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大兴安岭多宝山地区晚古生代碱长花岗岩锆石U-Pb年龄:对兴安和松嫩地块碰撞拼合时间的限定

贾旭[1],任俊光[1],徐文坦[2],马虎超[3],张超[4],石国明[5]

(1.成都理工大学地球科学学院,四川 成都 610059;2.防灾科技学院地球科学学院,河北 三河 065201;3.金川集团股份有限公司龙首矿,甘肃 金昌 737100;4.西南石油大学地球科学与技术学院,四川 成都 610500;5.黑龙江省地质调查研究总院,黑龙江 哈尔滨 150036)

提要:【研究目的】大兴安岭多宝山地区位于兴蒙造山带东部的兴安地块与松嫩地块之间的构造带上,区内构造演化复杂,岩浆活动频繁,本文通过对多宝山地区晚古生代碱长花岗岩的年代学和岩石地球化学研究,旨在约束兴安地块与松嫩地块碰撞拼合的时限。**【研究方法】**开展了LA-ICP-MS锆石U-Pb测年和岩石主微量元素的测试分析工作。**【研究结果】**测年获得的2件样品的加权平均年龄分别为(300.3±2.0)Ma和(307.3±1.7)Ma,属晚石炭世。岩石具有高硅 SiO_2=69.70%~77.42%,相对富铝 Al_2O_3=11.60%~15.05%,富钾和钠(K_2O=4.09%~5.67%; Na_2O=3.13%~4.13%),贫钙和镁(CaO=0.02%~0.8%; MgO=0.02%~0.48%)的特征;微量元素表现出富集Rb、Th、Zr和Hf,亏损Ba、Sr、Nb和Ta,(Zr+Nb+Ce+Y)含量较高,平均值为529.10×10^{-6};稀土元素配分模式呈右倾,具明显Eu负异常;同时岩石具有较高的锆石饱和温度,符合A型花岗岩的特征。**【结论】**结合区域构造演化史,认为该期碱长花岗岩为造山期后伸展构造环境下岩浆活动的产物,并指示兴安地块和松嫩地块碰撞拼合的结束。

关 键 词:晚古生代;碱长花岗岩;年代学;地球化学;构造环境;地质调查工程;多宝山地区;大兴安岭

创 新 点:厘定多宝山地区晚古生代碱长花岗岩类型;约束兴安地块与松嫩地块碰撞-拼合的时限。

中图分类号:P595; P588.12 **文献标志码:**A **文章编号:**1000-3657(2022)02-0586-14

Zircon U-Pb dating of Late Paleozoic alkali-feldspar granite in Duobaoshan, Daxing'anling Mountains: Constrains on collision and assembly time of Xing'an and Songnen Blocks

JIA Xu[1], REN Junguang[1], XU Wentan[2], MA Huchao[3], ZHANG Chao[4], SHI Guoming[5]

(1.*School of Earth Sciences, Chengdu University of Technology, Chengdu* 610059*, Sichuan, China;* 2.*School of Earth Sciences, Institute of Disaster Prevention, Sanhe 0*65201*, Hebei, China;*3. *Longshou Mine, Jinchuan Group CO.,LTD.,Jinchang* 737100*, Gansu, China;*4.*School of Geoscience and Technology, Southwest Petroleum University, Chengdu* 610500*, Sichuan, China*;5. *Heilongjiang Geological Survey and Research Institute, Haerbin* 150036*, Heilongjiang, China*)

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作者简介:贾旭,男,1994年生,硕士,主要从事地球化学研究;E-mail: jx3997@outlook.com。

Abstract:This paper is the result of geological survey engineering.

[Objective] The Duobaoshan area of the Greater Xing'an Mountains is located on the tectonic belt between the Xing'an block and the Songnen block in the east of the Xingmeng orogenic belt. In this paper, the chronology and petrogeochemistry of the Late Paleozoic alkali feldspar granites in the Duobaoshan area are used to constrain the time limit of the collision between the Xing'an block and the Songnen block.**[Methods]**In this paper, the zircon U-Pb geochronology and the whole rock geochemistry were carried out.**[Results]** The LA-ICPMS U-Pb ages of zircons from two alkali-feldspar granite samples were (300.3±2.0)Ma and (307.3±1.7) Ma, respectively. Two samples have the similar geochemistry characteristics, with high silicon (SiO_2= 69.70% to 77.42%), relatively high aluminum (Al_2O_3=11.60% to 15.05%), and high alkali (K_2O+ Na_2O=7.22% to 9.80%), low Ca and Mg (CaO=0.02% to 0.8%, MgO=0.02% to 0.48%), enrichment of Rb, Th, Zr and Hf, depleted of Ba, Sr, Nb and Ta, relatively high (Zr+Nb+Ce + Y). In addition, they also have significantly negative Eu anomalies, with the right-leaningdistribution of rare earth elements and high zircon saturation temperature, suggesting both of them are A-type granites. **[Conclusions]**Combined with the regionally tectonical evolution, it is concluded that the alkali-feldspar granite formed at extensional geological background of post-collision regime, marking the end of the collision between the Xing'an block and the Songnen block.

Key words: Late Paleozoic; alkali-feldspar granite; geochronology; geochemical characteristics; tectonic environment; geological exploration engineering;Duobaoshan area; Daxinganling Mountains

Highlights: Determine the type of late Paleozoic alkali-feldspar granite in Duobaoshan area;Constrains the collision and assembly time of Xing'an and Songnen blocks.

About the first author: JIA Xu, male, born in 1994, master, major in geochemical research;E-mail: jx3997@outlook.com.

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1　引　言

兴蒙造山带是中亚造山带的重要组成部分,其东段的大兴安岭地区主要包括额尔古纳、兴安与松嫩地块,中生代以来各微地块之间的碰撞拼贴过程一直是地质学研究的热点问题(李双林等,1998;孙德有等,2000;Chen et al.,2000;苗来成等,2003;周长勇等,2005;葛文春等,2005;张兴洲等,2008;隋振民等,2009;刘永江等,2010;赵芝等,2010;赵焕利等,2011;崔芳华等,2013;张磊等,2013;汪岩等,2013;尹志刚等,2018;钱程等,2018;徐文喜等,2018;陈会军等,2019;Ma et al.,2021;赵亮亮等,2021)。近年来,大量学者对兴安与松嫩地块拼接带附近的岩浆岩做了详尽的岩石地球化学、年代学方面的研究工作,但对碰撞拼合的时限及花岗岩岩石类型仍存有争议。其中关于拼合时限有早中生代(Chen et al., 2000; Wu et al., 2002;苗来成等,2003; 张彦龙等,2010)和晚古生代(周长勇等,2005;张兴洲等,2008;隋振民等,2009;赵焕利等,2011; 崔芳华等,2013;张磊等,2013;杨红章等, 2019)之争;多宝山早古生代碱长花岗岩岩石类型亦有S型和A型等不同见解(曲晖等,2011;赵焕利等,2011;郭奎城等,2011)。

本文对黑龙江省多宝山地区晚古生代的碱长花岗岩样品进行岩石学、岩石地球化学及锆石U-Pb年代学研究,进一步厘定岩石类型、成因及形成构造背景,以期为兴蒙造山带东段的构造演化提供重要信息。

