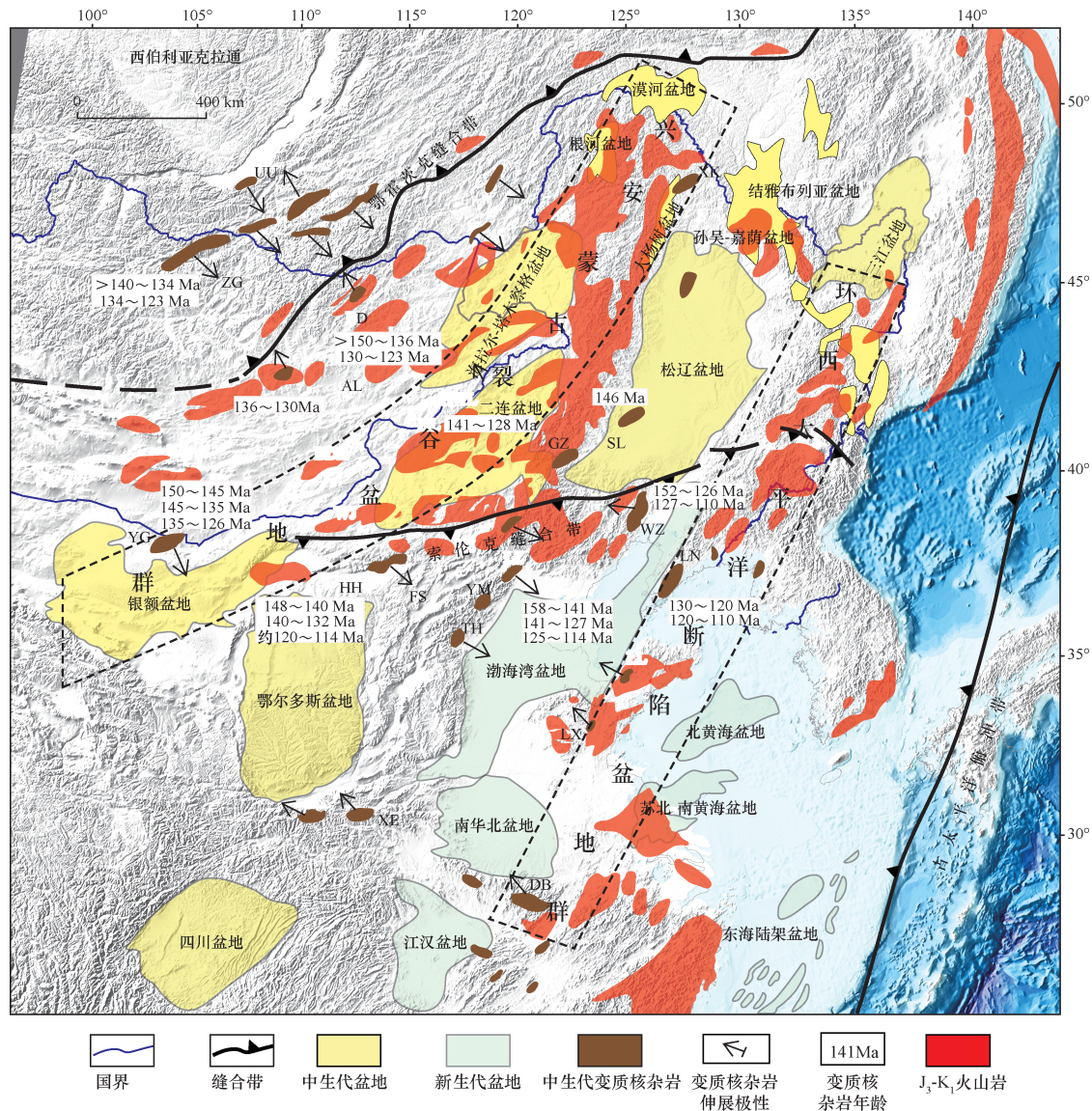


图2 蒙古-鄂霍茨克洋构造域与古太平洋构造域中、新生代盆地与火山岩耦合分布特征(据参考文献[6,52]修编)

