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辽西建平烧锅营子金矿花岗岩的锆石 U-Pb 年代学、 地球化学特征及地质意义

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摘要: 辽西建平烧锅营子花岗岩岩体位于华北地台北缘朝阳—赤峰金矿成矿带, 岩体周围分布着烧锅营子、撰山子等金矿床或金矿点。与金矿同源关系的岩体主要为二长花岗岩。3 个不同粒度的二长花岗岩 LA-ICP-MS 锆石 U-Pb 测年结果分别为 (159.1±1.5) Ma、(160.2±4.4) Ma、(160.1±1.1) Ma, 表明烧锅营子岩体形成晚侏罗世早期; 其周边金矿床也形成于此时期或稍晚。结合前人资料总结认为 160 Ma 左右是朝阳—赤峰地区一个重要的金矿成矿时期。烧锅营子花岗岩体主量元素以富 Si、低 Al、中偏低碱、高钾和低 Mg、低 Ca 为特点; 微量元素表现出富集 Th、Zr、Nd、Rb、K 和亏损 Ba、Sr、P、Ti 的特点, 具有强烈的负 Eu ($\delta\text{Eu}=0.08\sim0.60$)、Sr 异常。岩石总体上属于经历了高度结晶分异的高钾钙碱性 I 型花岗岩, Sr-Yb-Y 元素特征显示其源区深度为 30 km。晚侏罗世整个中国东部处于构造域转折期, 结合区域上构造环境分析, 烧锅营子岩体是太平洋板块俯冲背景下的弧后伸展环境的产物。

关 键 字: 烧锅营子岩体; 金矿床; 锆石 U-Pb 年代学; 地球化学; 动力学背景

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Zircon U-Pb geochronology, geochemical characteristics and geological significance of the pluton in the Shaoguoyingzi gold ore deposit in Jianping, western Liaoning

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Abstract: The Shaoguoyingzi intrusion is located in the Chifeng-Chaoyang gold concentration area on the northern margin of the North China Craton, surrounded by Shaoguoyingzi and Zhuanshanzi gold deposits or gold ore spots. The lithology of the intrusion is

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monzogranite which shares the same source with the gold deposits. The zircon U-Pb age data obtained by using laser ablation ICP-MS technique are 159.1 ± 1.5 Ma, 160.2 ± 4.4 Ma and 160.1 ± 1.1 Ma, which indicate that the Shaoguoyingzi intrusion was formed in Late Jurassic and the gold deposits were formed at the same time or a little later. The major and rare elements are characterized by high Si, low Al, medium alkali, poor Mg and Ca, rich Th, Zr, Nd, Rb and K and comparatively low Ba, Sr, P and Ti, with obvious negative Eu ($\delta\text{Eu}=0.08-0.60$) and Sr anomalies; which indicates that the Shaoguoyingzi intrusion is a high-K calc-alkaline I-type granite that has experienced a high degree of crystallization and differentiation. The depth of the source is about 30km, as shown by the characteristics of Sr-Yb-Y. This area was a tectonic transition period in late Jurassic, and the intrusion was formed by back-arc extension in the Pacific plate subduction environment, as shown by an analysis of the regional tectonic environment.

Key words: Shaoguoyingzi intrusion; gold deposit; zircon U-Pb age; characteristics of geochemistry; dynamic background

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赤峰—朝阳金矿化集中区是中国重要的金矿产地之一,一直是研究的热点^[1-3],区内已发现大中型金矿床4处,小型金矿床10余处,金矿化点200余处^[4]。前人对区内典型金矿的研究认为,与金成矿关系最为密切的是燕山期侵入体^[1-2,5-13]。对金厂沟梁金矿、二道沟金矿、郝杖子金矿、小塔子沟金矿及东五家子金矿的研究表明,金矿床受中心岩体的控制作用,分布在中心岩体周围特定的空间位置^[9-10,14]。陈勇等运用证据权方法对本区进行综合信息金矿成矿预测,认为该区还具有105 t金的潜在资源量,具有非常好的找矿前景^[15-17],所以对本区燕山期侵入体的研究对区域上金矿的找矿工作具有重要的指导意义。烧锅营子金矿区处于赤峰—朝阳金矿化集中区,乌克兰、张家沟、孟家沟(张家沟与孟家沟合起来也叫松岭金矿)、霍家地、偏山线及烧锅营子(黑水)金矿产于烧锅营子岩体南部内接触带^[18-20],笔者在此区域进行区域地质调查时,又新发现了山前与水泉沟2处金矿化点也处于岩体内接触带(图1),梨树沟金矿及撰山子金矿产于此岩体外接触带,这些金矿的成因与烧锅营子岩体关系密切^[21-28]。结合前人对金厂沟梁、二道沟、郝杖子、安家营子等金矿的研究结果,即在中心岩体的控制作用下,金矿床分布在中心岩体周围特定的空间位置^[9-10],因此对烧锅营子岩体的研究对本区地表、深部金矿找矿工作具有重要意义。