2　地质概况及岩石学特征

多宝山地区位于大兴安岭东北部,地处兴蒙造山带东段的兴安地块与松嫩地块拼合带附近(图1)。区内发育的地层由老到新依次为:下—中奥陶统铜山组($O_{1-2}t$)、下—中奥陶统多宝山组($O_{1-2}d$)、上奥陶统裸河组(O_3l)、下志留统黄花沟组(S_1h)、顶志留—中泥盆统泥鳅河组(S_4D_2n)、下白垩统的龙江组(K_1l)、光华组(K_1gh)、九峰山组(K_1j)、甘河组(K_1g)以及大面积的第四系河流堆积物和洪积物。区域上地质构造复杂,岩浆活动频繁,从加里东期—燕山早期均有不同规模的岩浆活动,形成了大量中酸性侵入岩体,同时岩石类型多变,由老到新分布有中奥陶世的花岗闪长岩、花岗闪长斑岩,早石炭世的正长花岗岩,晚石炭世—早二叠世的碱长花岗岩,中—晚三叠世的花岗闪长岩,早—中侏罗世的花岗闪长岩、二长花岗岩,早白垩世的花岗斑岩及

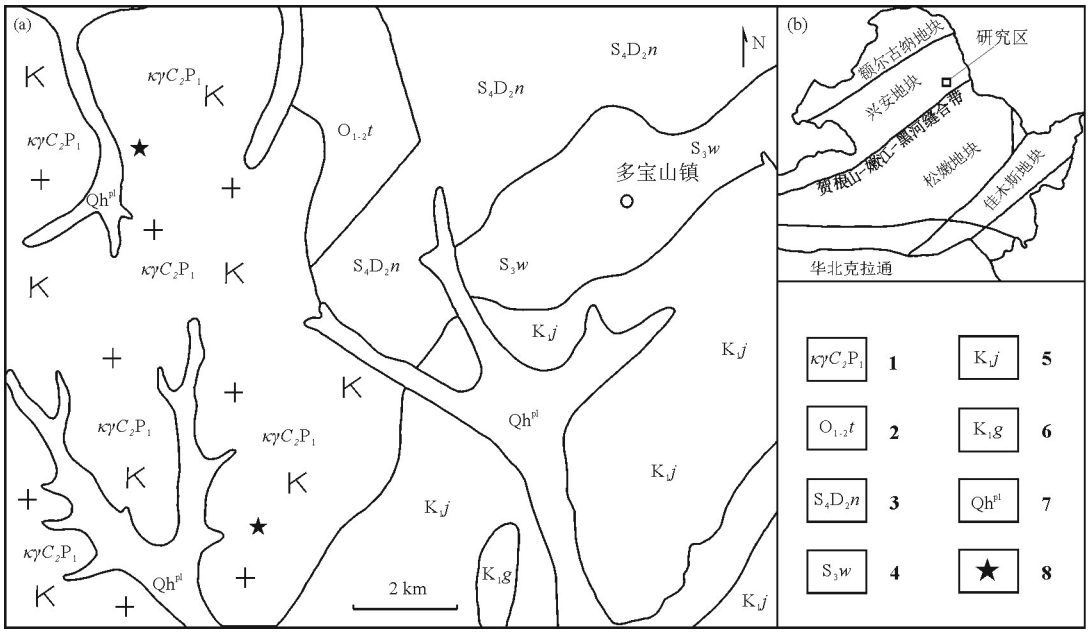

图1 多宝山地区地质简图(a)及区域构造简图(b)

1—早二叠世碱长花岗岩;2—下—中奥陶统铜山组;3—顶志留—中泥盆统泥鳅河组;4—上志留统卧都河组;5—下白垩统九峰山组;6—下白垩统甘河组;7—河流堆积物;8—锆石样品位置

Fig. 1 Simplified geological map (a) and tectonic setting map (b) of Dobaoshan area

1−Early Permian alkali feldspar granite;2−Lower−middle Ordovician Tongshan Formation;3−Upper Silurian−Middle Devonian Niqiuhe Formation; 4−Upper Silurian Woduhe Formation;5−Lower Cretaceous Jiufengshan Formation;6−Lower Cretaceous Ganhe Formation;7−River deposits;8−Zircon sampling location

不同期次的岩脉。

本文研究的晚古生代碱长花岗岩主要发育在多宝山地区西南侧,群富村以西一带,岩体大致呈N—NNE向展布,出露面积约60 km^2。其岩相学特征揭示:岩石具粗中粒结构,块状构造。岩石主要成分为碱性长石(63%±)、石英(30%±)、斜长石(5%±)、少量黑云母、副矿物(2%±)粒度小于6 mm。其中碱性长石为微斜条纹长石,发育纹状条纹、格子双晶结构,晶粒包裹少量净边结构的斜长石微粒(图2);斜长石为半自形柱状,聚片双晶发育,成分An为27的更长石,被碱性长石交代,裂纹发育,粒度为0.1~1.5 mm,交代斜长石具交代蚕食结构,粒度为0.2~5.5 mm;石英主要为他形粒状,部分细粒化,可见波状消光,变形条带发育,交代长石者为交代蚕食结构,裂纹发育,粒度小于6 mm;黑云母为片状,晶面完全被褐铁矿交代,片径小于0.2 mm。副矿物组合为:锆石、磷灰石、黄铁矿、锐钛矿、磁铁矿、白钛石、榍石、辉石、绿帘石、石榴石、角闪石及褐铁矿。

3 样品及测试方法

本文对2件样品PM104U−Pb(采样位置:125°33′57.82″E;50°1′10.5″N)和PM116U−Pb(采样位置:125°32′30.47″E;50°7′19.83″N)进行LA−ICP−MS锆石U−Pb法年龄的测定,另在研究区碱长花岗岩体的不同部位采集13件样品进行岩石地球化学的分析测试。

野外采集测年样品重约10 kg,锆石分选在河北省区域地质矿产调查研究所完成,用常规方法先将样品粉碎至80~100目,将过筛后的岩石粉末进行淘洗,去除轻矿物部分,保留重砂部分,后经过电磁选得到纯度较高的单矿物样品。在双目镜下挑选出晶形、透明度较好、裂隙和包体较少、表面洁净的锆石颗粒用于年龄测定。锆石制靶和阴极发光(CL)图像的采集在北京离子探针中心完成。锆石U−Pb同位素分析在中国地质调查局天津地质调查中心完成,检测依据为DZ/T0184.3−1997,所用仪器为ThermoFisHer公司制造的Neptune型LA−MIC−

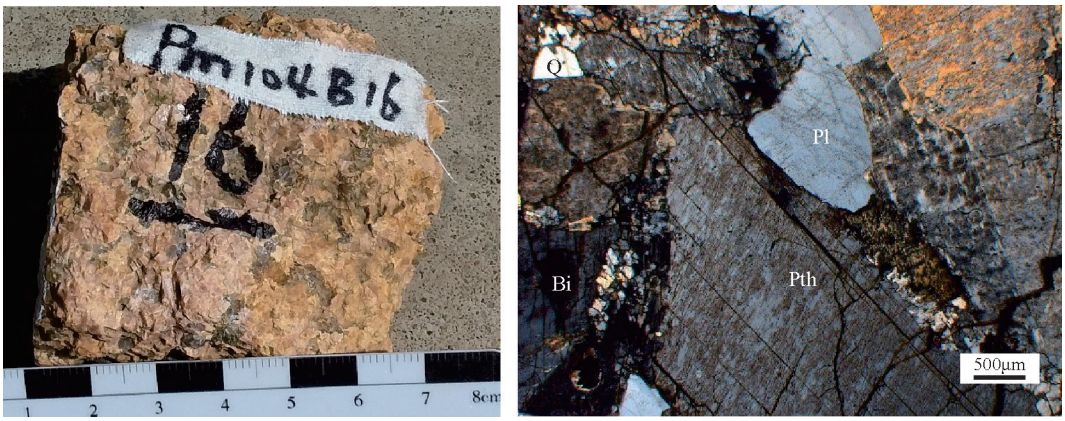

图2 粗中粒碱长岩的岩石手标本和镜下特征
Q—石英;Pl—斜长石;Pth—条纹长石;Bi—黑云母
Fig.2 Rock hand specimens and microphotograph features of coarse and medium-grained alkali feldspars
Q-Quartz;Pl-Plagioclase; Pth-Perthite; Bi-Biotite