Fig.2 Coupling distribution characteristics of the Mesozoic and Cenozoic basins and volcanic rocks in the Mongolia-Okhotsk tectonic domain and the paleo-Pacific tectonic domain (modified after references[6,52])

变质核杂岩名称: UU. Ulan-Ude; BT. Buteel; ZG. Zagan; ED. Erendavaa; NA. Nartyn; AL. Altanshiree; HWL. Khanuula; BDR. 宝德尔; YG. 亚干; HH. 呼和浩特; LZ. 楼子店; YM. 云蒙山; FS. 房山; TH. 太行山; WZ. 医巫闾山或瓦子峪; SL. 松辽; XK. 新开岭; LN. 辽南; LL. 玲珑; LX. 鲁西; XQ. 小秦岭; XE. 熊耳山; DB. 大别山

和 105 ~ 112 Ma^[13-14,71-72,90], 空间上基本沿控陷断裂呈条带状分布^[86]。断陷期地层总体上表现为两期火山岩到碎屑岩的沉积旋回, 每套沉积地层旋回组合顶部均为明显的角度不整合(图4, 图5)。

松辽盆地发育规模不等的次级断陷约 38 个(图 4a), 它们的形成与演化主要受基底断裂的控制, 位于松辽盆地中央隆起的德都-大安(孙吴-双辽)断裂是这些断陷东西分带的界限^[21-22]。按照断陷的长轴方向, 总体上可以分为东、西两组。发育在盆地西部的断陷(西部断陷群)多呈 NE 和 NNE 走向^[21,48], 与蒙古-鄂霍茨克缝合带以及海拉尔-塔木察格盆地中的次

级凹陷走向基本一致, 而发育在盆地东部的断陷(东部断陷群)以 NNE 和 NS 走向为主, 与太平洋构造系走向一致。宏观上, 火石岭组断陷多呈现出西断东超的不对称半地堑结构; 营城组沉积时期, 受深部拆离断层活动以及早期现存断层再次活化的影响, 断陷结构复杂, 既有东断西超和西断东超的半地堑, 同时也发育有大量的双断结构。火石岭组和营城组火山岩在盆地内均广泛发育, 早期的火石岭组火山岩沉积不完全受断陷控制, 总体上盆地西部更为发育^[21-22,92-93], 而营城组火山岩发育偏向盆地东部(图4)。前人的研究亦证实, 火石岭组火山岩在岩性以及时代上, 与松辽盆地西

