第48卷第1期 中 国 地 质 Vol.48, No.1
2021年2月 GEOLOGY IN CHINA Feb. , 2021

doi: 10.12029/gc20210116

许强伟,王玭,王志强,王成明,郑义,方京. 2021. 内蒙古克什克腾旗长岭子斜长花岗斑岩锆石U-Pb年龄、成因与碰撞造山作用[J]. 中国地质, 48(1): 229-246.

Xu Qiangwei, Wang Pin, Wang Zhiqiang, Wang Chengming, Zheng Yi, Fang Jing. 2021. Zirzon U-Pb age and petrogenisis of plagiogranite porphyry in Changlingzi, Hexigten Banner, Inner Mongolia and its collision orogery[J]. Geology in China, 48(1): 229-246(in Chinese with English abstract).

内蒙古克什克腾旗长岭子斜长花岗斑岩锆石U-Pb年龄、成因与碰撞造山作用

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提要:内蒙古克什克腾旗长岭子斜长花岗斑岩位于大兴安岭锡林浩特增生杂岩带内。本文对长岭子斜长花岗斑岩进行了主微量元素地球化学以及锆石U-Pb年代学和Lu-Hf同位素研究。长岭子斜长花岗斑岩锆石^{206}Pb/^{238}U加权平均年龄为(248.1±4.7) Ma,是早三叠世岩浆活动的产物;继承锆石除外,样品中锆石具有正的$\varepsilon_{Hf}(t)$值（5.78~12.41）,二阶段模式年龄T_{DM2}分别为914~488 Ma。长岭子斜长花岗斑岩具有较高的SiO_2、Na_2O和Al_2O_3含量以及较低的Fe_2O_3、MgO和CaO含量,属于偏铝质-过铝质的低钾-钙碱性系列I型花岗岩,富集Rb、K、U、Th、Pb、Sr等大离子亲石元素,亏损Nd、Ta、Ti等高场强元素。同时,斜长花岗斑岩具有高Sr低Y以及高Sr/Y比等特点,具有典型的埃达克质岩石特征,形成于加厚下地壳的部分熔融。综合上述地球化学特征,本文认为长岭子斜长花岗斑岩来源于加厚新生下地壳的部分熔融,表明早三叠世兴蒙地区并非岛弧的环境,而是处于碰撞造山环境,古亚洲洋在该时期已经闭合。

关 键 词:大兴安岭;早三叠世岩浆岩;锆石U-Pb定年;锆石Hf同位素;地球化学;古亚洲洋;地质调查工程

中图分类号:P597;P588.12^{+}1 **文献标志码:**A **文章编号:**1000-3657(2021)01-0229-18

Zirzon U-Pb age and petrogenisis of plagiogranite porphyry in Changlingzi, Hexigten Banner, Inner Mongolia and its collision orogeny

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收稿日期:2018-04-03;**改回日期:**2018-08-15

基金项目:国家自然科学基金青年基金项目(4160206)和克什克腾旗金达矿业开发有限责任公司项目(20150008)联合资助。

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Abstract: The Changlingzi plagiogranite porphyry is located in the Xilinhot Late Paleozoic Accretion Complex within the Da Hinggan Mountains. This study is focused on the zircon U−Pb isotopic geochronology, Hf isotopic composition analysis and geochemistry of the Changlingzi plagiogranite porphyry. Zircon crystals from the plagiogranite porphyry yielded weighted average $^{206}Pb/^{238}U$ age of (248.1±4.7)Ma. The zircons from this porphyry have positive $\varepsilon_{Hf}(t)$ values from 5.78 to 12.41, with $T_{DM2}(Hf)$ ages from 914 to 488Ma. The plagiogranite porphyry has high content of SiO_2, Na_2O and Al_2O_3, and low content of TiO_2, MgO and CaO, showing a metaluminous - peraluminouslow− K to calc− alkaline affinity, with LREE enrichment and HREE depletion, suggesting I−type granite. In addition, the plagiogranite porphyry has high Sr and low Y values as well as high Sr/Y ratios (74.5~103.4), indicating that the plagiogranite porphyry belongs to adakite. It is suggested that the plagiogranite porphyry was formed by partial melting of the thickened newborn lower crust. And in Early Triassic, Xing'an - Mongolian orogenic belt was in a collision−orogeny tectonic setting, indicating that the Paleo−Asian Ocean had been closed in this period.

Key words: Da Hinggan Mountains; Early Triassic magmatic rocks; zircon U−Pb ages; zircon Hf isotope; geochemistry; paleo−Asian Ocean; geological Survey engineering

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Fund support: Supported by National Natural Science Foundation of China (No. 4160206) and the program Jinda Mining Development Co., Ltd., of Hexigten Banner, Inner Mongolia (No. 20150008).

1 引 言

中亚造山带北与西伯利亚板块相邻,南与华北克拉通和塔里木克拉通毗邻(Sengör et al., 1993),在其构造演化过程中,经历了大洋开启与俯冲、板块碰撞拼合、后造山等阶段,由岛弧、蛇绿岩、洋岛、海山、增生楔、洋底高原和微陆块等增生拼贴而成(Dobretsov et al., 1995; Windley et al., 2007)。中国东北地区(兴蒙造山带)位于中亚造山带东段,夹于西伯利亚板块和华北克拉通之间,主要由松辽盆地、大兴安岭地区、华北克拉通北缘和吉黑褶皱带组成,以微地块与褶皱带的交织分布为特征(图1)。该地区构造演化历史复杂,既有古亚洲洋演化特征,又有滨太平洋造山带所叠加的特点(黄汲清, 1987; 任纪舜等, 1990; 邵济安等, 1995; 吴福元等, 1999; 彭玉鲸等, 2002),是大陆造山带地质构造研究遗留问题和争议较多的地区,也是研究构造域转换、叠合成矿作用的理想地区(陈衍景等, 2009, 2012; Chen et al., 2016)。

有关古亚洲洋闭合的时间就是目前争议较多的一个问题,主要有以下两种观点:(1)一部分学者认为古亚洲洋闭合于中晚泥盆世至早石炭世(Tang , 1990; 邵济安, 1991, 2015; 徐备等, 1997, 2014);另一部分学者认为,整个古生代期间古亚洲洋板片向南北两侧不断俯冲,并引起西伯利亚板块和华北克拉通不断的相对增生,最终古亚洲洋于晚二叠世至早三叠世闭合(王荃, 1991; Xiao et al., 2003, 2009; 李锦轶, 2007; Jian et al., 2008;陈斌等, 2009; 石玉若等, 2014; Chen et al., 2016)。内蒙古锡林浩特—林西地区是涉及上述争议关键地区之一,其广泛发育的中生代火成岩,蕴含着区域构造演化的重要信息(吴福元等, 1997),是揭示兴蒙造山带大地构造及岩浆演化的关键。本文对位于锡林浩特—林西地区的克什克腾旗长岭子斜长花岗斑岩进行了岩石学、岩石地球化学及锆石U−Pb年代学研究,进而探讨了其形成时代、岩石成因以及构造环境,为其构造环境和岩石成因提供依据,同时为古亚洲洋闭合的时间提供证据。

2 区域地质背景

中亚造山带西起哈萨克斯坦向东延伸至西伯利亚,宽约300 km,其北为西伯利亚克拉通,南为塔

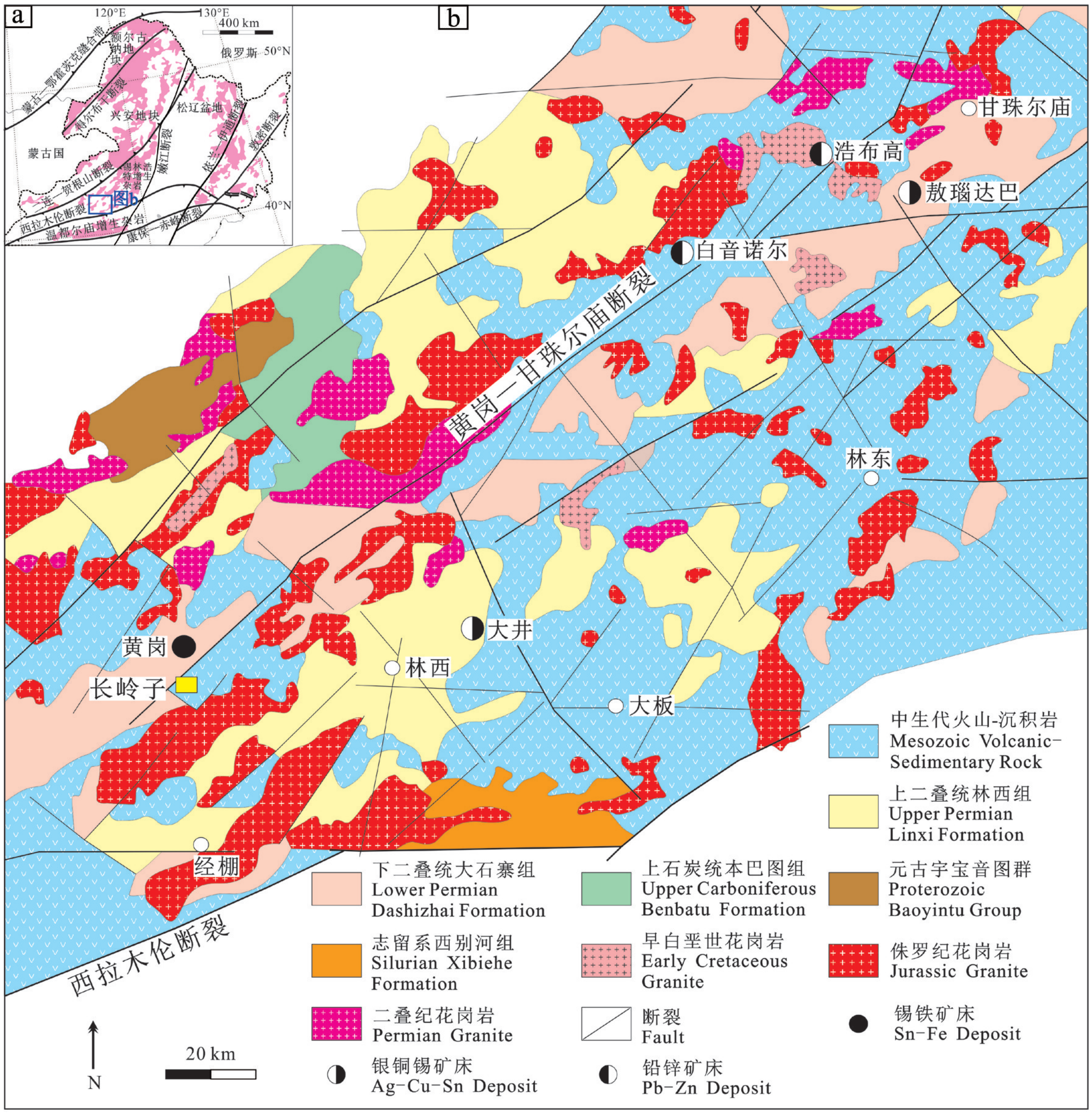

图1 中国东北大地构造简图(a，据陈衍景等, 2012; Chen et al., 2016修改)及黄岗—甘珠尔庙地区地质简图(b，据芮宗瑶等, 1994修改)

Fig.1 Simplified tectonic map of Northeast China (a, modified after Chen et al., 2012, 2016b); Sketch geological map of the Huanggang–Ganzhuermiao area (b, modified after Rui et al., 1994)

里木及华北克拉通(Xiao et al., 2003)。大兴安岭属于中亚造山带东段，其北以蒙古—鄂霍茨克缝合带与西伯利亚克拉通为界，南以康保—赤峰断裂与华北克拉通为界，东以嫩江断裂与松辽盆地为界，向西延伸至俄罗斯、蒙古境内(图1a)，区内包括4个主要的构造单元，自北向南依次为额尔古纳地块、兴安地块、锡林浩特晚古生代增生杂岩带以及温都尔庙早古生代弧增生杂岩带，分别以得尔布干断裂、二连—贺根山断裂、西拉木伦断裂为界(图1a；祁进平等, 2005; 陈衍景等, 2012; Li et al., 2012a)。二连—贺根山断裂带(索伦缝合带)，被认为是古亚洲洋最终闭合的位置(祁进平等, 2005; 陈衍景等, 2012)。

该区主要发育4个岩石地层序列：以额尔古纳地块中新元古代兴华渡口群为代表的前寒武纪变质基底(Wu et al., 2012)；由片岩、砂质页岩、大理岩和安山岩组成的早古生代变质火山–沉积岩序列；广泛发育的晚古生代低级变质火山–沉积岩；侏罗纪—白垩纪中酸性火山岩(Wu et al., 2011; Zhou et al., 2012; Zhai et al., 2014)。该区侵入岩主要形成