ICP-MS和Cetac公司制造的GeolasPro193准分子型激光系统,用193 nm激光器对锆石进行剥蚀,深度为20~40 μm,激光剥蚀斑束直径为35 μm,应用TEMORA和GJ-1作为外部锆石年龄标准进行分馏校正,详细的实验原理和流程见相关文献(李怀坤等, 2009)。数据处理采用Glitter(Jackson,2004)程序计算锆石表面年龄及标准偏差;使用Isoplot 3.0 (Ludwig,1991)程序进行锆石样品的年龄谐和图投图和加权平均年龄值计算。

13件新鲜、无蚀变样品的主量-微量-稀土元素的分析测试在中国地质调查局天津地质调查中心完成,其中主量元素分析采用X-荧光光谱法测定(XRF),所用仪器型号为PW2400/40型X-荧光光谱仪(荷兰帕纳科公司)。微量及稀土元素分析采用电感耦合等离子质谱法(ICP-MS)测定,仪器型号为X Series II型电感耦合等离子体质谱仪(美国热电公司)。

4 测试结果和分析

锆石CL图像(图3)显示锆石具有较好的晶形,整体多为自形、半自形粒状,晶棱和晶面相对清晰,可见自形生长纹和生长环带,长宽比较小,多数为1∶1~2∶1。参与加权年龄计算的锆石Th/U比值分别介于0.30~1.34(样品PM104U-Pb,均值0. 45)和0.36~0.75(样品PM116U-Pb,均值0. 43),比值均大于0.1,据此可以推断锆石性质为岩浆成因(吴元保等, 2004)。

本次对样品PM104U-Pb和PM116U-Pb均进行了25个点的测年分析(表1),剔除年龄谐和度低于95%的锆石后,年龄数据投影点落在谐和线上或附近,表明这些颗粒形成后U-Pb同位素体系是封闭的,基本没有U或Pb同位素的丢失或加入。样品PM104U-Pb的20颗锆石的$^{206}Pb/^{238}U$年龄介于(297±4)Ma~(304±4)Ma,计算加权年龄为(300.3±2.0)Ma

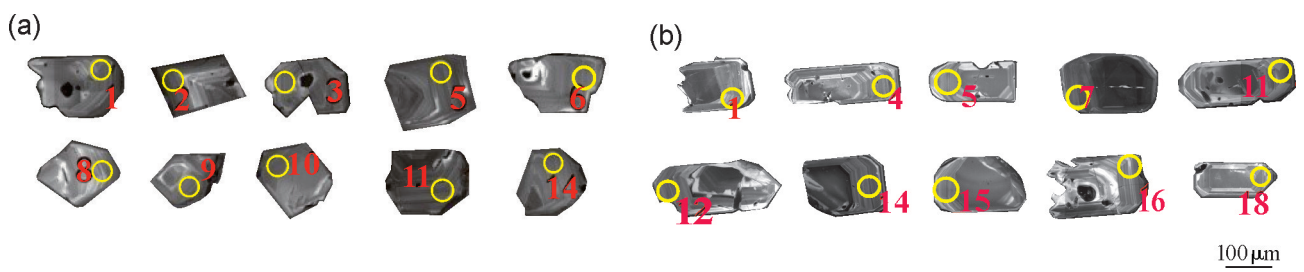

图3 样品PM104U-Pb(a)与PM116U-Pb(b)锆石阴极发光图像
Fig.3 CL images of zircons of PM104U-Pb(a) and PM116U-Pb(b)

表1 多宝山碱长花岗岩LA−ICP−MS锆石U−Pb测年分析结果

Table 1LA−ICP−MS zircon U−Pb dating results for the alkali−feldspar granite in Duobaoshan

测点号	元素含量/10^{-6}		Th/U	同位素比值				年龄/Ma				谐和度/%
	Th	U		$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	
样品PM104 U−Pb												
1	132.29	328.7	0.40	0.3469	0.012	0.0482	0.0009	302.42	8.83	303.47	5.4	99
2	270.85	677.2	0.40	0.3827	0.01	0.0478	0.0008	329.04	7.67	300.83	4.89	96
3	139.51	326	0.43	0.3441	0.01	0.0478	0.0008	300.28	7.54	300.94	4.76	99
4	244.94	570.6	0.43	0.4312	0.017	0.0476	0.0007	364.04	12.2	299.73	4.07	80
5	323.79	835	0.39	0.3433	0.009	0.0481	0.0007	299.67	6.66	302.95	4.38	98
6	145.16	411.1	0.35	0.3372	0.009	0.0472	0.0007	295.01	6.57	297.01	4.27	99
7	185.51	331.3	0.56	0.4955	0.025	0.0487	0.0009	408.68	17	306.25	5.64	71
8	136.89	412.1	0.33	0.3384	0.009	0.0478	0.0008	296	6.85	301.23	4.89	98
9	158.77	435.6	0.36	0.3386	0.011	0.0474	0.0006	296.13	8.33	298.64	3.84	99
10	179.38	514	0.35	0.3423	0.01	0.0474	0.0006	298.94	7.64	298.82	3.83	99
11	225.63	668.8	0.34	0.3414	0.008	0.0482	0.0008	298.2	5.82	303.32	4.87	98
12	340.21	850.8	0.40	0.349	0.01	0.0478	0.0007	303.94	7.53	301.12	4.51	99
13	629.28	471.2	1.34	0.3402	0.008	0.0477	0.0008	297.35	5.98	300.18	4.84	99
14	111.59	357.9	0.31	0.349	0.012	0.0482	0.0007	303.99	8.65	303.55	4.2	99
15	122.72	304.2	0.40	0.3728	0.02	0.0489	0.0006	321.72	14.7	307.76	3.88	91
16	452.79	1218	0.37	0.3735	0.01	0.0472	0.0007	322.28	7.13	297.08	4.27	95
17	146.08	376.4	0.39	0.3531	0.011	0.0479	0.0007	307.08	7.85	301.83	4.1	98
18	96.99	318.8	0.30	0.4254	0.017	0.0489	0.0007	359.93	12.1	307.69	4.46	84
19	141.9	346.1	0.41	0.3466	0.01	0.0476	0.0006	302.13	7.34	299.96	3.87	99
20	155.32	356.9	0.44	0.3364	0.014	0.0474	0.0007	294.46	10.9	298.47	4.56	98
21	192.02	450.9	0.43	0.3419	0.012	0.0473	0.0006	298.6	8.96	297.91	3.74	99
22	337.38	787.7	0.43	0.3502	0.008	0.0475	0.0007	304.88	5.96	299.18	4.47	98
23	345.09	738.1	0.47	0.346	0.009	0.0474	0.0007	301.67	6.55	298.6	4.5	98
24	296.5	402.1	0.74	0.3426	0.01	0.0478	0.0006	299.16	7.76	301.26	3.89	99
25	112.15	165.4	0.68	0.0182	0.047	0.0009	0.415	333.07	13.3	297	5.63	88
样品PM116 U−Pb												
1	121.23	293.9	0.41	0.368	0.01	0.0497	0.0007	318	7.12	312	4.33	98
2	169.36	408.9	0.41	0.3628	0.012	0.0482	0.0006	314	8.96	303	3.93	96
3	147.04	342.3	0.43	0.35	0.01	0.0493	0.0008	305	7.76	310	5.14	98
4	147.57	340.2	0.43	0.3661	0.012	0.0494	0.0007	317	8.93	311	4.52	98
5	139.22	326.2	0.43	0.3505	0.011	0.0485	0.0007	305	8.50	305	4.23	99
6	113.55	310.9	0.37	0.3389	0.011	0.0482	0.0007	296	8.04	303	4.24	97
7	130.21	352.4	0.37	0.365	0.011	0.0487	0.0007	316	8.36	307	4.25	97
8	122.83	311.7	0.39	0.3674	0.015	0.0492	0.0007	318	11.35	309	4.39	97
9	143.99	316	0.46	0.3562	0.014	0.0494	0.0008	309	11.55	311	4.85	99
10	125.83	296.5	0.42	0.3404	0.01	0.0495	0.0007	297	7.88	311	4.20	95
11	96.65	257.2	0.38	0.3543	0.012	0.0493	0.0007	308	9.25	310	4.07	99
12	112.42	276.7	0.41	0.3565	0.011	0.0492	0.0008	310	7.97	310	4.88	99
13	106.89	275.2	0.39	0.3785	0.015	0.0491	0.0008	326	11.35	309	4.78	94
14	124.4	343	0.36	0.3664	0.012	0.0495	0.0007	317	9.00	311	4.52	98
15	222.91	393.9	0.57	0.3613	0.011	0.0491	0.0008	313	8.41	309	4.68	98
16	100.48	243.4	0.41	0.3431	0.014	0.0494	0.0006	300	10.67	311	3.89	96
17	154.83	353.1	0.44	0.3552	0.012	0.0489	0.0007	309	8.58	308	4.60	99
18	154.2	336.1	0.46	0.3729	0.012	0.0491	0.0007	322	8.63	309	4.44	95
19	297.45	393.4	0.76	0.3533	0.012	0.048	0.0006	307	8.64	303	3.88	98
20	100.8	271.1	0.37	0.332	0.011	0.0483	0.0006	291	8.54	304	3.75	95
21	122.89	292.7	0.42	0.3432	0.011	0.0482	0.0006	300	8.14	303	3.87	98
22	155.63	356	0.44	0.3633	0.013	0.0486	0.0007	315	9.30	306	4.35	97
23	2491.7	1035	0.37	0.4439	0.01	0.0477	0.0011	373	6.96	300	6.54	78
24	123.11	288.2	0.43	0.3547	0.013	0.0478	0.0007	308	9.57	301	4.35	97
25	136.11	342.3	0.40	0.3366	0.012	0.0478	0.0008	295	8.71	301	4.68	97