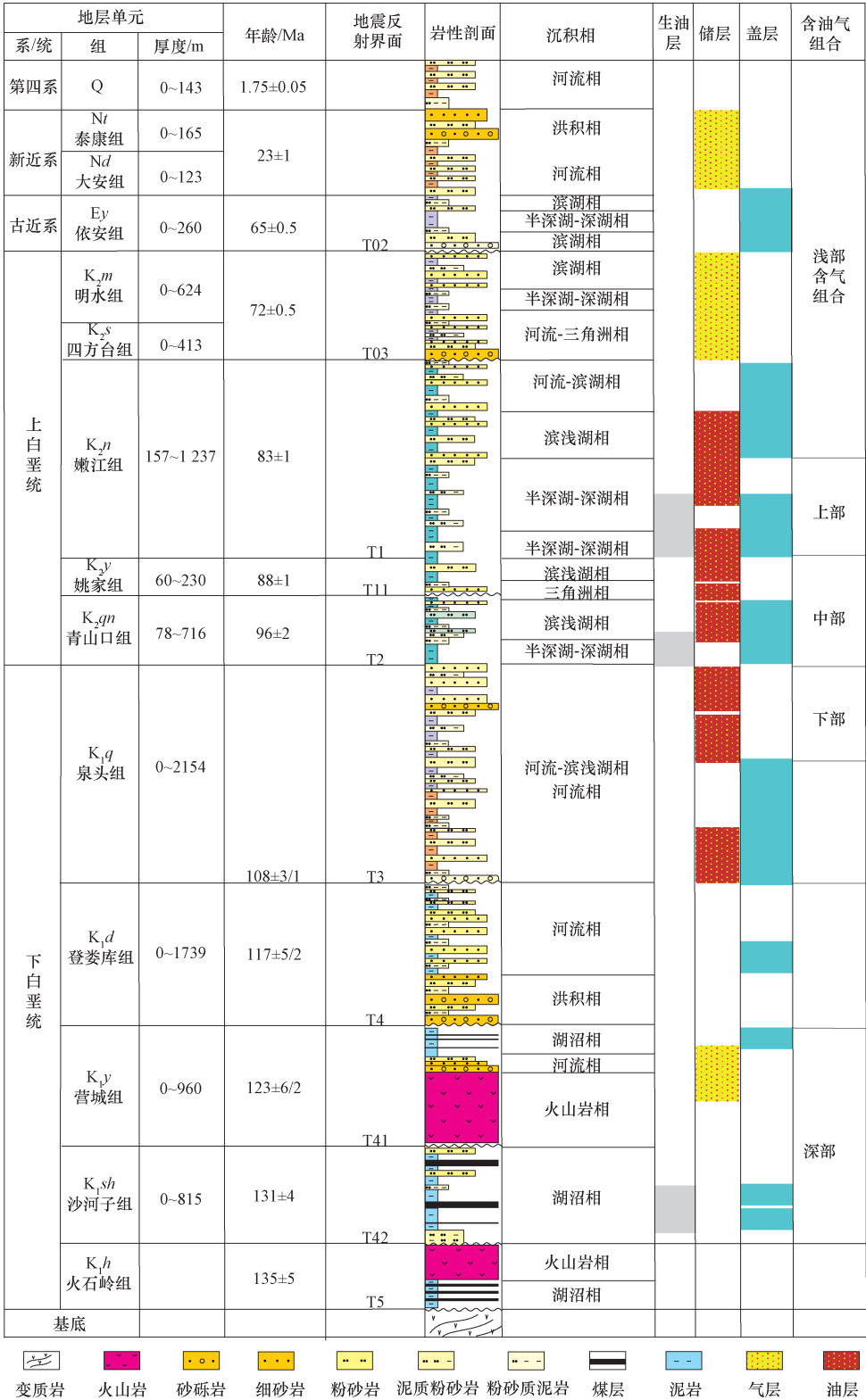


图 3 松辽盆地地层综合柱状图
Fig. 3 Stratigraphic column of the Songliao Basin

侧大兴安岭地区以及海拉尔盆地具有一致性^[94]。营城组沉积期,与中国东部早白垩世区域伸展构造作用一致,具有与板块俯冲作用有关的、发育于活动陆缘或岛弧的火山岩类似的演化组合^[89]。火石岭期断陷与

营城期断陷不同的结构特征表明,两者的形成应是不同大地构造背景下的产物。火石岭组断陷发育期,处于蒙古-鄂霍茨克洋关闭的造山后区域伸展阶段,在松辽盆地以西广大区域发育一系列伸展极性为南东向