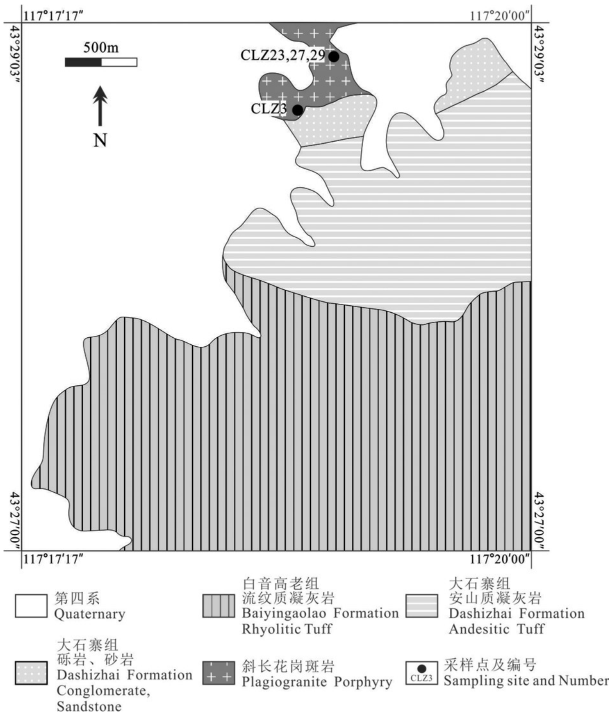

图2 长岭子研究区地质简图(据内蒙古山金地质矿产勘查有限公司❶修改)
Fig.2 Geological map of the Changlingzi area (after Inner Mongolia Shandong Gold Geological and Mineral Exploration Co. Ltd.❶)

于晚古生代和中生代,并有少量早古生代侵入岩出露于漠河、塔河以及多宝山地区(Ge et al., 2005; Liu et al., 2012; Wu et al., 2005, 2012)。晚古生代和中生代侵入岩主要为花岗岩类,可见少量晚古生代镁铁质—超镁铁质岩石沿构造单元的边界部位发育(刘建明等, 2004)。

内蒙古克什克腾旗长岭子地区位于大兴安岭南段黄岗—甘珠尔庙地区,西拉木伦断裂、二连—贺根山断裂以及嫩江断裂的交汇处,属于中亚造山带的东段(图1a)。区域内主要出露有元古宙、古生代、中生代和新生代地层,其中二叠纪和侏罗纪地层出露最为广泛。

区内古生代地层经历了强烈的褶皱,黄岗—甘珠尔庙复式背斜呈NE-SW向贯穿本区。区内断裂构造发育,以NE-NNE向和EW向为主。这些断裂近乎等距分布,相互切割成格子状,构成区域基本构造格架(图1b;舒启海等, 2011)。NE向的黄岗—甘珠尔庙断裂带对本区二叠纪和侏罗纪地质发展起着重要的控制作用(王琦, 1991; 舒启海等, 2011)。

区内海西期以来的岩浆活动频繁,表现为强烈的火山喷发和岩浆侵入活动,且自SW向NE火山岩呈现由基性向中酸性演化的趋势(王琦, 1991; 舒启海等, 2011)。伴随强烈的岩浆活动,区内燕山期成矿作用活跃,成为中亚造山带兴蒙段最主要的大规模成矿作用发生时期(陈衍景等, 2009)。区内晚侏罗世火山活动表现为一套陆相喷发的中酸性火山岩系列,其分布受区域构造的控制,总体呈NE向展布(图1c)。

3　岩体地质

长岭子地区地层出露简单,主要有早二叠世大石寨组、早白垩世白音高老组及第四系(图2)。大石寨组厚度大于1000 m,主要岩性为英安质岩屑晶屑凝灰岩、砾岩、砂岩,分布于研究区北部。白音高老组主要由流纹质岩屑晶屑凝灰岩和流纹质晶屑凝灰岩组成,分布于研究区南部,与大石寨组呈不整合接触关系,呈盖层状覆盖其上(图2)。

区内褶皱构造和断裂构造地表发育不明显。仅由钻孔揭露出区内发育少量断裂构造、构造角砾岩带和揉皱构造。

区内岩浆岩出露较少,仅在北部出露斜长花岗斑岩体,呈岩株状产出,侵入到大石寨组砾岩和砂岩中,出露面积约0.5 km^2(图2)。斜长花岗斑岩体地表呈黄白色,斑状结构,块状构造(图3a)。斑晶含量40%~50%,主要为斜长石(30%~40%)、钾长石(5%~15%)及少量黑云母(2%)和角闪石(1%)。斜长石斑晶呈白色—灰白色肉眼可见(图3a),自形—半自形板状、粒状,常见聚片双晶,有时可见格子双晶,粒度介于0.2~2 mm,普遍发生绿帘石化、高岭土化和绢云母化(图3b);钾长石斑晶半自形板状,常见典型的卡式双晶,粒度介于0.5~2 mm,普遍发生弱的高岭土化(图3c);黑云母斑晶多为褐色片状,一组极完全解理(图3d),粒度介于0.5~1 mm;角闪石可见其特征的菱形横切面,粒度介于0.1~0.2 mm,多被绿帘石交代(图3e)。基质为微晶-隐晶质,含量50%~60%,成分主要为石英、斜长石,钾长石以及少量的云母类矿物,半自形—他形粒状,粒度＜0.1 mm。

4　样品及测试方法

4.1　样品

本次研究共采集4块斜长花岗斑岩样品

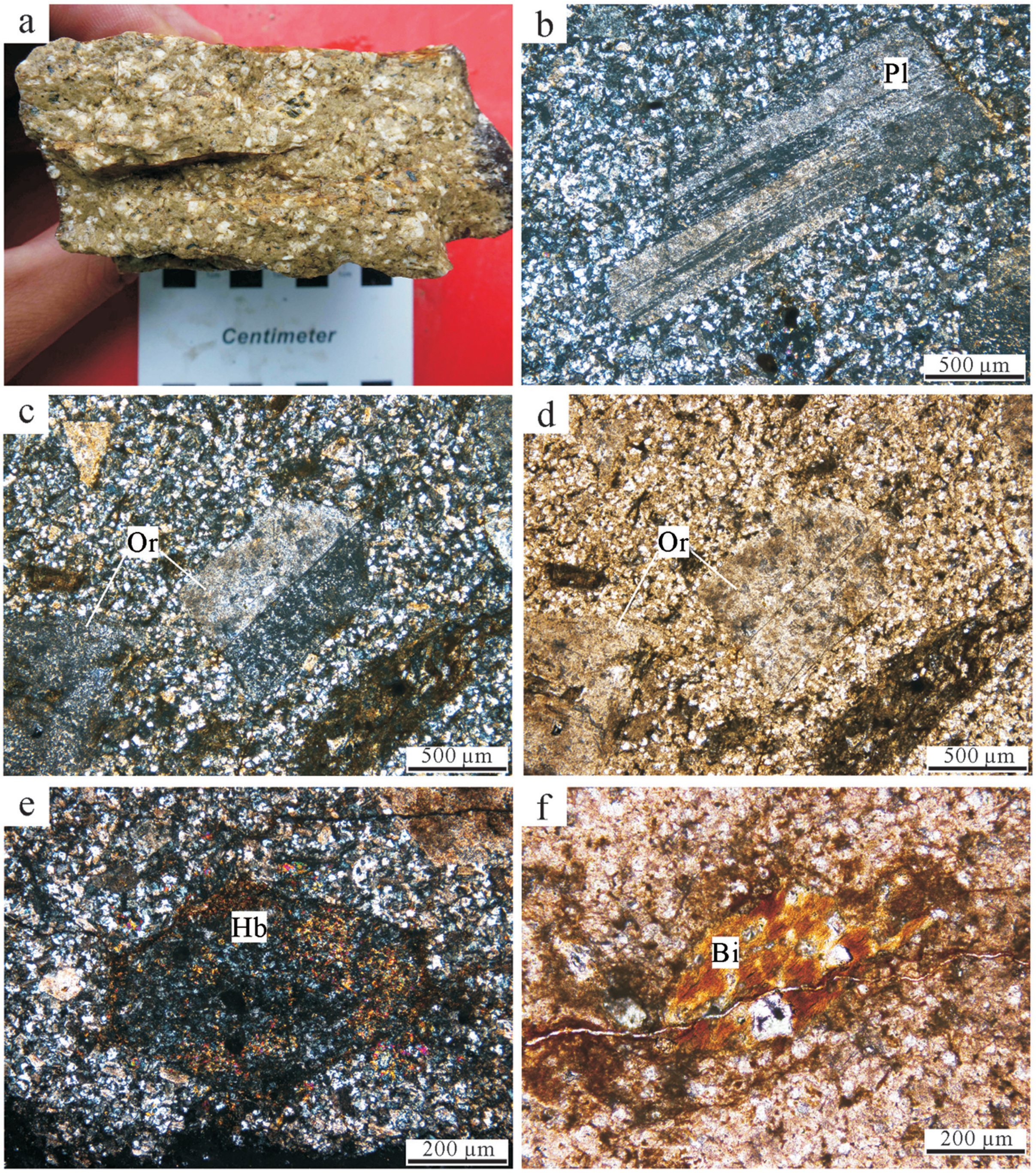

图3 长岭子斜长花岗斑岩岩相学特征

a—斜长花岗斑岩手标本照片;b—斜长花岗斑岩中斜长石斑晶发生绢云母化,可见聚片双晶,基质主要为长英质(正交偏光);c—斜长花岗斑岩中正长石斑晶,可见典型的卡式双晶(正交偏光);d—斜长花岗斑岩中正长石斑晶(单偏光);e—斜长花岗斑岩中角闪石斑晶,角闪石被绿帘石交代(正交偏光);f—斜长花岗斑岩中黑云母斑晶(单偏光);Q—石英;Pl—斜长石;Or—正长石;Hb—角闪石;Bi—黑云母

Fig.3 Petrographic characteristics of the plagiogranite porphyry in Changlingzi area

a−Hand specimen photo of the plagiogranite porphyry; b−The feldspar phenocrysts with sericitizationin in plagiogranite porphyry, polysynthetic twin observed in feldspar and the matrix being predominantly felsic (crossed nicols); c−The orthoclase phenocrysts in the plagiogranite porphyry with carlsbad twin observed in orthoclase (crossed nicols); d−The orthoclase phenocrysts in the plagiogranite porphyry (plainlight); e−The hornblende phenocrysts in the plagiogranite porphyry, the hornblende replaced by epidote (crossed nicols); f−The biotite phenocryst in the plagiogranite porphyry (plainlight);Q−Quartz; Pl−Plagioclase; Or−Orthocalse; Hb−Hornblende;Bi−Biotite

（CLZ3, 23, 27, 29）进行主量及微量元素分析。选择样品CLZ27进行锆石U-Pb定年及Hf同位素分析，采样位置如图2所示。

4.2 分析方法

全岩主微量分析在北京大学造山带与地壳演化教育部重点实验室进行，其中主量元素测试使用XRF（X射线荧光光谱）方法，微量元素测试使用ICP-MS（高分辨等离子质谱）方法（详见张文慧等, 2005）。样品测试误差普遍小于10%，稀土元素均小于5%。

锆石U-Pb同位素分析在北京大学造山带与地壳演化教育部重点实验室进行。激光剥蚀束斑直径为32 μm，激光能量密度为10 J/cm^2，剥蚀频率为5 Hz。实验中采用He作为剥蚀物质的载气，Ar为辅助气。锆石年龄计算采用标准锆石Plesovice（337 Ma）作为外标（Sláma et al., 2008），标准锆石91500为监控盲样。采样方式为单点剥蚀，每完成5个测点的样品测定，加测标样1次。在15个锆石样品点前、后各测2次NIST610。样品的同位素比值和元素含量数据处理采用GLITTER4.4.2程序计，普通铅校正使用Anderson（2002）给出的程序计算，加权平均年龄及谐和图的绘制使用Isoplot/Ex（3.0）（Ludwig, 2003）完成。分析数据及锆石U-Pb谐和图给出误差为2σ，95%的置信度。

锆石Hf同位素分析在西北大学地质学系大陆动力学教育部重点实验室进行。锆石原位Lu-Hf同位素测定采用Nu plasma HR (wrexham,UK)多接收电感耦合等离子体质谱仪完成(MC-ICP-Ms)。激光斑束直径44 μm，频率为8 Hz，激光能量为90 mJ，采用锆石国际标样91500作外标，每隔10个数据点测试1次标样。标样^{176}Hf/^{177}Hf和^{176}Lu/^{177}Hf值分别为0.282314±21和0.0003，与Wu et al.（2006）和Goolaerts et al.（2004）报道的数据在误差范围内一致，Hf分析步骤和数据处理方法详见文献Yuan et al.（2004）。

5 分析结果

5.1 元素地球化学

5.1.1 主量元素

长岭子斜长花岗斑岩样品主量元素组成见表1，SiO$_2$含量介于69.45%~74.40%，Al$_2$O$_3$含量介于14.56%~16.74%，贫MgO（0.23%~0.54%）、Fe$_2$O$_3^T$（1.54%~2.84%）、CaO（0.23%~3.78%），富Na（Na$_2$O= 4.78%~6.57%），贫K（K$_2$O= 0.66%~1.63%），K$_2$O+Na$_2$O介于5.52%~8.30%，K$_2$O/Na$_2$O介于0.14~0.25。在TAS图（图4a）中，样品均属于亚碱性系列，成分点集中落在花岗闪长岩-花岗岩区域。铝饱和指数A/CNK为0.97~1.35，A/NK值为1.31~1.74，为偏铝质-过铝质岩石（图4b）。里特曼指数（δ）介于1.08~2.45，属于钙碱性系列，在SiO$_2$-K$_2$O图解（图4c）中落在低钾—钙碱性系列区域。