前人对烧锅营子地区矿床开展过研究工作,在该区花岗岩体特征、矿田构造特征、矿床地质特征、矿物标型特征、矿床成因^[29-35]及构造控矿规律^[18]等方面取得了重要成果。前人研究结果表明,烧锅营

子岩体形成于燕山期早期,岩体与金矿脉体为同时、同源的产物^[34],确定岩体时代即为金矿成矿时代,但对其形成时代一直缺乏精确、可靠的年代学制约。故本文主要报道烧锅营子岩体的高精度锆石U-Pb年代学研究结果,以此限定烧锅营子金矿的形成时代,并结合花岗岩岩石地球化学特征,探讨岩石成因及其动力学背景,对华北克拉通北缘金矿床的成矿背景具有重要意义,为区域上此种类型岩体周边的金矿勘察提供岩石学依据。

1 地质概况及样品特征

烧锅营子岩体位于内蒙古自治区东南和辽宁省西部的交界位置,构造位置处于华北克拉通北缘中段,其北紧邻兴蒙造山带。烧锅营子岩体位于辽宁省建平县境内,向西距离赤峰约50 km(图1)。该岩体呈岩基状构成烧锅营子隆起主体,面积达388 km²。前人研究^①描述岩体中央相主要由粗-中粗粒黑云母花岗岩组成;边缘相多为细粒二长岩类。岩体因受构造破坏形状极不完整,其侵入古元古代宝音图群(Pt_{by})、二叠系三面井组(P_{1sm})、额里图组(P_{1e})并使其发生硅化、绿帘石化等;在岩体与孙家湾组(K_{2sj})接触位置发育有断层,岩体与断层一起被孙家湾组(K_{2sj})角度不整合覆盖(图1)。对于此岩体年代学研究还未见报道,仅根据其接触关系,认为烧锅营子花岗岩是燕山期的侵入体。

笔者在此区域进行1:5万区域地质调查时发现,该花岗岩体岩石类型较单一,仅出露二长花岗岩,边缘相为细粒二长花岗岩,往中心粒度逐渐变

① 辽宁地质局第二区域地质测量队. 1:20万敖汉旗幅区调地质调查报告[R]. 1976.