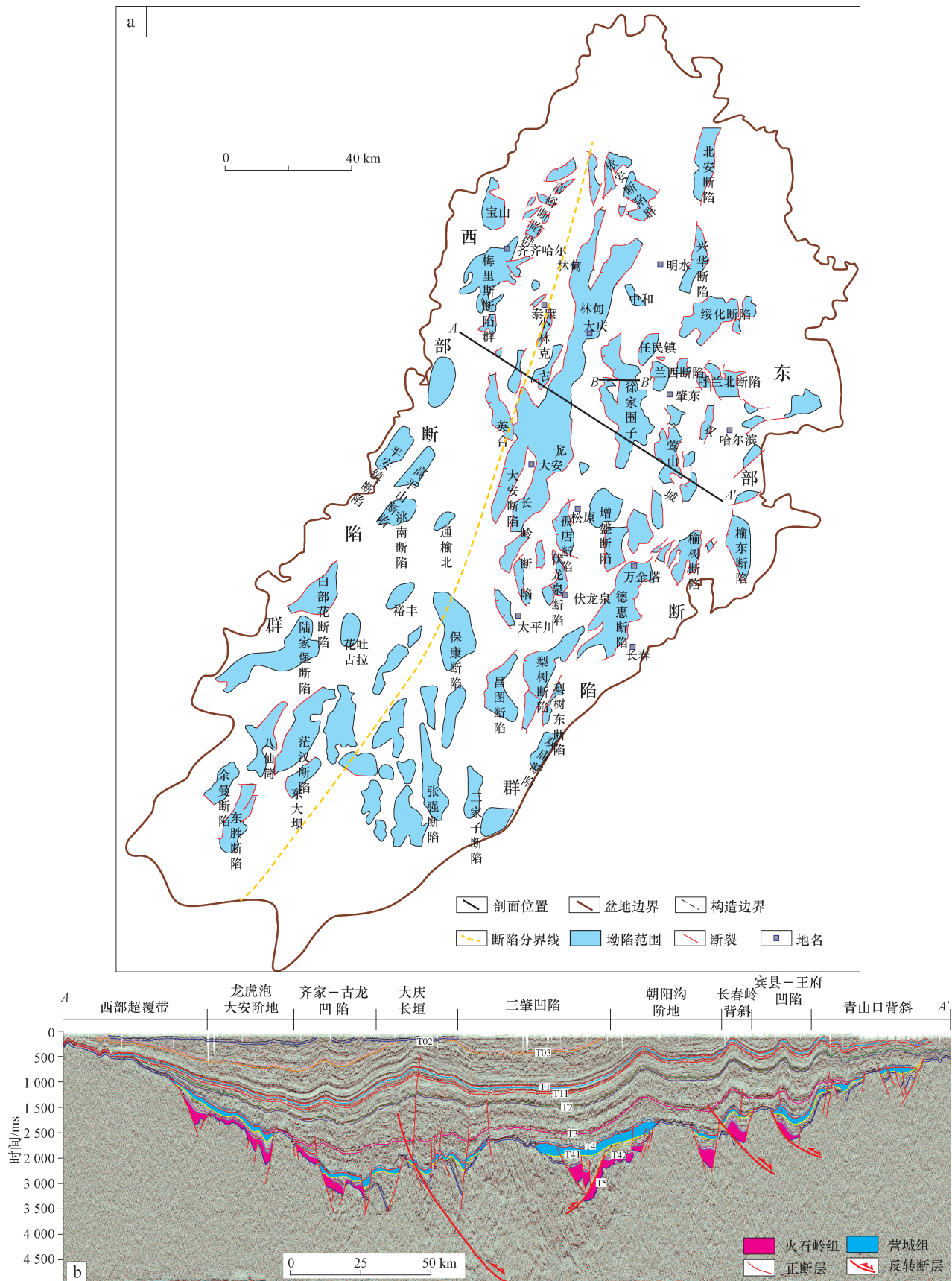


图 4 松辽盆地深层断陷平面展布规律(a)以及剖面结构特征(b)

Fig. 4 Planar distribution pattern (a) and section features (b) of the fault depression deep in the Songliao Basin

的变质核杂岩^[28]。而营城组断陷发育期,在松辽盆地以东发育一系列伸展极性为北西向的变质核杂岩^[28],同时,东北亚早白垩世大规模发育的A型花岗岩-火山岩的形成时代也呈现出西侧老、东侧新的趋势。不难看出,火石岭期断陷发育受控于西部体制——蒙古-鄂霍茨克洋关闭后的造山后伸展体制,而营城组断陷发育受控于东部体制——古太平洋向西俯冲的弧后伸展体制。两个拉张体制的叠加/转换时间在火石岭组沉积之后,营城组沉积之前。