5.1.2 微量元素特征

长岭子斜长花岗斑岩样品微量元素分析结果见表1。岩体呈现右倾的球粒陨石标准化稀土配分曲线（图5a），轻稀土富集，重稀土亏损；岩体∑REE含量为49.93×10^{-6}~68.67×10^{-6}, LREE/HREE为3.71~5.31, (La/Yb)$_N$介于13.90~29.98; (La/Sm)$_N$ = 3.30 ~ 4.96，轻稀土分馏明显，(Gd/Yb)$_N$ = 2.46~2.72，重稀土分馏不明显；无明显Eu异常，Eu/Eu*值为0.83 ~ 1.06。

在原始地幔标准化微量元素蛛网图上（图5b），岩体富集Rb、K、U、Th、Pb、Sr，亏损Nd、Ta、Ti。岩体具有高Sr（444×10^{-6}~602×10^{-6}）（除1个样品Sr = 161×10^{-6}含量较低以外），低Y（4.6×10^{-6}~6.3×10^{-6}）以及高Sr/Y（34.1~103.4）等特点（表1）。

5.2 锆石LA-ICP-MS U-Pb年龄

本次研究所选取的岩石样品中大多数锆石基本特征类似，为半自形—自形短柱状或长柱状，粒径77~176 μm，无色到略带浅黄色，透明度高，裂隙少。CL图像显示（图6a），大部分锆石可见振荡环带，为典型的岩浆锆石。斜长花岗斑岩样品中锆石的Th、U含量平均偏高，变化大，Th含量为26.0×10^{-6}~502.8×10^{-6}，U含量为76.4×10^{-6}~893.5×10^{-6}，Th/U比值在0.21~1.20，平均值为0.48（表2），显示出岩浆成因锆石的特点（吴元保和郑永飞, 2004），与CL照片（图6a）所得的结论一致。

长岭子岩浆岩锆石U-Pb年龄分析结果见表2和图6。由于样品颗粒大小、厚度的影响，本次研究最终获得20个锆石测年数据，其中，8、11和18号测点^{206}Pb/^{238}U年龄分别为(326 ± 6) Ma、(293 ± 4) Ma和(437 ± 5) Ma，Th/U值分别为1.20、0.36和0.65，锆石发育振荡环带，为岩浆锆石；12、13和20号测

表1 长岭子斜长花岗斑岩全岩主量元素（%）和微量元素（10^{-6}）分析结果

Table1 Major (%)and trace(10^{-6}) elements compositions of the plagiogranite porphyries in Changlingzi area

样品号	CLZ3	CLZ23	CLZ27	CLZ29	样品号	CLZ3	CLZ23	CLZ27	CLZ29
SiO_2	74.40	69.45	70.48	70.47	P	230	470	430	460
TiO_2	0.16	0.34	0.32	0.34	Pb	147	5.40	14.2	8.80
Al_2O_3	14.56	16.74	14.95	16.45	Rb	60.9	55.8	22.9	55.8
$Fe_2O_3^T$	1.92	1.97	2.84	1.54	Ti	970	2100	1900	2090
CaO	0.23	1.17	3.78	1.41	Ni	1.30	6.80	8.20	6.40
MgO	0.23	0.54	0.44	0.30	La	16.3	13.1	9.30	9.70
MnO	0.05	0.04	0.10	0.03	Ce	32.3	26.6	16.5	18.6
K_2O	1.48	1.57	0.66	1.63	Pr	3.55	3.20	2.16	2.36
Na_2O	5.31	6.47	4.78	6.57	Nd	12.4	11.9	9.00	9.30
P_2O_5	0.05	0.10	0.09	0.10	Sm	2.12	2.34	1.82	1.86
LOI	1.43	1.45	1.46	1.31	Eu	0.43	0.65	0.54	0.57
Total	99.82	99.84	99.99	100.15	Gd	1.18	1.73	1.58	1.46
K_2O/Na_2O	0.28	0.24	0.14	0.25	Tb	0.15	0.22	0.20	0.19
A/CNK	1.35	1.16	0.97	1.09	Dy	0.85	1.25	1.10	1.03
A/NK	1.41	1.36	1.74	1.31	Ho	0.16	0.24	0.22	0.21
Ba	147	521	274	510	Er	0.43	0.62	0.58	0.55
Cr	10.0	30.0	30.0	30.0	Tm	0.06	0.09	0.08	0.08
Hf	3.40	3.10	2.90	3.10	Yb	0.39	0.55	0.48	0.49
Nb	2.00	2.00	1.80	1.90	Lu	0.06	0.08	0.07	0.07
Sr	161	602	444	450	Y	4.60	6.10	6.30	5.50
Ta	0.20	0.20	0.10	0.20	ΣREE	75.0	68.7	49.9	52.0
Th	3.87	2.42	1.93	2.49	$(La/Yb)_N$	29.98	17.08	13.90	14.20
U	1.29	0.93	0.75	0.70	$(La/Sm)_N$	4.96	3.61	3.30	3.37
V	3.00	58.0	43.0	48.0	$(Gd/Yb)_N$	2.50	2.60	2.72	2.46
Zr	127	117	115	114	Sr/Y	34.09	103.39	74.48	88.63
K	12000	12800	5300	13200	Cr/Ni	7.69	4.41	3.66	4.69

点 ^{207}Pb/^{206}Pb年龄在1827~2458 Ma，Th/U值介于0.24~0.55，应为继承锆石；其余14个测点获得^{206}Pb/^{238}U加权平均年龄为(248.1 ± 4.7)Ma（MSWD＝4.7）。

5.3 锆石Hf同位素特征

锆石Hf同位素分析结果见表3，斜长花岗斑岩中锆石的^{176}Lu/^{177}Hf比值均小于0.002，说明锆石形成以后具有较低的放射性成因Hf积累，因而^{176}Hf/^{177}Hf测值可以代表锆石形成时的^{176}Hf/^{177}Hf比值（吴福元等, 2007）。表中斜长花岗斑岩$f_{Lu/Hf}$为−0.99~−0.96，平均为−0.97，明显小于镁铁质地壳的$f_{Lu/Hf}$（−0.34）和硅铝质地壳的$f_{Lu/Hf}$（−0.72）（Vervoort et al., 1996），故二阶段模式年龄能反映其源区物质从亏损地幔被抽取的时间。根据Hf同位素相关计算公式（吴福元等, 2007），采用硅铝质大陆地壳$f_{Lu/Hf}$计算了2个火成岩样品的初始$\varepsilon_{Hf}(t)$、T_{DM1}和T_{DM2}（表3）。

斜长花岗斑岩^{176}Lu/^{177}Hf和^{176}Hf/^{177}Hf分别为0.000315~0.001478和0.282786~0.282968。计算出$\varepsilon_{Hf}(t)$为5.8~12.2，$f_{Lu/Hf}$变化范围在−0.99~−0.96，T_{DM2}变化范围在909~492 Ma。

6 讨论

6.1 岩石成因

研究区早三叠世斜长花岗斑岩造岩矿物主要包括石英、斜长石、碱性长石以及黑云母和角闪石等暗色矿物（图3）；地球化学方面属于低钾-钙碱性系列，铝饱和指数指示岩石为偏铝质-过铝质（图5b）。在K_2O-Na_2O图解中（图7）（Collins et al., 1982）研究区样品皆落入I型花岗岩区域，以上岩石学和元素地球化学特征表明研究区斜长花岗斑岩

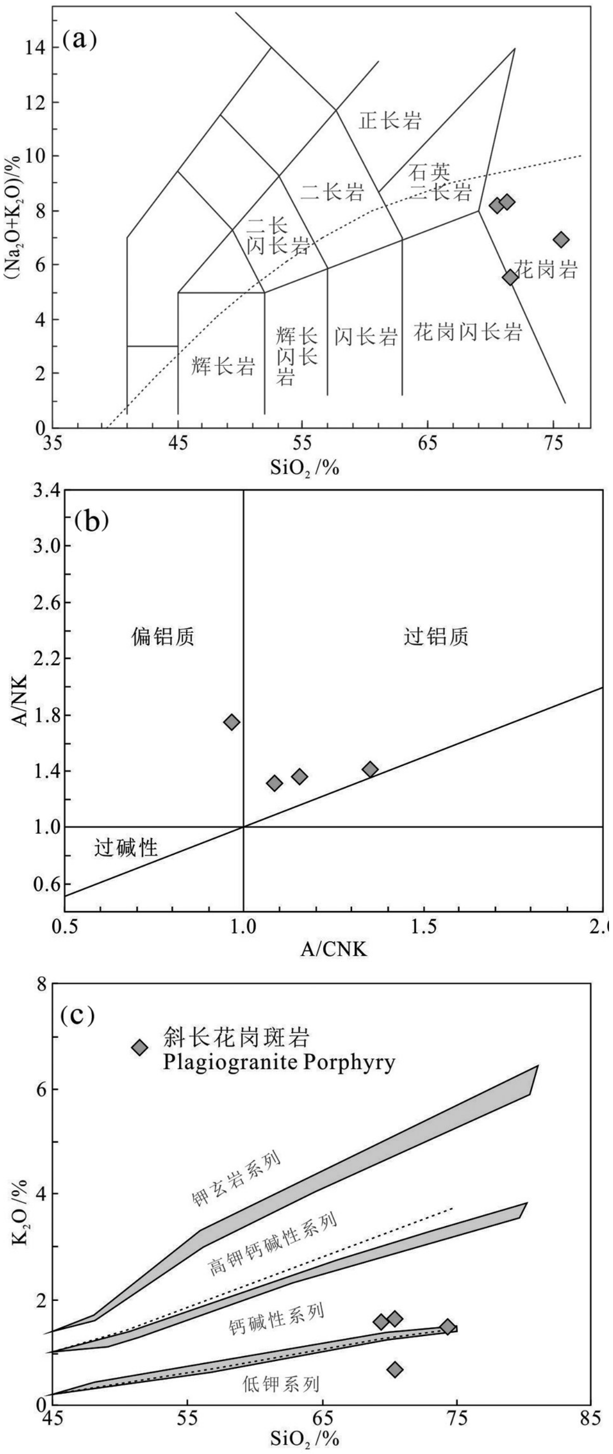

图4 长岭子斜长花岗斑岩SiO_2−(Na_2O + K_2O)图解(a，据Le Maitre, 2002)、A/CNK−A/NK图解(b，据Maniar and Piccoli, 1989)和SiO_2−K_2O图解(c，据Rickwood, 1989)

Fig.4 SiO_2−(Na_2O + K_2O) (a,after Le Maitre, 2002), ACNK−ANK (b,after Maniar and Piccoli, 1989) and SiO_2−K_2O (c, after Rickwood, 1989) diagrams for plagiogranite porphyries in Changlingzi area

属于I型花岗岩类。I型花岗岩起源于下部地壳(Infracrustal)或未经风化作用的火成岩(Igneous)的部分熔融，通过Hf同位素的示踪，可以对岩浆源区物质组成进行有效的约束(刘建峰等，2014)。

锆石的Lu−Hf同位素体系由于具有很高的封闭温度，其同位素比值不会随后期部分熔融或分离结晶而变化，因此锆石$\varepsilon_{\mathrm{Hf}}(t)$值代表了岩浆源区的成分特征。通常认为具有正$\varepsilon_{\mathrm{Hf}}(t)$值的花岗质岩石来自亏损地幔或从亏损地幔中新增生的年轻地壳物质部分熔融(隋振民等, 2009)，负值$\varepsilon_{\mathrm{Hf}}(t)$通常代表古老地壳成因(吴福元等, 2007)。前人研究表明，兴蒙造山带与华北克拉通北缘以西拉沐沦河断裂为界，二者显生宙时期的岩浆岩显示了截然不同的同位素特征。兴蒙造山带的岩浆岩多具有正的$\varepsilon_{\mathrm{Hf}}(t)$值以及年轻的模式年龄，显示亏损地幔或新生地壳来源的特征(吴福元等, 1999; Jahn et al., 2000, 2004; 洪大卫等, 2000, 2003; Wu et al., 2000; Chenet al., 2009; Liu et al., 2011, 2013)；而华北克拉通北缘的多具有负的$\varepsilon_{\mathrm{Hf}}(t)$值以及古老的模式年龄，显示富集岩石圈地幔或古老地壳物质重熔的特征(Yang et al., 2006; 田伟等, 2007; Zhang et al., 2007, 2009a, 2009b; 王芳等, 2009; Shi et al., 2010)。长岭子早三叠世斜长花岗斑岩在同位素特征上显示了正的$\varepsilon_{\mathrm{Hf}}(t)$值以及年轻的模式年龄(图8)，因此其源区可能为亏损地幔或新增生下地壳。此外，在锆石测年数据中出现古生代(测点8、11和18年龄分别为(326±6) Ma、(293±4) Ma和(437±5) Ma)和元古宙(测点12、13和20年龄分别为(2458±31) Ma、(1827±34) Ma和(2135 ± 6) Ma)的继承锆石，结合区域上前人研究成果，古生代继承锆石可能来源于兴蒙造山带(施光海等, 2003; 鲍庆中等, 2007; 刘建峰, 2009; 葛梦春等, 2011; 王炎阳等, 2014)，元古宙继承锆石可能来源于华北克拉通北缘(彭彭等, 2002; 郑永飞, 2004; 简平等, 2005; 翟明国等, 2007;刘树文等, 2007)。