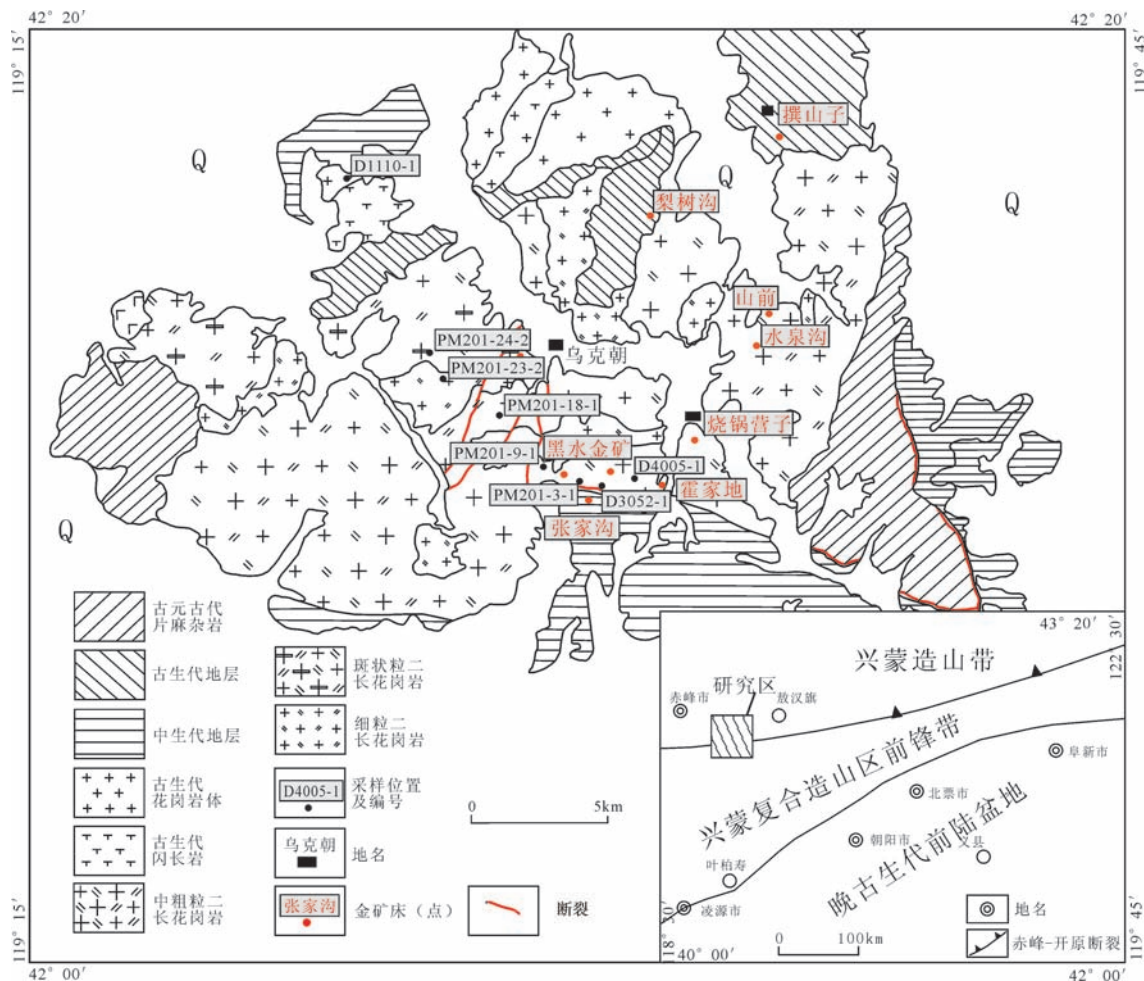


图1 烧锅营子地区地质简图

Fig.1 Simplified geological map of Shaoguoyingzi area

为中粗粒二长花岗岩,逐渐过渡为有粒径1~2 cm的似斑晶的斑状二长花岗岩。岩石风化面灰褐色,新鲜面浅肉红色,半自形粒状结构,块状构造。主要矿物成分为石英(25%~27%),颗粒大小不均一,波状消光明显,表面干净;斜长石(30%~35%)呈半自形粒状,粒径约为1 mm,聚片双晶发育,一般作为基质成分,多蚀变为绢云母和粘土矿物;碱性长石(30%~35%)多为斑晶,主要为正长石、条纹长石以及微斜长石等,镜下可见简单双晶和格子双晶,呈宽板状,颗粒较大约为3~5 mm×10~15 mm,斑晶周围可看到石英和长石形成的蠕虫结构;暗色矿物有少量黑云母(5%~8%)出现,副矿物有锆石、磷灰石、榍石及磁铁矿等。

2 锆石年代学

2.1 样品制备及测试

本文采集的样品采用常规方法进行粉碎、筛选、清洗和烘干,然后采用磁选和重液分选出锆石晶体,随后在双目镜下挑选透明度和晶形较好、无明显裂痕的锆石颗粒置于双面胶上,灌上环氧树脂制靶,固化后打磨抛光使锆石内部结构暴露,用于透射光、反射光、阴极发光(CL)锆石图像采集和锆石原位单点U-Pb定年。样品的破碎和锆石挑选由河北省廊坊市宇能矿物分选有限公司完成,背散射图像在吉林大学完成,锆石阴极发光图像(CL)采集在中国科学院地质与地球物理研究所完成。