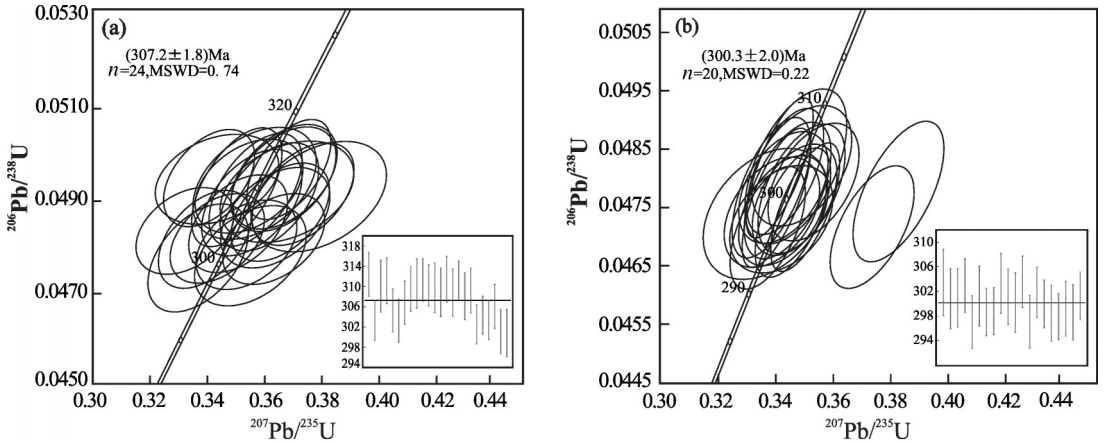

图4 样品PM104U-Pb(a)与PM116U-Pb(b)锆石U-Pb年龄谐和图
Fig.4 Zircon U-Pb age concordia diagrams of PM104U-Pb(a) and PM116U-Pb(b)

(MSWD=0.22)(图4a)。样品PM116U-Pb的24颗锆石的$^{206}Pb/^{238}U$年龄介于(330±4)Ma~(312±4)Ma,计算加权年龄为(307.3±1.7) Ma(MSWD=0.71)(图4b)。

5 岩石地球化学特征

5.1 主量元素特征

从表2中数据可知,该碱长花岗岩样品主量元素中SiO_2含量为69.70%~77.42%,TiO_2含量为0.08%~0.34%,Al_2O_3含量为11.60%~15.05%,Fe_2O_3含量为0.27%~2.46%,FeO含量为0.51%~0.93%,MnO含量为0.01%~0.09%,MgO含量为0.02%~0.48%,CaO含量为0.02%~0.8%,Na_2O含量为3.13%~4.13%,K_2O含量为4.09%~5.67%,P_2O_5含量0.01%~0.06%,整体上具有高硅、富钾和钠及贫钙、镁、磷特点。

全碱含量高,(Na_2O+K_2O)介于7.22%~9.8%,平均值8.43%;K_2O/Na_2O介于1.07~1.51,在K_2O-SiO_2图解(图5a)中表现为高钾钙碱性。碱度率*AR*介于2.43~4.97,为碱性系列岩石。A/NK介于1.07~1.53,A/CNK=1.05~1.45,在铝饱和指数判别图解(图5b)中投点均落入过铝质区内。FeO^T介于0.99~2.77,FeO^T/MgO值变化较大介于5.78~83.04,表现出富Fe特点。镁指数$Mg^{\#}$介于1.19~14.71,表明其可能是由地壳物质部分熔融组成(Rapp et al., 1995)。

5.2 微量与稀土元素特征

样品的微量与稀土元素含量见表2,大离子亲石元素(LILE)中Rb、Sr、Ba含量分别为58×10^{-6}~200×10^{-6}、10×10^{-6}~99×10^{-6}、9×10^{-6}~436×10^{-6};高场强元素(HFSE)Nb、Ta、Zr、Hf含量分别为10.4×