另一方面，长岭子早三叠世斜长花岗斑岩具有高SiO_2(69.45%~74.40%)、Al_2O_3(14.56% ~16.74%)、Sr(444×10^{-6}~602×10^{-6})(除1个样品Sr=161×10^{-6}含量较低以外)，低Y(5.5×10^{-6} ~6.3×10^{-6})和Yb(0.39×10^{-6}~0.55×10^{-6})以及高Sr/Y(74.5~103.4)等特点(表2, 图9a)，具有典型的埃达克质岩石特征。斜长花岗斑岩样品在Sr/Y−Y图解(Martin, 1999)和$(La/Yb)_N$−

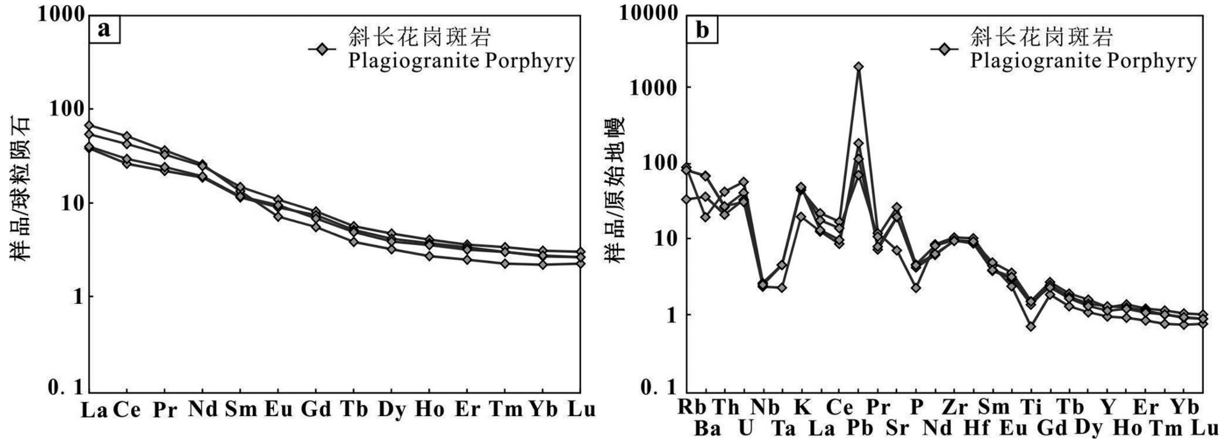

图5 长岭子研究区斜长花岗斑岩球粒陨石标准化稀土元素配分曲线(a)和原始地幔标准化微量元素蛛网图(b)(球粒陨石标准化值和原始地幔标准化值据Sun and McDonough, 1989)

Fig.5 Chondrite-normalized REE patterns (a) and primitive mantle normalized trace element spider diagrams (b) for plagiogranite porphyries in Changlingzi area (chondrite normalization values and primitive mantle normalization values after Sun and McDonough, 1989)

Yb_N图解(Defant et al., 1990)均投影到埃达克岩范围内(图9)，同样说明长岭子斜长花岗斑岩具有埃达克质岩石特征。此外，斜长花岗斑岩还具有富钠而贫钾(Na_2O/K_2O=3.59~7.24)的特征，表现出了O型埃达克岩的地球化学特征而明显不同于C型埃达克岩的富钾特征(Na_2O/K_2O≈1)(王强等, 2001;张旗等, 2001)。一般来说，O型埃达克岩形成于俯冲洋壳部分熔融或者形成于贫K的加厚下地壳部分熔

表2 长岭子斜长花岗斑岩锆石LA−ICP−MS U−Pb定年分析结果

Table 2 LA−ICP−MS Zircon U−Pb analysis for the plagiogranite porphyry in Changlingzi area

测点号	$Th/10^{-6}$	$U/10^{-6}$	Th/U	比值						年龄/Ma					
				Pb^{207}/Pb^{206}	2σ	Pb^{207}/U^{235}	2σ	Pb^{206}/U^{238}	2σ	Pb^{207}/Pb^{206}	2σ	Pb^{206}/U^{238}	2σ	Pb^{207}/U^{235}	2σ
C27-01	26.01	125.93	0.206543	0.05095	0.00177	0.28695	0.00964	0.04084	0.00052	238.4	78.16	258.1	3.24	256.2	7.6
C27-02	131.12	281.08	0.466486	0.05124	0.00118	0.2839	0.00628	0.04017	0.00044	251.8	52.33	253.9	2.74	253.7	4.97
C27-03	26.44	76.36	0.346255	0.05133	0.00216	0.28666	0.01173	0.04050	0.00055	255.6	93.81	255.9	3.4	255.9	9.26
C27-04	101.62	219.82	0.4622873	0.05103	0.00144	0.26493	0.00719	0.03765	0.00045	242.2	63.76	238.2	2.77	238.6	5.77
C27-05	112.21	297.8	0.376797	0.05111	0.00126	0.27269	0.00643	0.03870	0.00044	245.6	55.66	244.7	2.71	244.8	5.13
C27-06	75.17	302.02	0.248891	0.05083	0.00133	0.26934	0.00675	0.03843	0.00045	232.9	59.16	243.1	2.79	242.2	5.4
C27-07	174.8	259.07	0.6747211	0.05084	0.00138	0.25704	0.00671	0.03666	0.00043	233.7	61.42	232.1	2.68	232.3	5.42
C27-08	360.01	301.23	1.1951333	0.05295	0.00112	0.37811	0.00763	0.05179	0.00057	326.5	47.08	325.5	3.48	325.6	5.62
C27-09	31.03	84	0.369405	0.05007	0.00224	0.2806	0.01222	0.04064	0.00059	198.4	100.75	256.8	3.65	251.1	9.69
C27-10	299.21	579.48	0.516342	0.05112	0.00114	0.28196	0.00604	0.04000	0.00045	246.2	50.7	252.9	2.78	252.2	4.79
C27-11	51.23	142.16	0.3603686	0.05220	0.00156	0.33499	0.00969	0.04654	0.00058	294.4	66.7	293.3	3.55	293.4	7.37
C27-12	54.34	128.25	0.4237037	0.16023	0.00298	10.77156	0.19296	0.48760	0.00544	2458	31.08	2560.3	23.59	2503.6	16.64
C27-13	99.25	179.29	0.5535724	0.11169	0.00212	5.33087	0.09762	0.34618	0.00387	1827.1	34.08	1916.3	18.51	1873.8	15.66
C27-14	160.15	207.75	0.770878	0.05114	0.00164	0.27942	0.00868	0.03963	0.00051	247.1	72.21	250.5	3.18	250.2	6.89
C27-15	51.89	126.84	0.409098	0.05122	0.00171	0.28603	0.00927	0.04050	0.00052	250.7	74.88	256	3.21	255.4	7.32
C27-16	502.79	893.54	0.562694	0.05264	0.0012	0.29005	0.00638	0.03996	0.00047	313.5	50.86	252.6	2.9	258.6	5.02
C27-17	128.57	300.75	0.427498	0.05403	0.00155	0.2914	0.00811	0.03912	0.00050	372.1	63.39	247.4	3.1	259.7	6.38
C27-18	208.31	319.41	0.6521712	0.06008	0.00139	0.58091	0.01304	0.07013	0.00084	606.5	49.31	437	5.04	465	8.37
C27-19	48.69	144.97	0.3358626	0.05331	0.00221	0.2916	0.0117	0.03968	0.00061	342	90.79	250.8	3.75	259.8	9.2
C27-20	122.24	501.61	0.2436953	0.13274	0.00281	6.33378	0.13057	0.34610	0.00405	2134.6	36.61	1915.9	19.41	2023.1	18.08

表3 长岭子研究区斜长花岗斑岩锆石Lu-Hf同位素分析结果

Table 3 Zircon Lu−Hf isotope analysis for the plagiogranite porphyry in Changlingzi area

点号	年龄/Ma	^{176}Yb/^{177}Hf	^{176}Lu/^{177}Hf	^{176}Hf/^{177}Hf	2σ	$\varepsilon_{Hf}(0)$	$\varepsilon_{Hf}(t)$	T_{DM1}/Ma	T_{DM2}/Ma	$f_{Lu/Hf}$
CLZ27-01	258	0.015153	0.000640	0.282828	0.000028	2.0	7.5	596	804	-0.98
CLZ27-02	254	0.038582	0.001477	0.282786	0.000024	0.5	5.8	669	909	-0.96
CLZ27-03	256	0.017829	0.000720	0.282938	0.0002	5.9	11.4	442	555	-0.98
CLZ27-05	245	0.032846	0.001236	0.282822	0.000038	1.8	6.9	615	832	-0.96
CLZ27-06	243	0.007177	0.000314	0.282968	0.000024	6.9	12.2	396	492	-0.99
CLZ27-09	257	0.014335	0.000624	0.282899	0.000014	4.5	10.0	497	644	-0.98
CLZ27-10	253	0.019893	0.000784	0.282960	0.000018	6.7	12.1	411	507	-0.98
CLZ27-14	251	0.039451	0.001468	0.282818	0.00002	1.6	6.9	623	839	-0.96
CLZ27-15	256	0.014271	0.000594	0.282945	0.000018	6.1	11.7	430	538	-0.98
CLZ27-19	251	0.012793	0.000533	0.282924	0.000018	5.4	10.8	459	588	-0.98

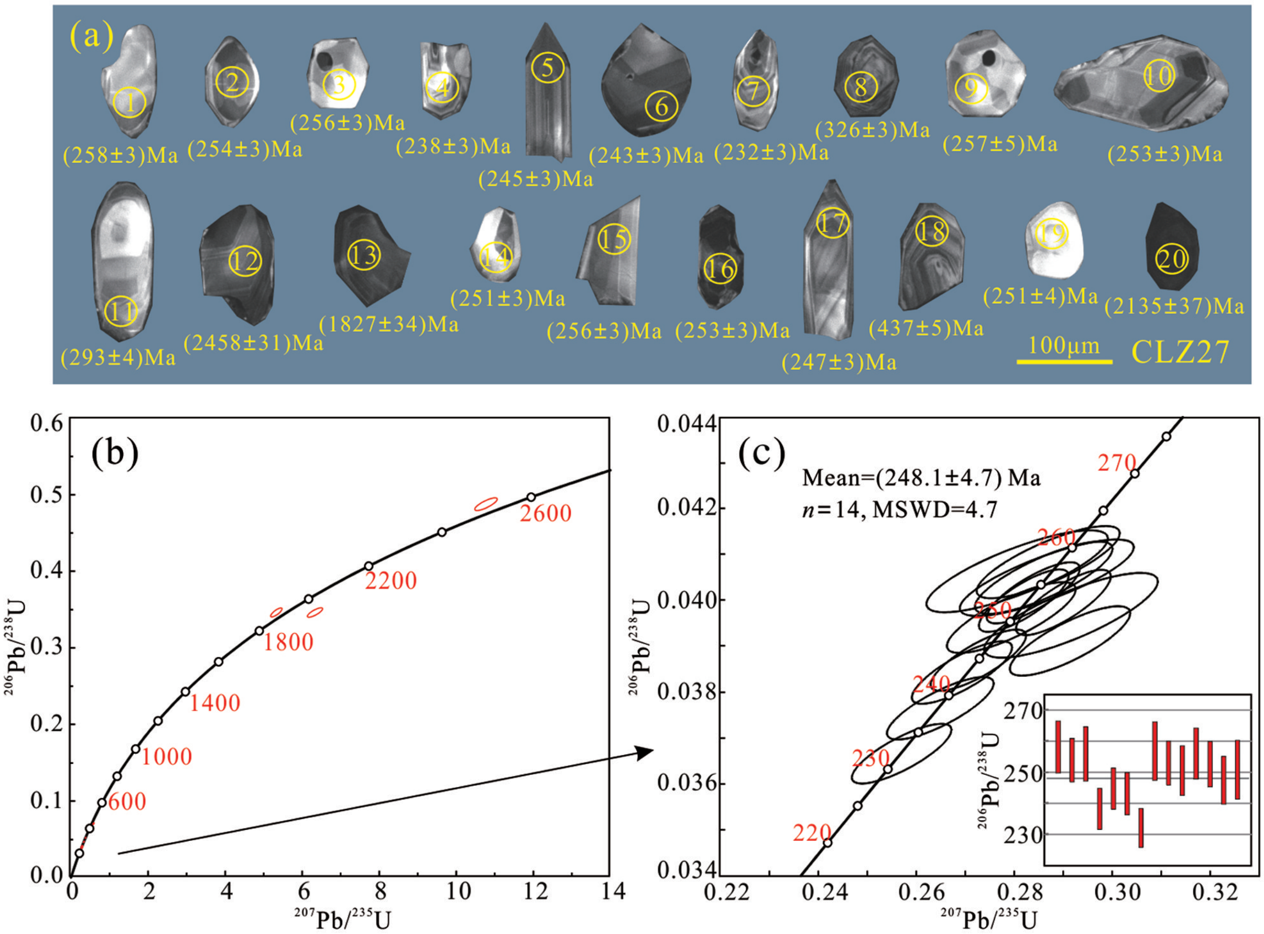

图6 长岭子研究区斜长花岗斑岩锆石CL图像(a)和LA-ICP-MS锆石U-Pb年龄谐和图(b,c)