松辽盆地整体上以张性构造为主,但也发育有多期挤压构造,展现了松辽盆地在宏观拉张背景下,也经历了多期挤压作用。盆地发育有多期不整合面,除登娄库组和营城组(T4,断陷期和坳陷期)、姚家组和青山口组(T11,坳陷期和坳陷前陆复合期)、白垩系和新生界三期之间(T02)的大型区域不整合外,断陷期的火石岭组、沙河子组和营城组之间(T42, T41)均发育区域角度不整合面(图3,图5)。断陷发育时期挤压作用比较强烈,尤其在沙河子组发育末期,自西向东逆冲断层较常见,地层遭受较强烈的挤压变形和剥蚀作用,在一些断陷内沙河子组和营城组之间出现了高角度不整合(图5);坳陷期挤压作用变弱, T11不整合面之下的登娄库组、泉头组和青山口组也可见一些自西向东的挤压构造,整体具有下强上弱和西强东弱的特点。而 T11不整合面以上的挤压构造(包括反转断层、逆冲断层和褶皱背斜)广泛发育(图4),挤压方向转变为自东向西,且呈现出明显的东强西弱的特点。T11界面以下的挤压作用应该是蒙古-鄂霍茨克洋关闭后的持续效应,而其上的挤压构造主要是由古太平洋板块

向西俯冲所致^[15,87]。88 Ma前的青山口组和姚家组的转换界面(T11)很有可能标志着蒙古-鄂霍茨克洋闭合影响的终结,东北亚全面进入太平洋构造域主导时期。

大杨树盆地位于松辽盆地西侧,大兴安岭造山带东缘,也展现了相近的挤压转换历史。盆地断陷期相当,3个主要断陷中有2个呈现出“西断东超”的结构特征^[95-96]。大杨树盆地发育的龙江组和甘河组两期火山岩,分别与松辽盆地火石岭组和营城组时代相对应。大杨树盆地早期发育的断陷受到了自西向东的挤压,形成了明显的逆断层以及反转构造,而白垩纪末期受到了自东向西的强烈挤压,盆地东部明显抬升遭受剥蚀^[97]。

5 松辽盆地成因机制再认识

松辽盆地位于蒙古-鄂霍茨克洋构造域和古太平洋构造域叠加区域,但早期多数研究者认为松辽盆地的形成和演化与古太平洋板块的俯冲作用有关^[25,82,98],与中国东部大部分中、新生代盆地成因并无二致^[99],即使前面谈到的兴安-蒙古裂谷盆地群,如海拉尔-塔木察格盆地、二连盆地,乃至距古太平洋俯冲带2 000 km以上的银额盆地,也多被认为是受控于古太平洋板块俯冲作用^[100]。松辽盆地的形成和演化受到古太平洋板块俯冲作用的影响和控制是不争的事实,但并不能轻视蒙古-鄂霍茨克洋东段闭合作用对它的影响。蒙古-鄂霍茨克带作为东北亚一个重要的构造单元^[76-80],其形成与演化无疑会对区