表1 烧锅营子侏罗纪花岗岩 LA-ICP-MS 锆石 U-Pb 分析结果

Table 1 LA-ICP-MS zircon U-Pb data of Jurassic granites of Shaoguoyingzi intrusion

样品号及分析点号	含量 /10 ⁻⁶			Th/U	同位素比值				表面年龄/Ma		
	Pb	Th	U		²⁰⁷ Pb/ ²³⁵ U		²⁰⁶ Pb/ ²³⁸ U		²⁰⁶ Pb/ ²³⁸ U	±1σ	
					±1σ		±1σ				
PM201-18-1-01	4.95	119	167	0.71	0.16675	0.00722	0.02455	0.00034	156	2	
PM201-18-1-02	8.26	221	274	0.81	0.16489	0.00494	0.02444	0.00032	156	2	
PM201-18-1-03	4.50	126	145	0.87	0.16819	0.00581	0.02471	0.00034	157	2	
PM201-18-1-04	13.28	317	438	0.72	0.16942	0.00438	0.02517	0.00032	160	2	
PM201-18-1-05	5.30	126	173	0.72	0.17082	0.00724	0.02519	0.00034	160	2	
PM201-18-1-06	14.07	455	419	1.09	0.17498	0.00451	0.02556	0.00033	163	2	
PM201-18-1-07	11.44	309	352	0.88	0.17972	0.00514	0.02619	0.00034	167	2	
PM201-18-1-08	17.10	544	509	1.07	0.17461	0.00416	0.02578	0.00033	164	2	
PM201-18-1-09*	3.19	65.7	113	0.58	0.17283	0.00834	0.02406	0.00035	153	2	
PM201-18-1-10	5.34	122	170	0.71	0.17285	0.00634	0.02590	0.00036	165	2	
PM201-18-1-11	16.05	592	469	1.26	0.21578	0.00580	0.02546	0.00033	162	2	
PM201-18-1-12	5.72	143	188	0.76	0.16947	0.00612	0.02493	0.00034	159	2	
PM201-18-1-13	8.36	252	268	0.94	0.16883	0.00601	0.02457	0.00032	156	2	
PM201-18-1-14	10.13	343	317	1.08	0.16706	0.00485	0.02429	0.00032	155	2	
PM201-18-1-15	3.99	90.9	133	0.68	0.17355	0.00670	0.02505	0.00035	159	2	
PM201-18-1-16	7.35	220	236	0.93	0.16600	0.00584	0.02447	0.00033	156	2	
PM201-18-1-17	8.38	254	273	0.93	0.16664	0.00614	0.02442	0.00033	156	2	
PM201-18-1-18	6.62	221	202	1.09	0.17259	0.00570	0.02503	0.00034	159	2	
PM201-18-1-19	3.85	103	119	0.87	0.17660	0.00829	0.02583	0.00038	164	2	
PM201-18-1-20	5.74	127	199	0.64	0.16608	0.00771	0.02459	0.00034	157	2	
PM201-18-1-21*	6.30	220	204	1.08	0.16453	0.00675	0.02378	0.00032	152	2	
PM201-18-1-22	4.08	129	127	1.01	0.17067	0.00668	0.02501	0.00036	159	2	
PM201-18-1-23	3.01	63.4	103	0.62	0.18094	0.00881	0.02526	0.00037	161	2	
PM201-18-1-24	6.59	197	212	0.93	0.17094	0.00560	0.02495	0.00034	159	2	
PM201-18-1-25	7.16	281	211	1.34	0.17404	0.00750	0.02495	0.00035	159	2	
PM201-23-2-01	334	1507	5946	0.25	0.15713	0.02035	0.02475	0.00031	158	2	
PM201-23-2-02	320	1141	5761	0.20	0.17550	0.02705	0.02694	0.00039	171	2	
PM201-23-2-03*	380	4655	10128	0.46	0.25210	0.00697	0.03400	0.00042	216	3	
PM201-23-2-04*	320	3304	6195	0.53	0.33579	0.02990	0.02895	0.00045	184	3	
PM201-23-2-05	212	914	4029								

表2 烧锅营子花岗岩体主量元素(%)、微量元素及稀土元素(10^{-6})分析结果Table 2 Major element (%), rare element and trace element(10^{-6}) composition of Shaoguoyingzi intrusion