Fig.6 Cathodoluminescent images (a) and LA−ICP−MS zircon U−Pb concordia diagrams (b,c) for plagiogranite porphyry in Changlingzi area

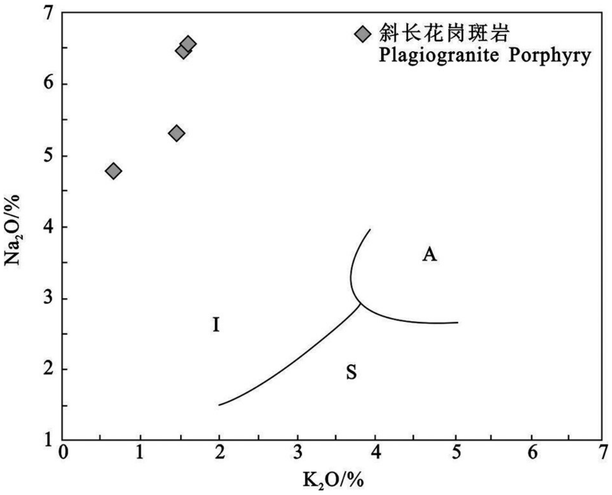

图7 长岭子斜长花岗斑岩K_2O−Na_2O图解（据Collins et al., 1982）

Fig.7 K_2O−Na_2O diagram for plagiogranite porphyry in Changlingzi area (after Collins et al., 1982)

融（王强等, 2001; 张旗等, 2004, 2008）。在Mg$^{\#}$−SiO$_2$图解和MgO−SiO$_2$图解中（Wang et al., 2006, 图10），样品主要落入变质玄武岩/榴辉岩部分熔融产生的熔体或者加厚下地壳形成的埃达克质岩体区域，表明斜长花岗斑岩可能是加厚下地壳部分熔融的产物。

斜长花岗斑岩样品虽然在花岗岩构造环境判别图解（图11）中落入火山弧区，但斜长花岗斑岩的岩石特征并不符合典型火山弧岩浆的特征。张旗等（2009）的研究表明，埃达克岩由于形成的压力大，从而强烈亏损Y、Yb、Ta和Nb等微量元素，样品

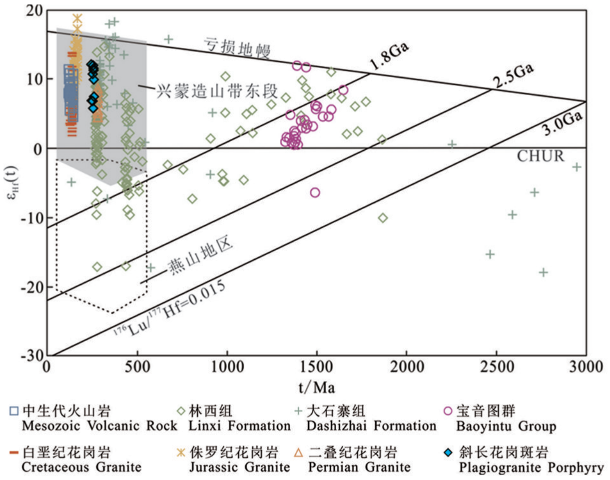

图8 长岭子斜长花岗斑岩锆石$\varepsilon_{Hf}(t)$−t图解

（阴影部分代表兴蒙造山带东段中生代花岗岩和辉长岩，虚线框部分代表燕山地区岩浆岩；数据来源：兴蒙造山带东段和燕山地区岩浆岩锆石$\varepsilon_{Hf}(t)$范围据Yang et al., 2006；中生代火山岩据张超等（2014）和谭皓元等（2017）；林西组据朱俊宾等（2017）；大石寨组据张健（2012）和作者未发表数据；宝音图群据孙立新等（2013）；白垩纪花岗岩据杨奇荻等（2014）、周振华等（2011）和Zhou ZH et al., 2012；侏罗纪花岗岩据杨奇荻等（2014）、刘伟等（2007）和Liu et al., 2009；二叠纪花岗岩据Wang et al., 2017）

Fig.8 Zircon $\varepsilon_{Hf}(t)$−t diagram for plagiogranite porphyry in Changlingzi area

(The shaded part represents the Mesozoic granites and gabbros in the eastern segment of the Xingmeng orogenic belt, and the dotted section \ represents the magmatic rocks in the Yanshan area)Data sources: Xing'an−Mongolian Orogenic belt and Yanshan area zircon $\varepsilon_{Hf}(t)$ range after Yang et al., 2006; Mesozoic volcanic rocks after Zhang et al., 2014 and Tan et al., 2017; the Linxi Formation after Zhu et al., 2017; the Dashizhai Formation after Zhang, 2012 and the authors'unpublished data; the Baoyintu Group after Sun et al., 2013; Cretaceous granite after Yang et al., 2014 and Zhou et al., 2011, 2012; Jurassic granite after Yang et al., 2012 and Liu et al., 2007, 2009; Permian granite after Wang et al., 2017）

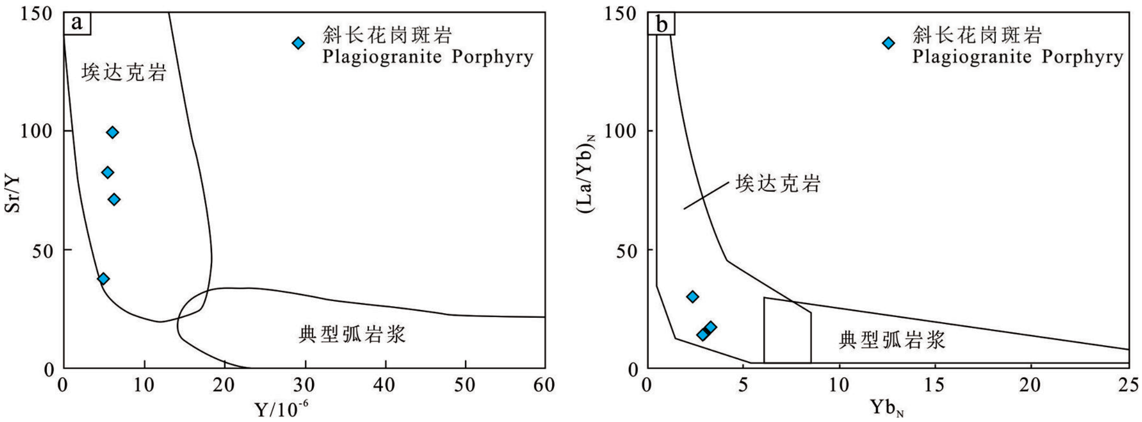

图9 长岭子斜长花岗斑岩Sr/Y−Y图解（a,据Martin , 1999）和$(La/Yb)_N$−Yb_N图解（b,据Defant et al., 1990）

Fig.9 Sr/Y−Y (a, after Martin, 1999) and $(La/Yb)_N$−Yb_N (b, after Defant et al., 1990) diagrams of the plagiogranite porphyry in Changlingzi area

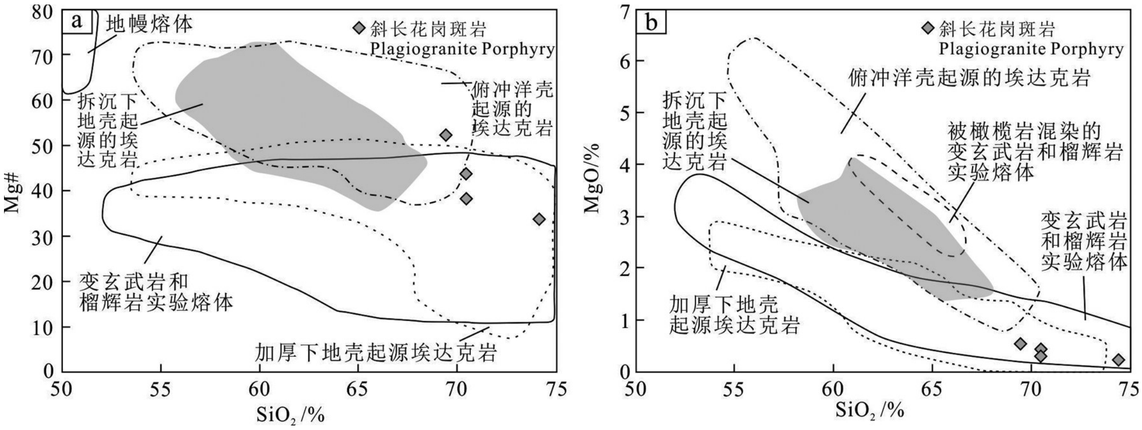

图10 长岭子斜长花岗斑岩SiO$_2$−Mg$^{\#}$(a)图解和SiO$_2$−MgO图解(b)(据Wang et al., 2006)

Fig.10 SiO$_2$−Mg$^{\#}$ (a) diagram and SiO$_2$−MgO diagram (b) for the plagiogranite porphyry in Changlingzi area (after Wang et al., 2006)

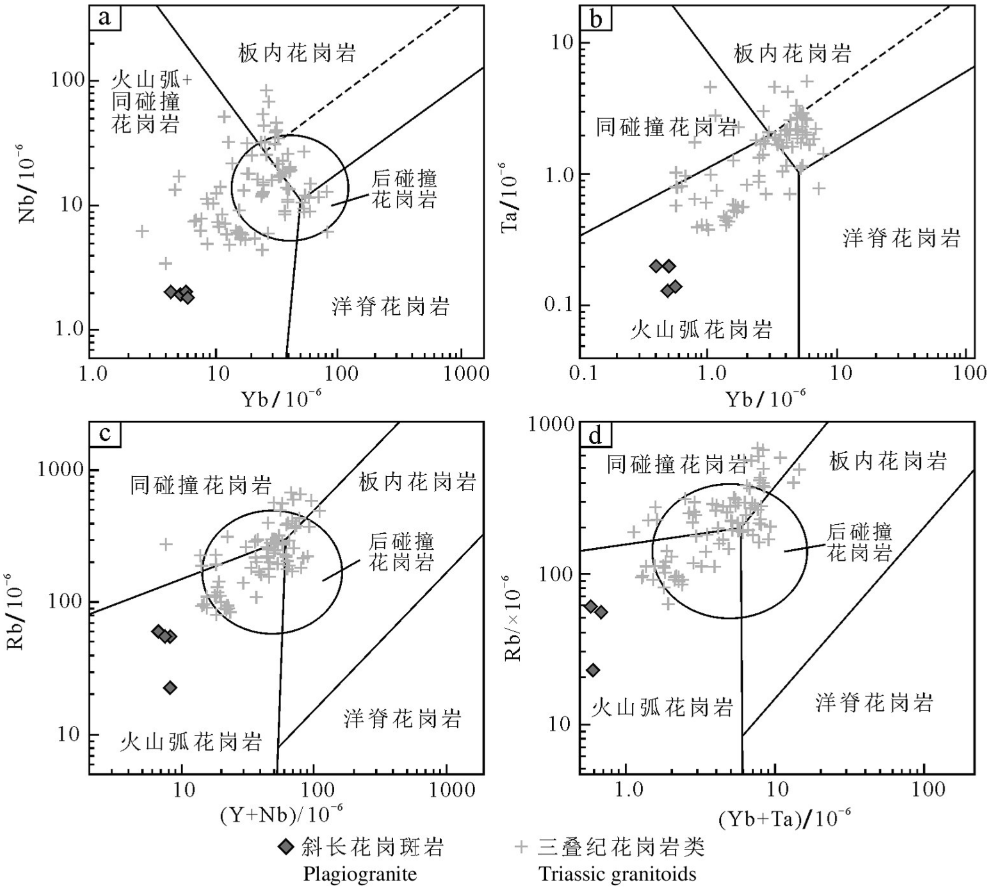

图11 长岭子斜长花岗斑岩Nb−Y(a), Ta−Yb(b), Rb−(Y+Nb)(c)和Rb−(Yb+Ta)(d)图解(据Pearce et al., 1984, 1996; 数据来源：三叠纪花岗岩类据李锦轶等,2007;石玉若等,2007;张维等,2010;叶栩松等,2011;张万益等,2012;刘建峰等,2014;吴荣泽等,2015;张海华等,2015;李晓海等,2016

Fig.11 Nb−Y (a), Ta−Yb (b), Rb−(Y+Nb) (c) and Rb−(Yb+Ta) (d) diagram (after Pearce et al.,1984, 1996) of plagiogranite porphyries in Changlingzi area

Data sources: Triassic granitoids after Li et al., 2007; Shi et al., 2007; Zhang et al., 2010; Ye et al., 2011; Zhang et al., 2012; Liu et al., 2014; Wu et al., 2015; Zhang et al., 2015 and Li et al., 2016

则会在Rb-(Y+Nb)和Rb-(Yb+Ta)图解（Pearce et al., 1984）中向左偏移进入岛弧区域，造成构造环境的误判。因此，张旗等（2009）认为O型埃达克岩的构造环境需要从埃达克岩形成时的构造环境和与埃达克岩伴生的岩浆岩组合及其地球化学的资料等方面进行判断。