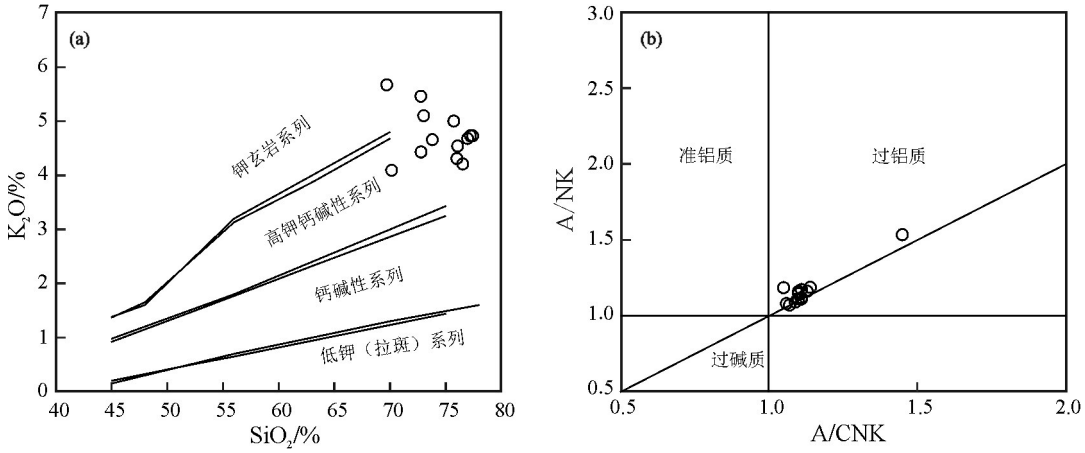

图5 多宝山碱长花岗岩K_2O-SiO_2(a,据Peccerillo et al.,1976)与A/NK- A/CNK图解(b ,据Maniar et al., 1989)
Fig.5 K_2O-SiO_2(a ,after Peccerillo et al., 1976) and A/NK- A/CNK(b,after Maniar et al., 1989)diagrams of the alkali-feldspar granite in Duobaoshan

表2 多宝山碱长花岗岩主量、微量和稀土元素岩石化学分析结果及相关参数

Table 2 Major,rare earth and trace element of alkali−feldspar granite in Duobaoshan

样品号	Pm119	Pm119	Pm119	Gs	Pm118	Pm118	Pm118	Pm118	Pm116	Pm104	Pm104	Pm104	Gs
	Gs48	Gs46	Gs23	6606	Gs33	Gs29	Gs137	Gs131	Gs40	Gs33	GS28	Gs15	2161A
SiO_2	76	76.52	76.06	72.78	70.14	73.8	69.7	73.02	72.76	77.42	76.96	77.22	75.72
TiO_2	0.12	0.13	0.18	0.31	0.34	0.19	0.34	0.23	0.21	0.08	0.08	0.09	0.17
Al_2O_3	12.13	11.92	12.8	13.46	14.7	13.49	15.05	13.21	13.93	11.6	11.81	11.7	13.26
Fe_2O_3	1.63	1.55	1.09	1.9	2.46	1.47	1.99	1.73	1.5	1.02	1.38	0.99	0.27
FeO	0.62	0.51	0.51	0.75	0.56	0.59	0.57	0.81	0.93	0.78	0.63	0.77	0.75
MnO	0.09	0.05	0.02	0.06	0.07	0.05	0.02	0.06	0.04	0.03	0.02	0.02	0.01
MgO	0.03	0.13	0.05	0.3	0.48	0.12	0.11	0.11	0.13	0.04	0.03	0.02	0.08
CaO	0.02	0.1	0.07	0.8	0.31	0.35	0.23	0.24	0.39	0.03	0.04	0.03	0.25
Na_2O	4.04	3.93	4.01	3.98	3.13	4	4.13	3.4	3.62	3.23	3.33	3.4	3.74
K_2O	4.31	4.21	4.54	4.43	4.09	4.66	5.67	5.1	5.46	4.73	4.68	4.73	5
P_2O_5	0.02	0.02	0.03	0.08	0.04	0.04	0.06	0.03	0.03	0.02	0.02	0.01	0.03
烧矢量	0.4	0.32	0.46	0.52	3.14	0.66	1.62	1.64	0.62	0.48	0.6	0.38	0.38
总量	99.41	99.39	99.82	99.37	99.46	99.42	99.49	99.58	99.61	99.45	99.58	99.35	99.67
Na_2O+K_2O	8.35	8.14	8.55	8.41	7.22	8.66	9.8	8.5	9.08	7.96	8.01	8.13	8.74
K_2O/Na_2O	1.07	1.07	1.13	1.11	1.31	1.17	1.37	1.5	1.51	1.46	1.41	1.39	1.34
FeO^T	2.09	1.9	1.49	2.46	2.77	1.91	2.36	2.37	2.28	1.7	1.87	1.66	0.99
FeO^T/MgO	83.47	14.65	29.23	8.2	5.78	15.94	21.46	21.52	17.54	47.16	58.49	83.04	12.26
A/NK	1.07	1.08	1.11	1.19	1.53	1.16	1.16	1.19	1.17	1.11	1.12	1.09	1.15
A/CNK	1.07	1.06	1.1	1.05	1.45	1.1	1.13	1.14	1.11	1.11	1.11	1.09	1.1
$Mg^{\#}$	0.02	0.11	0.06	0.18	0.24	0.1	0.08	0.08	0.09	0.04	0.03	0.02	0.13
Rb	143	143	135	110	130	141	76	82	58	200	194	188	104
Sr	16	18	32	99	80	77	21	36	29	10	12	17	33
Ba	81	67	201	289	436	368	132	171	108	9	28	31	81
Nb	32.4	32.1	28.7	24.9	21.3	26.3	23.5	18	10.4	44.5	29.6	34.6	20.4
Ta	2.87	3.09	1.68	2.34	1.34	2.73	1.31	1.04	0.52	4.69	3.82	3.32	1.79
Zr	390	370	345	316	207	201	642	401	380	321	278	295	333
Hf	8	9.1	8.1	6.6	4.8	5.1	11.9	7.7	6.8	8.9	7.3	7.4	7.6
Th	16.8	15.5	13.1	11.9	13.9	15.2	14.9	9.28	8.62	19.3	12.5	16.7	13.7
Cr	31.2	8.1	38.2	13	37.9	39	2.6	21.7	23.6	31.3	8.8	26.9	11.4
Sc	5.65	5.22	5.17	4.88	6.25	4.65	6.85	4.06	5.56	1.88	1.9	1.83	4.13
U	2.38	2.28	0.85	2.27	2.19	2.13	1.31	0.86	0.8	3.95	3.66	3.33	2.83
Rb/Sr	8.94	7.94	4.22	1.11	1.63	1.83	3.62	2.28	2	20	16.17	11.06	3.15
Rb/Ba	1.77	2.13	0.67	0.38	0.3	0.38	0.58	0.48	0.54	22.22	6.93	6.06	1.28
Zr/Hf	48.75	40.66	42.59	47.88	43.13	39.41	53.95	52.08	55.88	36.07	38.08	39.86	43.82
La	28	24.4	42.1	48.5	24.7	11	143	58.5	56.4	6.17	5.47	15.3	69.9
Ce	103	86.2	97.4	108	80.5	67.4	309	165	139	45.5	47.3	93.1	153
Pr	8.52	7.17	10.9	13	6.02	3.08	33.5	14.1	14.8	1.7	1.37	3.82	17.1
Nd	32.5	27.3	42.9	49.9	22.4	11.4	120	51	54.6	6	4.88	13.4	62.2
Sm	7.51	6.13	7.22	10.3	4.3	2.47	16.6	8.18	8.34	1.31	1.19	2.84	10.2
Eu	0.46	0.38	0.71	0.84	0.75	0.58	0.42	0.46	0.35	0.03	0.03	0.07	0.26
Gd	8.68	7.22	6.07	9.88	4.41	3	11.5	6.59	5.87	1.84	1.79	3.54	8.72
Tb	1.68	1.44	0.89	1.6	0.8	0.65	1.39	0.92	0.75	0.61	0.54	0.94	1.24
Dy	11.1	9.71	5.04	9.45	5.11	4.83	6.73	5.1	3.71	6.38	5.15	8.14	6.81
Ho	2.37	2.07	1	1.91	1.07	1.14	1.19	1	0.67	1.89	1.44	2.08	1.32
Er	7.32	6.39	3.01	5.62	3.23	3.89	3.09	2.92	1.84	7.66	5.5	7.28	3.82
Tm	1.07	0.93	0.45	0.79	0.47	0.66	0.41	0.42	0.26	1.29	0.94	1.14	0.54
Yb	6.82	6.07	3.09	4.78	2.87	4.62	2.68	2.71	1.75	8.66	6.37	7.43	3.49
Lu	1.13	0.96	0.53	0.71	0.43	0.75	0.47	0.47	0.3	1.41	1.03	1.19	0.59
Y	71.5	62.9	29.3	54.6	30.3	35.5	29.6	26.6	17.3	54.9	43	62.5	40.1
ΣREE	220.16	186.37	221.31	265.28	157.06	115.47	649.98	317.37	288.64	90.45	83	160.27	339.19
LREE/HREE	4.48	4.36	10.02	6.64	7.54	4.91	22.67	14.77	18.05	2.04	2.65	4.05	11.79
δEu	0.17	0.17	0.32	0.25	0.52	0.65	0.09	0.19	0.15	0.06	0.06	0.06	0.08
δCe	1.59	1.55	1.07	1.02	1.54	2.75	1.04	1.34	1.13	3.33	4.05	2.86	1.04
$(La/Yb)_N$	2.77	2.71	9.19	6.84	5.8	1.61	35.97	14.55	21.73	0.48	0.58	1.39	13.5
Zr+Nb+Ce+Y	596.9	551.2	500.4	503.5	339.1	330.2	1004.1	610.6	546.7	465.9	397.9	485.2	546.5
锆石饱和温度	794.73	824.72	869.45	912.51	833.2	826.6	841.8	845.67	861.41	902.78	832.25	858.43	844.7