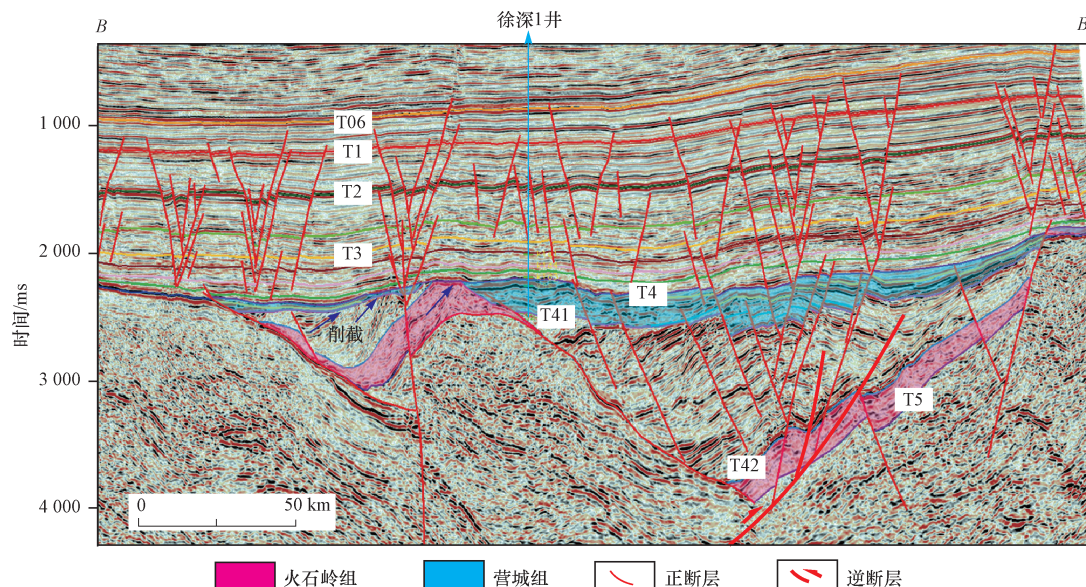


图5 松辽盆地徐家围子断陷地震剖面

Fig.5 Diagram showing the seismic section of Xujiaweizi Fault Depression in the Songliao Basin

域地质产生重要影响。而随着资料的进一步丰富,越来越多的证据显示蒙古-鄂霍茨克洋东段的关闭对中国东北地区的中生代盆-山演化产生了重要的影响^[21-22,24,38,40,44,47-48,50]。中国东北地区以及俄罗斯远东地区的岩浆活动特征和盆山耦合关系均展示出鄂霍茨克洋板块向南俯冲的事实,造山结束后的后伸展作用控制了松辽盆地及其西部中生代盆地群的形成和演化。

1) 蒙古-鄂霍茨克洋东段向南侧的华北-佳蒙板块俯冲。①蒙古-鄂霍茨克洋在早侏罗世(至少在三叠纪及以前)是开阔的泛大洋的一部分,西伯利亚板块和华北-佳蒙板块同在泛大洋西侧;西伯利亚板块为活动大陆边缘,其南侧也应为面向古太平洋(蒙古-鄂霍茨克洋)的同一个活动大陆边缘^[18,33]。②大兴安岭位于蒙古-鄂霍茨克缝合带和古太平洋俯冲带中央,岩浆岩以及火山岩最为发育,且向其东西两侧变少、变新(图1)。③兴安-蒙古裂谷盆地群展布方向呈弧状平行于蒙古-鄂霍茨克缝合带,且绝大多数盆地的轴向与构造带平行;而环西太平洋断陷盆地群平行于古太平洋缝合带展布,盆地的轴向同样展示出平行于缝合带的特征。

2) 蒙古-鄂霍茨克洋东段的关闭对中国东北地区形成了强大的挤压作用。持续的挤压作用改变了中国东北地区的地貌,由原来的东高西低转变为西高东低,在西部形成了蒙古高原,原有的造山带(尤其是古生代晚期的缝合带,如大兴安岭)发生活化并再次造山。在中国东北地区形成大量晚侏罗世到早白垩世早期的挤压构造,无论在蒙古国境内,还是在中国大兴安岭山脉,乃至到南部的燕山山脉,均发现了该时期的大型推覆构造^[101-104];在该区域的盆地内部下白垩统普遍发育向东、向南推覆的逆冲断层和背斜构造(图5)。强烈的挤压作用不仅造成中国东北地区的抬升剥蚀,还将更深层的地壳抬升、剥蚀,如松辽盆地基底抬升剥蚀和大兴安岭地区的隆升,导致基底大量的古生界花岗岩出露,杜11井基底糜棱岩化花岗岩的形成时代(146Ma)提供了一个很好的时间限定^[105]。

3) 早白垩世(K_1)早期,早期俯冲的板片拆沉,造成大量岩浆上涌,产生大规模火山沉积。从蒙古国中部到俄罗斯远东,以及中国东北的整个东北亚地区发生大量岩浆侵入和火山喷发,在松辽盆地的火山岭组中发育有大规模的火山岩。此时,整个东北亚地区发育以变质核杂岩、断陷盆地为代表的大规模伸展构造,在蒙古-鄂霍茨克缝合带以南发育一系列呈弧状分布的断陷盆地,包括海拉尔-塔木察格盆地、二连盆地以