长岭子早三叠世斜长花岗斑岩具有埃达克质岩石的特征，为加厚下地壳部分熔融的产物，指示早三叠世兴蒙地区并非弧的环境，而是处于碰撞造山环境。刘建峰等（2013）通过研究巴林右旗地区建设屯埃达克岩认为该岩体是古亚洲洋闭合后，在西伯利亚古板块和中朝板块碰撞造山初期的新生下地壳部分熔融作用的产物，这一结论也支持本文的讨论结果；此外，笔者统计了研究区区域上三叠纪广泛发育的花岗岩类地球化学数据，发现该时期的花岗岩类在Pearce构造判别图解中大部分都落入了同碰撞-后碰撞区域（图11,李锦轶等, 2007; 石玉若等, 2007; 田伟等, 2007; Chen et al., 2009; 张拴宏等, 2010；张维等, 2010；叶栩松等, 2011；张万益等, 2012；刘建峰等, 2014；吴荣泽等, 2015；张海华等, 2015；李晓海等, 2016），也说明在三叠纪西伯利亚板块与华北克拉通已经进入碰撞环境。由此，本文认为长岭子早三叠世斜长花岗斑岩的形成，很可能是由于古亚洲洋闭合后，西伯利亚板块与华北克拉通碰撞加厚，导致基性下地壳被转化成榴辉岩，在早三叠世软流圈地幔上涌导致榴辉岩化下地壳发生部分熔融形成中酸性岩浆，后者由于与榴辉岩残留体平衡而具有高Sr和低Y、HREE（陈斌等，2013），从而形成具有埃达克质岩石特征的岩浆岩。

6.2 对古亚洲洋闭合时间的指示意义

中亚造山带是世界最大的增生型造山带之一，形成于古亚洲洋的长期演化及其南北两侧三大板块（西伯利亚板块与华北克拉通和塔里木板块）的碰撞拼贴。关于古亚洲洋闭合时限，前人进行了大量研究，提出一系列观点，时间涵盖晚志留世至早三叠世（Tang, 1990；王荃，1991；邵济安，1991, 2015；徐备等，1997, 2014；Xiao et al., 2003, 2009；李锦轶, 2007；Jian et al., 2008；陈斌等, 2009；石玉若等, 2014；Chen et al., 2016）。近10年来，随着地质年代学的发展，大量火成岩得以确定时代归属，越来越多的学者开始倾向于接受古亚洲洋闭合于晚二叠世至早三叠世的观点（Xiao et al., 2003；Chen et al., 2009；Wu et al., 2011；Jian et al., 2010；Liu et al., 2017；朱雪峰等, 2018）。

本文通过对锡林浩特—林西地区克什克腾旗长岭子斜长花岗斑岩的研究，认为其形成于碰撞造山环境，形成时代为248 Ma，指示古亚洲洋在早三叠世已经闭合，西伯利亚板块与华北克拉通已经进入碰撞造山环境。

7 结　论

（1）内蒙古克什克腾旗长岭子斜长花岗斑岩的成岩年龄为(248.1±4.7)Ma（MSWD = 4.7），形成于早三叠世。

（2）长岭子斜长花岗斑岩具有高SiO_2、Al_2O_3、Sr，低Y以及高Sr/Y的特点，显示了典型的埃达克质岩石特征，为加厚下地壳部分熔融的产物。

（3）长岭子斜长花岗斑岩形成于古亚洲洋闭合后西伯利亚板块与华北克拉通碰撞造山环境。

注释

①内蒙古山金地质矿产勘查有限公司. 2014. 内蒙古自治区克什克腾旗长岭子铅锌矿勘查2014年工作总结[R].

参考文献

Bao Qingzhong, Zhang Changjie, Wu Zhili, Wang Hong, Li Wei, Sang Jiahe, Liu Yongsheng. 2007. SHRIMP U-Pb zircon geochronology of a Carboniferous quartz-diorite in Baiyingaole area, Inner Mongolia and its implications[J]. Journal of Jilin University(Earth Science Edition), 37(1): 15-23(in Chinese with English abstract).

Chen Bin, Chen Changjian, He Jingbo, Liu Ankun. 2013. Origin of Mesozoic high-Mg adakitic rocks from northeastern China: Petrological and Nd-Sr-Os isotopic constraints[J]. Chinese Science Bulletin, 58(20): 1941-1953(in Chinese).

Chen Bin, Jahn B M, Tian Wei. 2009. Evolution of the Solonker suture zone: Constraints from zircon U-Pb ages, Hf isotopic ratios and whole-rock Nd-Sr isotope compositions of subduction- and collision-related magmas and forearc sediments[J]. Journal of Asian Earth Sciences, 34(3): 245-257.

Chen Bin, Jahn B M, Wilde S, Xu Bei. 2000. Two contrasting paleozoic magmatic belts in northern Inner Mongolia, China: Petrogenesis and tectonic implications[J]. Tectonophysics, 328(1): 157-182.

Chen Bin, Ma Xinghua, Liu Ankun, Muhetaer Zhari. 2009. Zircon U-Pb ages of the Xilinhot metamorphic complex and blueschist, and implications for tectonic evolution of the Solonker suture[J]. Acta Petrologica Sinica, 25(12): 3123-3129(in Chinese with English abstract).

Chen Yanjing, Zhai Mingguo, Jiang Shaoyong. 2009. Significant achievements and open issues in study of orogenesis and metallogenesis surrounding the North China continent[J]. Acta Petrologica Sinica, 25(11): 2695− 2726(in Chinese with English abstract).

Chen Yanjing, Zhang Cheng, Li Nuo, Yang Yongfei, Deng Ke. 2012. Geology of the Mo deposits in Northeast China[J]. Journal of Jilin University(Earth Science Edition), 42(5): 1223− 1268(in Chinese with English abstract).

Chen Yanjing, Zhang Cheng, Wang Pin, Pirajno F, Li Nuo. 2016. The Mo deposits of Northeast China: A powerful indicator of tectonic settings and associated evolutionary trends[J]. Ore Geology Reviews, 81(2): 602−640.

Collins W J, Beams S D, White A J R, Chappell B W. 1982. Nature and origin of A−type Granites with Particular reference to Southeastern Australia[J]. Contributions to Mineralogy and Petrology, 80: 189−200.

Defant M J, Drummond M S. 1990.Derivation of some modern arc magmas by melting of young subducted lithosphere[J]. Nature, 347 (6294): 662−665.

Dobretsov N L, Berzin N A, Buslov M M. 1995. Opening and tectonic evolution of the Paleo− Asian ocean[J]. International Geological Review, 37: 335−360

Ge Mengchun, Zhou Wenxiao, Yu Yang, Sun Junjun, Bao Jianquan, Wang Shihai. 2011. Dissolution and supracrustal rocks dating of Xilin Gol Complex, Inner Mongolia, China[J]. Earth Science Frontiers, 18(5): 182−195(in Chinese with English abstract).

Ge Wenchun, Wu Fuyuan, Zhou Changyong, Rahman A A A. 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[J]. Chinese Science Bulletin, 50(18): 2097−2105.

Goolaerts A, Mattielli N, Jong J D, Weis D, Scoates J S. 2004. Hf and Lu isotopic reference values for the zircon standard 91500 by MC−ICP−MS[J]. Chemical Geology, 206(1): 1−9

Han Baofu, Kagami H, Li Huimin. 2004. Age and Nd− Sr isotopic geochemistry of the Guangtoushan alkaline granite, Hebei Province, China: Impications for early Mesozoic crust− mantle interaction in North China Block[J]. Acta Petrologica Sinica, 20(6): 1375−1388(in Chinese with English abstract).

Hong Dawei, Wang Shiguang, Xie Xilin, Zhang Jisheng, Wang Tao. 2003. Correlation between continental crustal growth and the supercontinental cycle: Evidence from the granites with positive ε_{Nd} in the Central Asian Orogenic Belt[J]. Acta Geologica Sinica, 77 (2): 203−209(in Chinese with English abstract).

Hong Dawei, Wang Shiguang, Xie Xilin, Zhang Jisheng. 2000. Genesis of positive ε(Nd, t) granitoids in the Da Hinggan Mts. −Mongolia Orogenic Belt and growth continental crust[J]. Earth Science Frontiers, 7(2): 441−456(in Chinese with English abstract).

Huang Jiqing, Chen Bingwei. 1987. The Evolution of the Tethys in China and Adjacent Regions[M]. Beijing: Geological Publishing House (in Chinese).

Jahn B M, Wu Fuyuan, Hong Dawei. 2000. Important crustal growth in the Phanerozoic: Isotopic evidence of granitoids from east−central Asia[J]. Journal of Earth System Science, 109(1): 5−20.

Jahn B M. 2004. The Central Asian Orogenic Belt and growth of the continental crust in the Phanerozoic[J]. Geological Society London Special Publications, 226(1): 73−100.

Jian Ping, Liu Dunyi, Kröner A, Windley B F, Shi Yuruo, Zhang Fuqin, Shi Guanghai, Miao Laicheng, Zhang Wei, Zhang Qi, Zhang Liqiao, Ren Jishun. 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[J]. Lithos, 101(3): 233−259.

Jian Ping, Liu Dunyi, Kroner A, Windley B F, Shi Yuruo, Zhang Wei, Zhang Fuqin, Miao Liangcheng, Zhang Liqiao, Tomurhuu D. 2010. Evolution of a Permian intraoceanic arc− trench system in the Solonker suture zone, Central Asian Orogenic Belt, China and Mongolia[J]. Lithos, 118(1/2): 169−190.

Jian Ping, Zhang Qi, Liu Dunyi, Jin Weijun, Jia Xiuqin, Qian Qing. 2005. SHRIMP dating and geological significance of Late Achaean high− Mg diorite(sanukite) and hornblende− granite at Guyang of Inner Mongolia[J]. Acta Petrololica Sinica, 21(1): 151− 157(in Chinese with English abstract).

Le Maitre R W. 2002.Igneous Rocks: A Classification and Glossary of Terms[M]. Cambridge U. K.: Cambridge University Press.

Li Jinyi, Gao Liming, Sun Guihua, Li Yaping, Wang Yanbin. 2007. Shuangjingzi middle Triassic syn−collisional crust−derived granite in the east Inner Mongolia and its constraint on the timing of collision between Siberian and Sino−Korean paleo−plates[J]. Acta Petrologica Sinica, 23(3): 565− 582(in Chinese with English abstract).

Li Nnuo, Chen Yanjing, Ulrich T, Lai Yong. 2012a. Fluid inclusion study of the Wunugetu Cu−Mo deposit, Inner Mongolia, China[J]. Mineralium Deposita, 47(5): 467−481.

Li Nuo, Chen Yanjing, Pirajno F, Gong Hujun, Mao Shidong, Ni Zhiyong. 2012b. LA−ICP−MS zircon U−Pb dating, trace element and Hf isotope geochemistry of the Heyu granite batholith, eastern Qinling, central China: Implications for Mesozoic tectono−magmatic evolution[J]. Lithos, 142−143(6): 34−47.

Liu Jianfeng, Chi Xiaoguo, Zhao Zhi, Hu Zhaochu, Chen Junqiang. 2013. Zircon U−Pb age and petrogenetic discussion on Jianshetun adakite in Balinyouqi, Inner Mongolia[J]. Acta Petrologica Sinica, 29(3): 827−839(in Chinese with English abstract).

Liu Jianfeng, Chi Xiaoguo, Zhao Zhi, Zhang Xingzhou, Ma Zhihong, Wang Tiefu, Hu Zhaochu. 2011. Geochemical characteristics and geological significance of Early Permian Baya'ertuhushuo Gabbro in South Great Xing'an Range[J]. Acta Geologica Sinica, 85(1): 116−129.

Liu Jianfeng, Li Jinyi, Chi Xiaoguo, Qu Junfeng, Hu Zhaochu, Fang Shu, Zhang Zhong. 2013. A late− Carboniferous to early early−Permian subduction− accretion complex in Daqing pasture, southeastern Inner Mongolia: Evidence of northward subduction beneath the Siberian paleoplate southern margin[J]. Lithos, 177(2): 285−296.

Liu Jianfeng, Li Jinyi, Chi Xiaoguo, Qu Junfeng, Hu Zhaochu, Guo Chunli. 2014. Petrological and geochemical characteristics of the Early Triassic Granite Belt of Southeastern Inner Mongolia and its tectonic setting[J]. Acta Geologica Sinica, 88(9): 1677− 1690(in Chinese with English abstract).

Liu Jianfeng. 2009. Late Paleozoic Magmatism and its Constraints on Regional Tectonic Evolution in Linxi—Dongwuqi Area, Inner Mongolia[D]. Changchun: Jilin University(in Chinese with English abstract).

Liu Jianming, Zhang Rui, Zhang Qingzhou. 2004. The regional metallogeny of Da Hinggan Ling, China[J]. Earth Science Frontiers, 11(1): 269−277(in Chinese with English abstract).

Liu Jun, Wu Guang, Li Yuan, Zhu Mingtian, Zhong Wei. 2012. Re−Os sulfide (chalcopyrite, pyrite and molybdenite) systematics and fluid inclusion study of the Duobaoshan porphyry Cu (Mo) deposit, Heilongjiang Province, China[J]. Journal of Asian Earth Sciences, 49(3): 300−312.

Liu Shuwen, Lü Yongjun, Feng Yonggang, Zhang Chen, Tian Wei, Yan Quanren, Liu Xiaoming. 2007. Geology and Zircon U− Pb isotoic chronology of Dantazi Complex, Northern Hebei Province[J]. Geological Journal of China Universities, 13(3): 484− 497(in Chinese with English abstract).