注:主量元素质量分数单位为%,微量元素含量单位为g/t, 锆石饱和温度单位为℃。

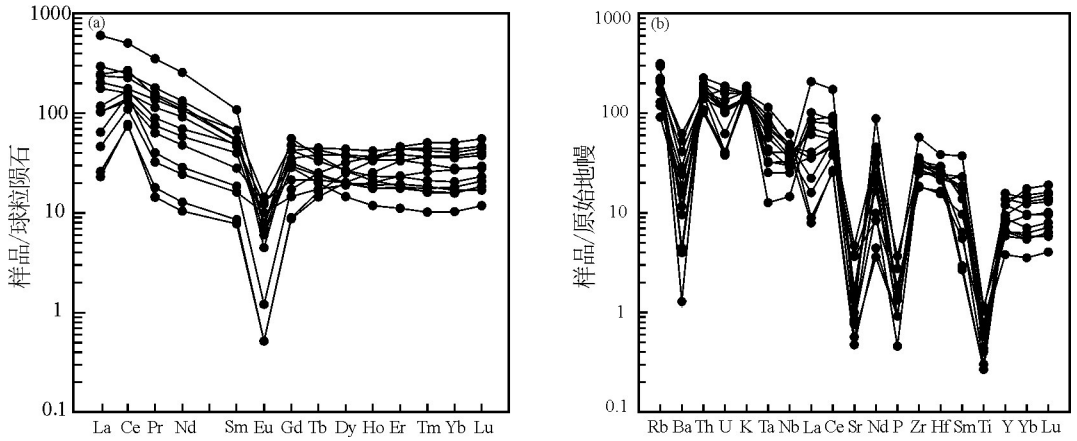

图6 多宝山碱长花岗岩稀土元素球粒陨石标准化配分曲线图(a)及微量元素原始地幔标准化蛛网图(b)
(标准化数值据Sun et al.,1989)

Fig.6 Chondrite-normalized REE patterns (a)and primitive mantle-normalized trace element patterns(b) of the alkali-feldspar granite in Duobaoshan(normalized data after Sun et al.,1989)

10^{-6}~44.5×10^{-6}、0.52×10^{-6}~4.69×10^{-6}、201×10^{-6}~642×10^{-6}、4.8×10^{-6}~11.9×10^{-6};放射性生热元素(RPH)U、Th含量分别为0.8×10^{-6}~3.95×10^{-6}、8.62×10^{-6}~19.3×10^{-6}。

微量元素对原始地幔标准化蛛网图(图6b)上,表现出Rb、Th、K、Nd、Zr、Hf元素的富集和Ba、Sr、P、Ti的亏损,表明岩浆在演化过程中存在金红石、磷灰石以及钛铁矿的残留或分离结晶(康磊等,2016)。Nb/Ta值为8~20,均值为13.02,接近大陆地壳的Nb/Ta比值10~14(赵振华等,2008),但低于上地幔Nb/Ta的平均值17.5(McDonough et al.,1995)。Rb/Sr比值为1.11~20,平均为6.46,明显高于原始地幔的Rb/Sr值0.03,且大于地壳的Rb/Sr平均值0.24(黎彤,1994),上述比值均表明花岗岩可能为壳源。

稀土总量(REE)为126×10^{-6}~679.58×10^{-6},平均值为280.97×10^{-6},其中轻稀土元素(LREE)含量为60.71×10^{-6}~622.52×10^{-6},平均值为211.80×10^{-6};重稀土元素(HREE)含量为15.15×10^{-6}~40.17×10^{-6},平均值为26.25×10^{-6};轻稀土与重稀土元素含量的比值(LREE/HREE)为2.04~22.67,平均值8.77,为轻稀土富集型。La_N/Yb_N值为0.48~35.98,均值为9.58,表明轻、重稀土元素分馏较明显。δEu为0.05~0.65,均值为0.21,表现出明显的Eu负异常,可能是在岩体演化过程中斜长石结晶分异作用强烈造成的。δCe介于1.02~4.05,均值为1.87,存在弱正Ce异常。球粒陨石标准化的稀土元素配分模式表现为轻稀土元素富集的右倾"海鸥型"(图6a)。

6 讨　论

6.1 形成时代

前人对多宝山地区碱长花岗岩的研究工作相对较少,在卧都河幅(1:25万)地质调查工作中将其归属为华力西晚期白岗质花岗岩,但其数据分散,不够精确,可信度较差。赵焕利等(2011)及曲晖等(2011)对区内3件碱长花岗岩样品进行了单颗粒锆石U-Pb法定年,获得年龄值分别为(300±3)Ma、(304±2)Ma和(309±3)Ma。本次定年结果显示2件碱长花岗岩样品的加权年龄为(300.3±2.0)Ma(MSWD=0.22,n=20)和(307.3±1.8) Ma(MSWD = 0.74,n=24),与前人所得年龄数据基本一致,可将其形成时代限定为300~310Ma,为晚华力西期晚石炭世岩浆活动的产物。

6.2 岩石成因类型

Loiselle and Wones(1979)将非造山环境下形成的花岗岩称为A型花岗岩,以碱性(Alkaline)、贫水(Anhydrous)和非造山(Anorogenic)的首字母命名。但长久以来,对A型花岗岩的判定目前存在着不少争议,综合来说可通过矿物学和岩石地球化学特征来对A型花岗岩进行判定。矿物学特征上,A型花岗岩主要的矿物组合为碱性长石(钾长石)、石英及(富Fe)镁铁质暗色矿物,斜长石缺失或含量很