及银额盆地等。这些盆地的展布方向以及轴向与蒙古-鄂霍茨克缝合带展布相一致^[45-46]。断陷盆地结构多呈现西断东超的特征,如海拉尔盆地和松辽盆地的火石岭组断陷。时空一致性特征表明,松辽盆地的断陷发育可能是早白垩世蒙古-鄂霍茨克缝合带东段闭合引发的造山后伸展作用下的产物^[28]。

4) 火石岭组和沙河子组沉积后,古太平洋板块也俯冲到松辽盆地之下并回返,甚至可能与早期俯冲的蒙古-鄂霍茨克洋大洋板片双向交会,松辽盆地再次发生大规模火山活动和热隆裂陷,发育了营城组断陷(图4,图5)。该期火山活动规模更大,拉张速率更快^[21-22],沉积了一套火山岩-沉积岩组合^[84]。在断陷发育时期,短期挤压和大规模拉张裂陷同时存在,地壳也在不断整体抬升,形成多个挤压构造和不整合面(图5)。

5) 早白垩世晚期到晚白垩世,随着蒙古-鄂霍茨克洋影响渐微,早期巨量热隆的地幔冷却,松辽盆地地壳发生大幅度沉降,形成了大型坳陷湖盆,进入坳陷期稳定沉积阶段。沉积了登娄库组、泉头组到青山口组沉积构造层。白垩纪晚期(88 Ma左右),因太平洋板块重组,Izanaqi 板块由斜向俯冲转向正向低角度俯冲,来自古太平洋板块的俯冲挤压作用,致使松辽盆地整体抬升遭受剥蚀,形成了青山口组顶界(T11)区域不整合,此时,鄂霍茨克缝合带的影响已基本消失,东北亚地区全面受到古太平洋构造域的控制。随着挤压增强,早期缝合带——张广才岭造山带活化,造山隆升,松辽盆地进入前陆和热沉降复合发展时期^[87]。松辽盆地东部抬升剥蚀,沉降中心和沉积中心不断向西迁移,主要物源从西北大兴安岭造山带转变为东侧的张广才岭方向,沉积了东厚、西薄的姚家组、嫩江组、四方台组和明水组构造层,嫩江组展现了强烈的向西进积特征。白垩纪末期的盆地整体抬升遭受剥蚀,形成了T02区域角度不整合。新生代以来,盆地构造活动微弱,沉积局限在盆地西部白垩纪末期的侵蚀低洼地^[15,87]。

6 结论

1) 蒙古-鄂霍茨克洋自晚古生代开始至晚中生代,自西向东呈“剪刀状”幕式闭合,对其缝合带南北两侧块体产生多期次的叠加改造作用,形成了大量挤压推覆构造,随后的造山后伸展作用催生了一系列伸展盆地,且触发了大规模的岩浆活动。

2) 松辽盆地位于蒙古-鄂霍茨克和古太平洋两

个构造域交汇处,可能是蒙古-鄂霍茨克洋和古太平洋(Izanagi 洋)板片双向俯冲作用的产物。夹于两个构造域之间的松辽地块上发生的两次地幔热隆活动,导致火石岭组火山岩-沙河子陆相碎屑岩和营城组火山岩-碎屑岩两期断陷盆地的形成;随后的巨幅热沉降,造就了中国东部独一无二的大型坳陷盆地。

3) 白垩纪晚期,蒙古-鄂霍茨克洋东段闭合后的挤压效应基本消失,来自古太平洋的俯冲挤压作用占据主导地位,松辽盆地的构造、沉积演化开始受到古太平洋构造域的全面控制。

4) 坳陷期发育的青山口组一段深湖相富含有机质泥岩,T11 不整合面上下河流-三角洲相复合砂体和前陆-坳陷复合期发育的几乎覆盖全盆地的嫩江组一、二段深湖相泥岩,形成了良好的生储盖组合;白垩纪晚期的挤压不仅形成了大庆长垣等大型圈闭构造,同时驱动和促进了油气运移和成藏,为形成举世瞩目的特大型陆相油气田奠定了基础^[106]。

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