Liu Yongjiang, Li Weiming, Feng Zhiqiang, Wen Quanbo, Neubauer F, Liang Chenyue. 2017. A review of the Paleozoic tectonics in the eastern part of Central Asian Orogenic Belt[J]. Gondwana Research, 43: 123−148.

Maniar P D, Piccoli P M. 1989. Tectonic discrimination of granitoids[J]. Geological Society of America Bulletin, 101(5): 635−643.

Martin H. 1999. Adakitic magmas: modern analogues of Archaean granitoids[J]. Lithos, 46(3): 411−429.

Mu Baolei, Yan Guohan. 1992. Geochemistry of Triassic alkaline or subalkaline igneous complexes in the Yan− Liao area and their significance[J]. Acta Geologica Sinica, 66(2): 108−122(in Chinese with English abstract).

Pearce J A, Harris N B W, Tindle A G. 1984. Trace element discriminastion diagrams for the tectonic interpretation of granitic rocks[J]. J.Petrol., 25: 956−983.

Peng Peng, Zhai Mingguo. 2002. Two major Precambrian geological events of North China Block(NCB): Characteristics and propery[J]. Advance in Earth Sciences, 17(6): 818− 825(in Chinese with English abstract).

Peng Yuqiong, Ji Chunhua, Xin Yulian. 2002. Petrology and geochronology of the Paleo−Jilin−Heilongjiang Orogenic Belt in the adjacent areas of China, Russia and Korea[J]. Geology and Resources, 11(2): 65−75(in Chinese with English abstract).

Peter C. Rickwood. 1989. Boundary lines within petrologic diagrams which use oxides of major and minor elements[J]. Lithos, 22(4): 247−263.

Qi Jinping, Chen Yanjing, Franco F. 2005. Geological characteristics and tectonic setting of the epithermal deposits in the Northeast China[J]. Journal of Mineralogy and Petrology, 25(2): 47− 59(in Chinese with English abstract).

Ren Jishun, Chen Tingyu, Niu Baogui. 1990. Tectonics Evolution of the Continental Lithosphere and Metallogeny in Eastern China and Adjacent Areas[M]. Beijing: Science Press (in Chinese with English abstract).

Rui Zongyao. 1994.Geology of Nonferrous Metallic Deposits in the Northern Margin of the North China Landmass and its Adjacent Area[M]. Beijing: Geological Publishing House (in Chinese with English abstract).

Sengör A M C, Natal'in B A, Burtman V S. 1993. Evolution of the Altaid tectonic collage and Paleozoic crustal growth in Eurasia[J]. Nature, 364: 299−307

Shao Ji'an. 1991. Crust Evolution in the Middle Part of the Northern Margin of Sino−Korean Plate[M]. Beijing: Peking University Press (in Chinese with English abstract).

Shao Ji’an, Tang Kedong. 1995. Terranes in Northeast China and Evolution of Northeast Asia Continental Margin[M]. Beijing: Seismological Press (in Chinese).

Shao Ji’an, He Guoqi, Tang Kedong. 2015. The evolution of Permian continental crust in northern part of North China[J]. Acta Petrologica Sinica, 31(1): 47−55(in Chinese with English abstract).

Shi Yuruo, Liu Cui, Deng Jinfu, Jian Ping. 2014. Geochronological frame of granitoids from Central Inner Mongolia and its tectonomagmatic evolution[J]. Acta Petrologica Sinica, 30(11): 3155−3171(in Chinese with English abstract).

Shi Yuruo, Liu Dunyi, Miao Laicheng, Zhang Fuqin, Jian Ping, Zhang Wei, Hou Kejun, Xu Junyu. 2010. Devonian A− type granitic magmatism on the northern margin of the North China Craton: SHRIMP U− Pb zircon dating and Hf− isotopes of the Hongshan granite at Chifeng, Inner Mongolia, China[J]. Gondwana Research, 17(4): 632−641.

Shi Yuruo, Liu Dunyi, Zhang Qi, Jian Ping, Zhang Fuqin, Miao Laicheng, Zhang Lvqiao. 2007. SHRIMP U− Pb zircon dating of Triassic A−type granites in Sonid Zuoqi, central Inner Mongolia, China and its tectonic implications[J]. Geological Bulletin of China, 26(2): 183−189(in Chinese with English abstract).

Shu Qihai, Lai Yong, Wei Liangmin, Sun Yi, Wang Chao. 2011. Fluid inclusion study of the Baiyinnuo’er Zn−Pb deposit, south segment of the Great Xing’an Mountain, northeastern China[J]. Acta Petrologica Sinica, 27(5): 1467− 1482(in Chinese with English abstract).

Sláma J, Košler J, Condon D J. 2008. Plešovice zircon−A new natural reference material for U− Pb and Hf isotopic microanalysis[J]. Chemical Geology, 249(1−2): 1−35.

Sui Zhenmin, Ge Wenchun, Wu Fuyuan, Zhang Jiheng, Xu Xuechun, Cheng Ruiyu. 2006. Zircon U−Pb ages, Hf isotopic characteristics and their implications of the Early granits in the northeastern Da

Hinggan Mts., northeastern China[C]//National Symposium on Petrology and Geodynamics(in Chinese).

Sun S S, McDonough W E. 1989. Chemical and isotopic systematics of oceanic basalts:Implications for mantle composition and processes [C]// Saunders A D, Norry M J. Magmatism in the Ocean Basins. Geological Society, London, Special Publications, 42: 313−345.

Tang Kedong. 1990. Tectonic development of Paleozoic fold belts at the north margin of the Sino−Korean Craton[J]. Tectonics, 9(2): 249−260.

Tian Wei, Chen Bin, Liu Chaoqun, Zhang Huafeng. 2007. Zircon U−Pb age and Hf isotopic composition of the Xiaozhangjiakou ultramafic pluton in norther Hebei[J]. Acta Petrologica Sinica, 23 (3): 583−590(in Chinese with English abstract).

Vervoort J D, Patchett P J. 1996. Behavior of hafnium and neodymium isotopes in the crust: Constraints from Precambrian crustally derived granites[J]. Geochimica et Cosmochimica Acta, 60(19): 3717−3733.

Wang Fang, Chen Fukun, Hou Zhenhui, Peng Peng, Zhai Mingguo. 2009. Zircon ages and Sr− Nd− Hf isotopic composition of late Paleozoic granitoids in the Chongli− Chicheng area, northern margin of the North China Block[J]. Acta Petrologica Sinica, 25 (11): 3057−3074(in Chinese with English abstract).

Wang Qi. 1991. Skarn and its Prospective Evaluation of Baiyinnuoer Pb−Zn Deposit, Inner Mongolia[D]. Beijing: Peking University(in Chinese).

Wang Qiang, Xu Jifeng, Jian Ping, Bao Zhiwei, Zhao Zhenhuan, Li Chaofeng, Xiong Xiaolin, Ma Jinlong. 2006. Petrogenesis of Adakitic Porphyries in an Extensional Tectonic Setting, Dexing, South China: Implications for the Genesis of Porphyry Copper Mineralization[J]. Journal of Petrology, 47(1): 119−144.

Wang Qiang, Xu Jifeng, Zhao Zhenhua. 2001. The summary and commention research on a new kind of igneous rock−Adakite[J]. Advance in Earth Sciences, 16(2): 201− 208(in Chinese with English abstract).

Wang Quan. 1991. Plate Tectonics between Cathaysia and Angaraland in China[M]. Beijing: Peking University Press (in Chinese with English abstract).

Wang Yanyang, Xu Bei, Cheng Shengdong, Liao Wen, Shao Jun, Wang Yan. 2014. Zircon U− Pb dating of the mafic lava from Wudaoshimen, Hexigten, Inner Mongolia and its geological significance[J]. Acta Petrologica Sinica, 30(7): 2055− 2062(in Chinese with English abstract).

Windley B F, Alexeiev D, Xiao Wenjiao, Kroner A, Badarch G. 2007. Tectonic models for accretion of the Central Asian Orogenic Belt[J]. Journal of the Geological Society, 164: 31−47.

Wu Fuyuan, Cao Lin. 1999. Some important problems of geology in Northeastern Asia[J]. World Geology, 30(7): 2055− 2062(in Chinese with English abstract).

Wu Fuyuan, Jahn B M, Wilde S, Sun Deyou. 2000. Phanerozoic crustal growth: U− Pb and Sr− Nd isotopic evidence from the granites in northeastern China[J]. Tectonophysics, 328(1/2): 89−113.

Wu Fuyuan, Li Xianhua, Zheng Yongfei, Gao Shan. 2007. Lu− Hf isotopic systematic and their application in petrology[J]. Acta Petrologica Sinica, 23(2): 185− 220(in Chinese with English abstract).

Wu Fuyuan, Sun Deyou, Ge Wenchun, Zhang Yanbin, Grant M L, Wilde S, Jahn B M. 2011. Geochronology of the Phanerozoic granitoids in northeastern China[J]. Journal of Asian Earth Sciences, 41(1): 1−30.

Wu Fuyuan, Sun Deyou, Lin Qiang. 1999. Petrogenesis of the Phanerozoic granites and crustal growth in Northeast China[J]. Acta Petrologica Sinica, 15(2): 181− 189(in Chinese with English abstract).

Wu Fuyuan, Yang Yueheng, Xie Liewen, Yang Jinhui, Xu Ping. 2006. Hf isotopic compositions of the standard zircons and baddeleyites used in U− Pb geochronology[J]. Chemical Geology, 234(1/2): 105−126.

Wu Guana, Sun Fengyue, Zhao Caisheng, Li Zhitong, Zhao Ailin, Pang Qingbang, Li Guangyuan. 2005. Discoverry of the Early Paleozoic post− collisional granites in northern margin of the Erguna massif and its geological significance[J]. Chinese Science Bulletin, 50(23): 2733−2743.

Wu Guang, Chen Yuchuan, Chen Yanjing, Zeng Qingtao. 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[J]. Journal of Asian Earth Sciences, 49(3): 214−233.

Xiao Wenjiao, Windley B F, Hao Jie, Zhai Mingguo. 2003. Accretion leading to collision and the Permian Solonker suture, Inner Mongolia, China: Termination of the central Asian orogenic belt[J]. Tectonics, 22(6): 1−20.

Xiao Wenjiao, Windley B F, Huang Baochun, Han Chunming, Yuan Chao, Chen Hui, Sun Mengru, Sun Shiru. 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[J]. International Journal of Earth Sciences, 98(6): 1189−1217.

Xu Bei, Zhao Pan, Bao Qingzhong, Zhou Yongheng, Wang Yanyang, Luo Zhiwen. 2014. Preliminary study on the pre− Mesozoic tectonic unit division of the Xing− meng Orogenic Belt[J]. Acta Petrologica Sinica, 30(7): 1841− 1857(in Chinese with English abstract).

Yan Guohan, Cai Jianhui, Ren Kangxu, He Guoqi, Mu Baolei, Xu Baoliang, Li Fengtang, Yang Bin. 2007. Intraplate extensional magmatism of North China Craton and break− up of three supercontinents and their deep dynamics[J]. Geological Journal of China Universities, 13(2): 161− 174(in Chinese with English abstract).

Yang Jinhui, Wu Fuyuan, Shao Ji’an, Wilde S A, Xie Liewen, Liu Xiaoming. 2006. Constraints on the timing of uplift of the Yanshan

Fold and Thrust Belt, North China[J]. Earth & Planetary Science Letters, 246(3): 336−352.

Yuan Hongli, Gao Shan, Liu Xiaoming, Li Huiming, Gunther D, Wu Fuyuan. 2004. Accurate U−Pb Age and Trace Element Determinations of Zircon by Laser Ablation−Inductively Coupled Plasma−Mass Spectrometry[J]. Geostandards and Geoanalytical Research, 28(3): 353−370

Zhai Degao, Liu Jiajun, Wang Jianping, Yang Yongqiang, Zhang Hongyu, Wang Xilong, Zhang Qibin, Wang Gongwen, Liu Zhenjiang. 2014. Zircon U−Pb and molybdenite Re−Os geochronology, and whole−rock geochemistry of the Hashitu molybdenum deposit and host granitoids, Inner Mongolia, NE China[J]. Journal of Asian Earth Sciences, 79(2): 144−160.

Zhai Mingguo, Peng Peng. 2007. Paleoproterozoic events in the North China Craton[J]. Acta Petrologica Sinica, 23(11): 2665−2682(in Chinese with English abstract).

Zhang Qi, Jin Weijun, Xiong Xiaolin, Li Chengdong, Wang Yuanlong. 2009. Characteristics and implication of O−type adakite in China during different geological periods[J]. Geotectonica et Metallogenia, 33(3): 432−447(in Chinese with English abstract).

Zhang Qi, Qian Qing, Wang Erqi, Wang Yan, Zhao Taiping, Hao Jie, Guo Guangjun. 2001. An east China plateau in mid−late Yanshanian period: Implication from adakites[J]. Chinese Journal of Geology, 36(2): 248−255(in Chinese with English abstract).

Zhang Qi, Wang Yan, Xiong Xiaolin. 2008. Adakite and Granite: Challenge and Opportunity[M]. Beijing: China Land Press (in Chinese with English abstract).