少(顾连兴,1990),常在岩浆作用晚期形成霓石、霓辉石、钠闪石、钠铁闪石、萤石、富氟的稀土矿物及富钍锆石等特征矿物(吴锁平等,2007;李小伟等,2010)。地球化学特征上,A型花岗岩在主量元素上主要表现为富Si,富K(K_2O>4%),贫Ca、Mg(张旗等,2012)。元素组合上(K_2O+Na_2O) /CaO、K_2O/Na_2O 、FeO^T/MgO值均较高(Whalen et al.,1987)。微量元素上主要表现为富集高场强元素Nb、Ta、Zr、Hf、Th,亏损Ba、Sr、P、Ti,且(Zr+Nb+Ce + Y)>350×10^{-6}(Whalen et al.,1987)。稀土元素总量高,常为轻稀土元素富集型(陈培荣等,1998),配分模式常呈"右倾海鸥型"展布并伴随有明显的Eu负异常(贾小辉等,2009)。

本区碱长花岗岩以碱性长石、石英为主要造岩矿物,斜长石含量很少,副矿物包含有锆石、磷灰石和磁铁矿等,镜下未见白云母、堇青石等S型花岗岩类富铝特征矿物。

岩石地球化学方面,样品主量元素以高Si(均值74.47%)、富K(均值4.73%)、贫Ca和Mg(均值0.22%和0.13%)、相对富Al(均值13.00%)为主要特征;(K_2O+Na_2O) /CaO介于10.51~417.50,比值较高且变化范围较大;K_2O/Na_2O介于1.07~1.51,表现出富钾特征;FeO^T/MgO介于5.78~83.04,远高于一般I型(均值2.27)、S型(均值2.38)及M型(均值2.37)花岗岩类(Whalen et al.,1987)。微量元素蛛网图显示该岩体样品富集大离子亲石元素Rb、U、K和高场强元素Zr、Hf等,亏损Ba、Nb、Ta、Sr、P、Ti元素;(Zr+Nb+Ce + Y)介于330.2×10^{-6}~1004.1×10^{-6},均值529.1×10^{-6},远大于S型、I型花岗岩的平均值(分别为235×10^{-6}和247×10^{-6})(刘昌实等,2003)。δEu均值为0.21, Eu负异常明显,稀土元素配分模式表现为轻稀土元素富集的右倾型。

实验岩石学资料和锆石饱和温度已证明(Clemens et al.,1986;King et al.,1997)A型花岗岩通常形成于高温低压环境(Breiter., 2011)。本文利用锆石地质温度计公式(Watson,1979)计算锆石饱和温度为794.73~912.51℃,平均值849.87,符合A型花岗岩形成温度比I型花岗岩(764℃)一般较高的特点,也相近于中国东北地区晚古生代A型花岗岩锆石饱和温度的范围(843~921℃)(隋振民等,2011)。

综合上述矿物学、岩石地球化学及结晶温度特征认为该期碱长花岗岩为A型花岗岩。同样在Na_2O-K_2O图解、(K_2O + Na_2O)/CaO−(Zr+Nb+Ce + Y)图解和FeO^T/MgO−(Zr+Nb+Ce + Y)判别图解中(图7a~c),大多数样品均投影于A型花岗岩区域。

6.3 构造意义

传统意义上A花岗岩的构造背景被定义为"非造山"的张性环境。Eby(1992)在系统总结A型花岗岩的岩石学和地球化学特征之后,将其进一步分为A_1和A_2型两个亚类,前者源自地幔,代表大陆裂谷环境和地幔热柱/热点环境;后者系由地壳或岛弧派生,代表碰撞后或造山后的张性构造环境。对应的洪大卫等(1995)根据野外地质特征、岩石学特征及地球化学特征将A型花岗岩分为非造山和后造山花岗岩。因Y/Nb比值对于A型花岗岩而言比较稳定,因此可据此判别其成因类型(Eby,1992),当其值小于1.2时为A_1亚类;其值大于1.2时,归属为A_2亚类。本期碱长花岗岩Y/Nb比值为1.25~2.2,同样在Nb−Y−Ce图解(图8a)上,大多数样品落入A_2区。在$Al_2O_3-SiO_2$、R_1-R_2及(Y+Nb)−Rb构造判别图解(图8b~d)上,样品大部分落入造山期后花岗岩区域中,表明岩石为地壳伸展背景下的产物。

兴蒙造山带古生代构造格局主要受控于古亚洲洋的演化。大兴安岭地区在古生代期间经历了额尔古纳、兴安、松嫩等微地块之间的碰撞拼合演化过程。额尔古纳地块与兴安地块沿塔源—喜桂图断裂于早古生代碰撞拼合为一体(葛文春等,2005),两者的联合体沿北东向于贺根山—嫩江一带与松嫩地块拼贴。近年有资料表明嫩江地区莫尔根河组火山岩(353 Ma)(李宝民,2012)及大兴安岭北段扎兰屯地区的高钾−钾玄质钙碱性、准铝质—弱过铝质I型−分异I型花岗岩类(365~350 Ma)(钱程等,2018)为岛弧岩浆活动形成的,结合形成于洋壳俯冲构造背景下红山梁地区的含钠闪石糜棱岩(352 Ma)及蘑菇气地区的辉长岩(353 Ma)(刘宾强,2016),反映碰撞拼合应发生在~350 Ma之后。

研究区南部的霍龙门地区和全胜林场地区发现的与碰撞相关的二长花岗岩(351.5 Ma)(李成禄等,2013)、二长−正长花岗岩(322.2 Ma)(崔芳华等,2013)和碰撞−拼合的直接产物蓝片岩(334 Ma)(张兴洲,1992),以及嫩江—黑河构造带新开岭群变质地层中发现的与兴安—松嫩地块碰撞拼贴有关的

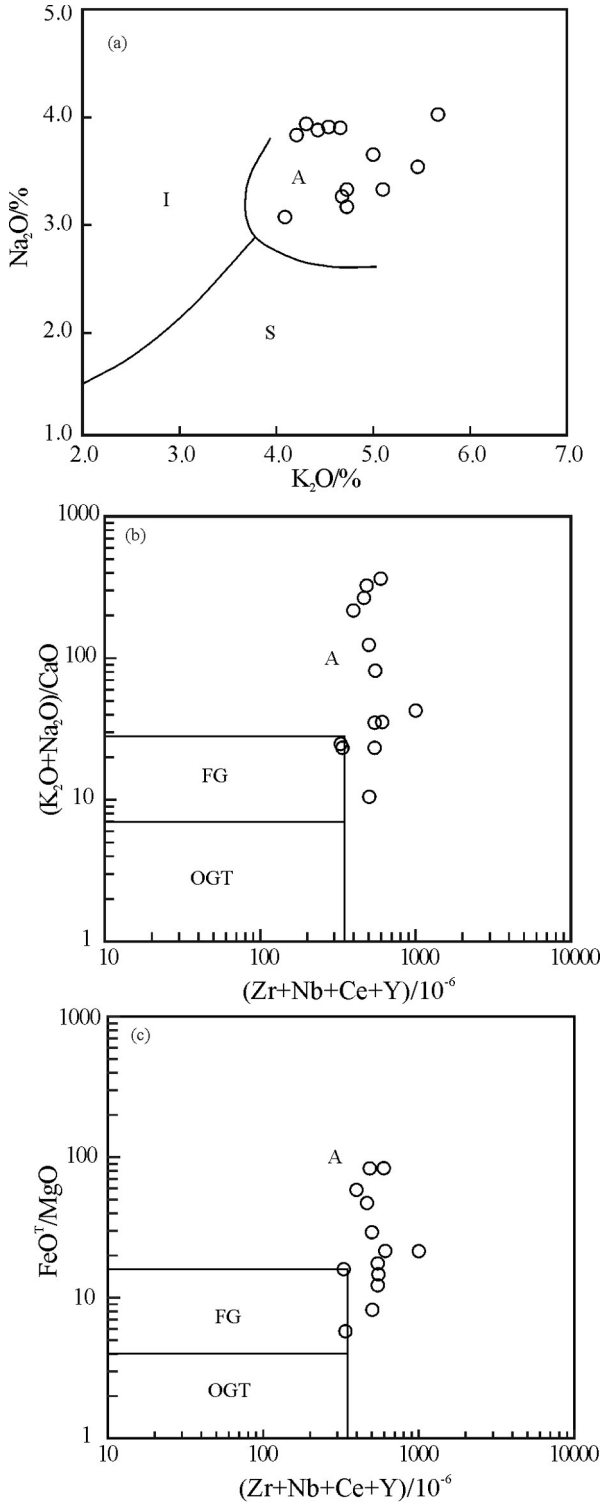

图7 多宝山碱长花岗岩类型判别图解(a,据Collins et al.,1982;b,c,据Whalen et al.,1987)