Zhang Qi, Xu Jifeng, Wang Yan, Xiao Long, Liu Hongtao, Wang Yuanlong. 2004. Diversity of adakite[J]. Geological Bulletin of China, 23(z2): 959−965(in Chinese with English abstract).

Zhang Quanhong, Zhao Yue, Liu Jianmin, Hu Jianmin, Song Biao, Liu Jian, Wu Hai. 2010. Geochronology, geochemistry and tectonic setting of the Late Paleozoic−Early Mesozoic magmatism in the northern margin of the North China Block: A preliminary view[J]. Acta Petrologica et Mineralogica, 29(6): 824−842(in Chinese with English abstract).

Zhang Shuanhong, Zhao Yue, Kröner A, Liu Xiaoming, Xie Liewen, Chen Fukun. 2008. Early Permian plutons from the northern North China Block: constraints on continental arc evolution and convergent margin magmatism related to the Central Asian Orogenic Belt[J]. International Journal of Earth Sciences, 98(6): 1441−1467.

Zhang Shuanhong, Zhao Yue, Song Biao, Hu Jianmin, Liu Shuwen, Yang Yueheng, Chen Fukun, Liu Xiaoming, Liu Jian. 2009. Contrasting Late Carboniferous and Late Permian−Middle Triassic intrusive suites from the northern margin of the North China craton: Geochronology, petrogenesis, and tectonic implications[J]. Geological Society of America Bulletin, 121(1/2): 181−200.

Zhang Shuanhong, Zhao Yue, Song Biao, Yang Zhenyu, Hu Jianmin, Wu Hai. 2007. Carboniferous granitic plutons from the northern margin of the North China block: Implications for a late Paleozoic active continental margin[J]. Journal of the Geological Society, 164 (2): 451−463.

Zhou Zhenhua, Mao Jingwen, Lyckberg P. 2012. Geochronology and isotopic geochemistry of the A−type granites from the Huanggang Sn−Fe deposit, southern Great Hinggan Range, NE China: Implication for their origin and tectonic setting[J]. Journal of Asian Earth Sciences, 49(3): 272−286.

Zhu Xuefeng, Chen Yanjing, Wang Pin, Zhang Cheng, Cai Yunlong, Deng Ke, Xu Qiangwei, Li Kaiyue. 2018. Zircon U−Pb age, geochemistry and Hf isotopes of the causative porphyry from the Bilihe porphyry gold deposit, Inner Mongolia[J]. Earth Science Frontiers, 25(5):199−134 (in Chinese with English abstract).

附中文参考文献

鲍庆中, 张长捷, 吴之理, 王宏, 李伟, 桑家和, 刘永生. 2007. 内蒙古白音高勒地区石炭纪石英闪长岩SHRIMP锆石U−Pb年代学及其意义[J]. 吉林大学学报(地球科学版), 37(1):15−23.

陈斌, 陈长健, 贺敬博, 刘安坤. 2013. 华北东部中生代高镁埃达克质岩浆的起源: 岩石学和Nd−Sr−Os同位素证据[J]. 科学通报, 58 (20): 1941−1953.

陈斌, 马星华, 刘安坤, 木合塔尔.扎日. 2009. 锡林浩特杂岩和蓝片岩的锆石U−Pb年代学及其对索仑缝合带演化的意义[J]. 岩石学报, 25(12): 3123−3129.

陈衍景, 翟明国, 蒋少涌. 2009. 华北大陆边缘造山过程与成矿研究的重要进展和问题[J]. 岩石学报, 25(11): 3−34.

陈衍景, 张成, 李诺, 杨永飞, 邓轲. 2012. 中国东北钼矿床地质[J]. 吉林大学学报(地球科学版), 42(5): 1223−1268.

葛梦春, 周文孝, 于洋, 孙俊俊, 鲍建泉, 王世海. 2011. 内蒙古锡林郭勒杂岩解体及表壳岩系年代确定[J]. 地学前缘, 18(5):182−195.

韩宝福, 加加美宽雄, 李惠民. 2004. 河北平泉光头山碱性花岗岩的时代、Nd−Sr同位素特征及其对华北早中生代壳幔相互作用的意义[J]. 岩石学报, 20(6): 1375−1388.

洪大卫, 王式洸, 谢锡林, 张季生, 王涛. 2003. 从中亚正ε_{Nd}值花岗岩看超大陆演化和大陆地壳生长的关系[J]. 地质学报, 77(2): 203−209.

洪大卫, 王式洸, 谢锡林, 张季生. 2000. 兴蒙造山带正ε(Nd,t)值花岗岩的成因和大陆地壳生长[J]. 地学前缘, 7(2): 441−456.

黄汲清, 陈炳蔚. 1987. 中国及邻区特提斯海的演化[M]. 北京: 地质出版社.

简平, 张旗, 刘敦一, 金维浚, 贾秀勤, 钱青. 2005. 内蒙古固阳晚太古代赞岐岩(sanukite)−角闪花岗岩的SHRIMP定年及其意义[J]. 岩石学报, 21(01): 153−159.

李锦轶, 高立明, 孙桂华, 李亚萍, 王彦斌. 2007. 内蒙古东部双井子中三叠世同碰撞壳源花岗岩的确定及其对西伯利亚与中朝古板块碰撞的约束[J]. 岩石学报, 23(3): 565−582.

刘建峰, 迟效国, 赵芝, 胡兆初, 陈军强. 2013. 内蒙古巴林右旗建设屯埃达克岩锆石U−Pb年龄及成因讨论[J]. 岩石学报, 29(3): 827−839.

刘建峰, 李锦轶, 迟效国, 曲军峰, 胡兆初, 郭春丽. 2014. 内蒙古东南

部早三叠世花岗岩带岩石地球化学特征及其构造环境[J]. 地质学报, 88(9): 1677−1690.

刘建峰. 2009. 内蒙古林西—东乌旗地区晚古生代岩浆作用及其对区域构造演化的制约[D]. 长春吉林大学.

刘建明, 张锐, 张庆洲. 2004. 大兴安岭地区的区域成矿特征[J]. 地学前缘, 11(1): 269−277.

刘树文, 吕勇军, 凤永刚, 张臣, 田伟, 闫全人, 柳小明. 2007. 冀北单塔子杂岩的地质学和锆石U−Pb年代学[J]. 高校地质学报, 13(03): 484−497.

牟保磊, 阎国翰. 1992. 燕辽三叠纪碱性偏碱性杂岩体地球化学特征及意义[J]. 地质学报, 66(2): 108−121.

彭澎, 翟明国. 2002. 华北陆块前寒武纪两次重大地质事件的特征和性质[J]. 地球科学进展, 17(06): 818−825.

彭玉鲸, 纪春华, 辛玉莲. 2002. 中俄朝毗邻地区古吉黑造山带岩石及年代记录[J]. 地质与资源, 11(2): 65−75.

祁进平, 陈衍景, Franco F. 2005. 东北地区浅成低温热液矿床的地质特征和构造背景[J]. 矿物岩石, 25(2): 47−59.

任纪舜, 陈廷愚, 牛宝贵. 1990. 中国东部及邻区大陆岩石圈的构造演化与成矿[M]. 北京: 科学出版社.

芮宗瑶. 1994. 华北陆块北缘及邻区有色金属矿床地质[M]. 北京: 地质出版社.

邵济安, 何国琦, 唐克东. 2015. 华北北部二叠纪陆壳演化[J]. 岩石学报, 31(1): 47−55.

邵济安, 唐克东. 1995. 中国东北地体与东北亚大陆边缘演化[M]. 北京: 地震出版社.

邵济安. 1991. 中朝板块北缘中段地壳演化[M]. 北京: 北京大学出版社.

施光海, 刘敦一, 张福勤,简平, 苗来成, 石玉若, 陶华. 2003. 中国内蒙古锡林郭勒杂岩SHRIMP锆石U−Pb年代学及意义[J]. 科学通报, 48(20):2187−2192.

石玉若, 刘翠, 邓晋福, 简平. 2014. 内蒙古中部花岗质岩类年代学格架及该区构造岩浆演化讨论[J]. 岩石学报, 30(11): 3155−3171.

石玉若, 刘敦一, 张旗, 简平, 张福勤, 苗来成, 张履桥. 2007. 内蒙古中部苏尼特左旗地区三叠纪A型花岗岩锆石SHRIMP U−Pb年龄及其区域构造意义[J]. 地质通报, 26(2): 69−75.

舒启海, 赖勇, 魏良民, 孙艺, 王潮. 2011. 大兴安岭南段白音诺尔铅锌矿床流体包裹体研究[J]. 岩石学报, 27(5): 1467−1482.

隋振民, 葛文春, 吴福元, 张吉衡, 徐学纯, 程瑞玉. 2006. 大兴安岭东北部地区早古生代花岗岩锆石U−Pb年龄、Hf同位素特征及地质意义[C]// 全国岩石学与地球动力学研讨会.

田伟, 陈斌, 刘超群, 张华峰. 2007. 冀北小张家口超基性岩体的锆石U−Pb年龄和Hf同位素组成[J]. 岩石学报, 23(3): 57−64.

王芳, 陈福坤, 侯振辉, 彭澎, 翟明国. 2009. 华北陆块北缘崇礼—赤城地区晚古生代花岗岩类的锆石年龄和Sr−Nd−Hf同位素组成[J]. 岩石学报, 25(11): 3057−3074.

王琦. 1991. 内蒙古白音诺铅锌多金属矿床矽卡岩及其含矿性研究[D]. 北京:北京大学.

王强, 许继锋, 赵振华. 2001. 一种新的火成岩—埃达克岩的研究综述[J]. 地球科学进展, 16(2): 201−208.

王荃. 1991. 中国华夏与安加拉古陆间的板块构造[M]. 北京: 北京大学出版社.

王炎阳, 徐备, 程胜东, 廖闻, 邵军, 汪岩. 2014. 内蒙古克什克腾旗五道石门基性火山岩锆石U−Pb年龄及其地质意义[J]. 岩石学报, 30(7):2055−2062.

吴福元, 曹林. 1999. 东北亚地区的若干重要基础地质问题[J]. 世界地质, 18(2): 1−13.

吴福元, 李献华, 郑永飞, 高山. 2007. Lu−Hf同位素体系及其岩石学应用[J]. 岩石学报, 23(2): 185−220.

吴福元, 林强, 江博明. 1997. 中国北方造山带造山后花岗岩的同位素特点与地壳生长意义[J]. 科学通报, 42(20): 2188−2192.

吴福元, 孙德有, 林强. 1999. 东北地区显生宙花岗岩的成因与地壳增生[J]. 岩石学报, 15(2): 181−189.

吴元保, 郑永飞. 2004. 锆石成因矿物学研究及其对U−Pb年龄解释的制约[J]. 科学通报, 49(16): 1589−1604.

徐备, 陈斌. 1997. 内蒙古北部华北板块与西伯利亚板块之间中古生代造山带的结构及演化[J]. 中国科学(D辑), 27(3): 227−232.

徐备, 赵盼, 鲍庆中, 周永恒, 王炎阳, 罗志文. 2014. 兴蒙造山带前中生代构造单元划分初探[J].岩石学报, 30(7): 1841−1857.

阎国翰, 蔡剑辉, 任康绪, 何国琦, 牟保磊, 许保良, 李凤棠, 杨斌. 2007. 华北克拉通板内拉张性岩浆作用与三个超大陆裂解及深部地球动力学[J]. 高校地质学报, 13(2): 161−174.

阎国翰, 牟保磊, 许保良, 何国琦, 谭林坤, 赵晖, 何中甫, 张任祜, 乔广生. 2000. 燕辽—阴山三叠纪碱性侵入岩年代学和Sr,Nd,Pb同位素特征及意义[J]. 中国科学, 30(4): 383−67.

翟明国, 彭澎. 2007. 华北克拉通古元古代构造事件[J]. 岩石学报, 23(11): 2665−2682.

张旗, 金惟俊, 熊小林, 李承东, 王元龙. 2009. 中国不同时代O型埃达克岩的特征及其意义[J]. 大地构造与成矿学, 33(3): 432−447.

张旗, 钱青, 王二七, 王焰, 赵太平, 郝杰, 郭光军. 2001. 燕山中晚期的中国东部高原:埃达克岩的启示[J]. 地质科学, 36(2): 248−255.

张旗, 王焰, 熊小林. 2008. 埃达克岩和花岗岩: 挑战与机遇[M]. 北京: 中国大地出版社.

张旗, 许继峰, 王焰, 肖龙, 刘红涛, 王元龙. 2004. 埃达克岩的多样性[J]. 地质通报, 23(z2): 959−965.

张拴宏, 赵越, 刘建民, 胡健民, 宋彪, 刘健, 吴海. 2010. 华北地块北缘晚古生代—早中生代岩浆活动期次、特征及构造背景[J]. 岩石矿物学杂志, 29(6): 824−842.

郑永飞. 2004 . 新元古代岩浆活动与全球变化[J]. 科学通报, 48(16): 1705−1720。

朱雪峰, 陈衍景, 王玭, 张成, 蔡云龙, 邓轲, 许强伟, 李凯月. 2018. 内蒙古毕力赫斑岩型金矿成矿岩体锆石U−Pb年代学、地球化学及Hf同位素研究[J]. 地学前缘, 25(5): 125−140.