FG—分异的长英质花岗岩;NG—未分异的M,I和S型花岗岩

Fig.7 Discrimination diagram for granite types in Duobaoshan (a, after Collins et al.,1982; b,c, after Whalen et al.,1987)

FG−Fractional granitoids; NG− Nonfractionated M−I−S−type granitoids

花岗质糜棱岩(324.5 Ma)(汪岩等,2013),还有以贺根山—嫩江—黑河一线为界,由早石炭世的北海南陆转变为晚石炭世的北陆南海(刘永江等,2011)的海陆变迁事件,均说明两地块的拼贴时间应为早石炭世早期—晚石炭世早期。在此之后,形成时间为260~315 Ma,广泛出露于兴安地块嫩江—黑河一带的大黑山、小山屯、固河与松木山岩体(孙德有等,2000),达音河岩体(赵院冬等,2013),巴升河岩体(陈会军等, 2019),新晟、新立与泥鳅河岩体(杨红章等,2019)等造山运动之后的I型和A型花岗岩体,标志着两地块碰撞拼合(造山运动)的结束。研究区碱长花岗岩形成于300~310 Ma,且具有造山后花岗岩的特点,应为该花岗岩带的一部分。

部分学者根据小兴安岭西北部新开岭—科洛杂岩216 Ma的变质年龄(苗来成等,2003)及贺根山蛇绿岩的辉长岩时代290~298 Ma(Miao et al., 2008),认为两地块的碰撞拼合应发生在早中生代,晚古生代的岩浆活动与碰撞前洋壳俯冲板片的局部走滑拉分作用有关,但难以解释近些年新发现造山后花岗岩的大面积出露。这些花岗岩体可能不单是俯冲板片的断离造成的,其形成应与兴安地块和松嫩地块拼合后地壳的伸展减薄有关。研究表明,在古亚洲洋闭合后,区域上仍存在贺根山弧后盆地俯冲消减运动。同样小规模的造山运动可以在后造山阶段存在(Zhang et al.,2011),并且该区域在石炭纪—二叠纪存在从俯冲到碰撞的构造旋回(Jian et al.,2010),贺根山地区与俯冲作用有关的辉长岩(290~298 Ma)可能为此次构造旋回的产物。

综上所述,本文认为兴安地块与松嫩地块在早石炭世早期—晚石炭世早期处于碰撞-拼合阶段,而后转入造山后伸展阶段。

6 结　论

(1)定年结果显示2件碱长花岗岩样品的加权年龄为(300.3±2.0)Ma(MSWD=0.22,n=20)和(307.2±1.8)Ma(MSWD = 0.74,n=24),结合前人研究成果,表明其形成于晚石炭世,属兴蒙造山带海西运动晚期岩浆活动的产物。

(2)综合矿物学及地球化学特征,多宝山碱长花岗岩具A型花岗岩特征,并可细分为A_2型。

(3)多宝山碱长花岗岩形成于造山后的伸展构造

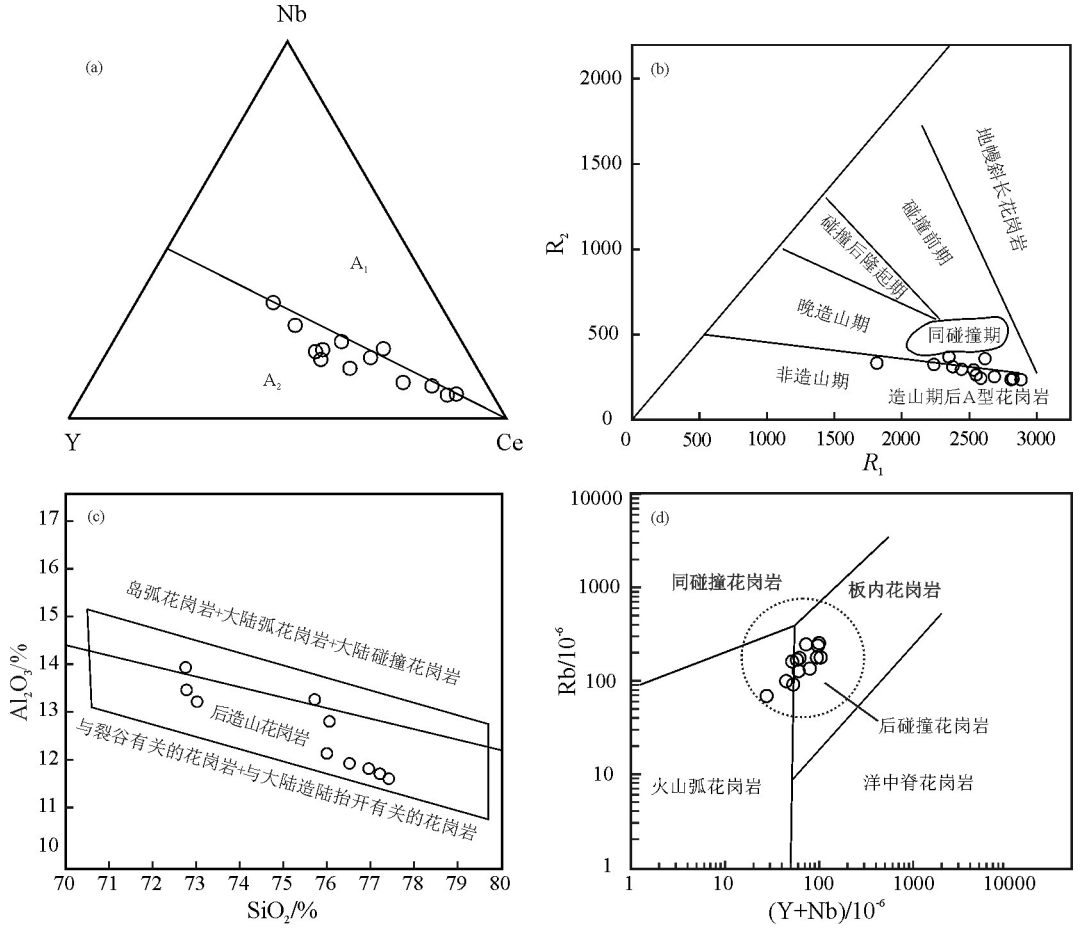

图8 多宝山碱长花岗岩构造环境判别图

（a，据 Eby,1992; b，据 Maniar et al.,1989; c，据 Whalen,1987; d，据 Pearce,1984）

Fig.8 Tectonic discrimination diagrams for the alkali−feldspar granite in Duobaoshan

(a, after Eby,1992; b, after Maniar et al.,1989; c, after Whalen,1987; d, after Pearce,1984)

环境，并标志着兴安与松嫩地块碰撞拼合的结束。

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