分析项目	D3052-1	D4005-1	PM201-18-1	PM201-3-1	PM201-9-1	D1110-1	PM201-23-2	PM201-24-2
	中粗粒黑云母二长花岗岩				细粒黑云母二长花岗岩		斑状黑云母二长花岗岩	
SiO ₂	74.94	73.99	75.12	76.13	77.80	75.67	75.98	75.90
TiO ₂	0.08	0.12	0.15	0.14	0.07	0.09	0.13	0.21
Al ₂ O ₃	12.65	12.73	12.56	12.55	11.37	12.05	12.26	12.30
TF ₂ O ₃	1.47	1.84	0.40	0.75	0.31	1.14	1.96	0.71
FeO	0.70	1.15	2.05	0.97	1.64	0.61	1.51	1.42
MnO	0.03	0.04	0.08	0.02	0.11	0.02	0.07	0.06
MgO	0.14	0.21	0.24	0.19	0.21	0.12	0.19	0.36
CaO	1.02	0.82	0.24	0.62	0.85	0.35	0.62	1.24
Na ₂ O	4.03	3.97	3.21	3.37	2.91	3.62	3.65	3.63
K ₂ O	4.89	4.67	5.12	4.85	4.34	5.13	5.02	3.76
P ₂ O ₅	0.00	0.01	0.02	0.01	0.02	0.00	0.01	0.05
LOI	0.57	0.42	0.43	0.13	0.04	0.51	0.04	0.08
K ₂ O+Na ₂ O	8.92	8.64	8.32	8.22	7.25	8.75	8.67	7.39
K ₂ O/Na ₂ O	1.21	1.18	1.60	1.44	1.49	1.42	1.38	1.03
A/CNK	0.92	0.97	1.12	1.05	1.03	0.99	1.01	1.00
A/NK	1.06	1.10	1.16	1.16	1.20	1.05	1.08	1.22
分异指数(DI)	93.89	92.41	92.68	93.50	91.53	96.03	92.88	89.79
La	22.50	17.6	30.96	32.37	15.42	25.19	52.20	30.53
Ce	44.90	38.10	64.10	94.95	29.92	58.52	105.76	69.95
Pr	5.60	4.13	6.55	6.92	3.41	5.27	13.10	6.94
Nd	19.60	15.10	21.70	22.90	11.30	17.40	51.95	23.05
Sm	4.29	3.43	3.62	3.69	2.44	3.35	9.01	4.79
Eu	0.38	0.63	0.29	0.17	0.20	0.46	1.63	0.32
Gd	2.77	2.30	3.06	3.22	1.53	2.26	6.00	3.60
Tb	0.56	0.46	0.40	0.39	0.24	0.37	0.85	0.53
Dy	4.44	4.30	2.62	1.87	1.80	2.60	4.23	4.38
Ho	0.89	0.88	0.55	0.36	0.44	0.54	0.75	1.03
Er	2.20	2.14	1.53	0.92	1.25	1.32	1.97	2.92
Tm	0.47	0.49	0.26	0.16	0.19	0.26	0.27	0.57
Yb	2.09	2.07	1.58	0.95	1.05	1.60	1.84	3.37
Lu	0.44	0.41	0.27	0.15	0.19	0.24	0.28	0.54
ΣREE	111.12	92.06	137.54	169.04	69.39	119.40	249.84	152.53
LREE/HREE	7.02	6.06	12.38	20.09	9.40	11.98	14.43	8.00
(La/Yb) _N	5.40	4.40	14.06	24.46	10.49	11.28	1.45	6.50
δEu _N	0.31	0.60	0.32	0.20	0.33	0.54	0.08	0.23
Y	27.42	24.77	14.72	10.96	12.21	15.50	18.99	27.76
K	40552	38734	42444	40228	36038	42593	41680	31175
Ti	473.60	731.39	917.23	851.29	437.63	515.57	761.36	1240.96
P	15.27	48.00	74.18	52.37	65.46	0.00	48.00	218.19
Hf	4.23	3.70	6.73	10.07	13.61	2.88	3.89	5.84
Ta	2.73	3.17	7.85	5.24	1.98	2.67	0.57	

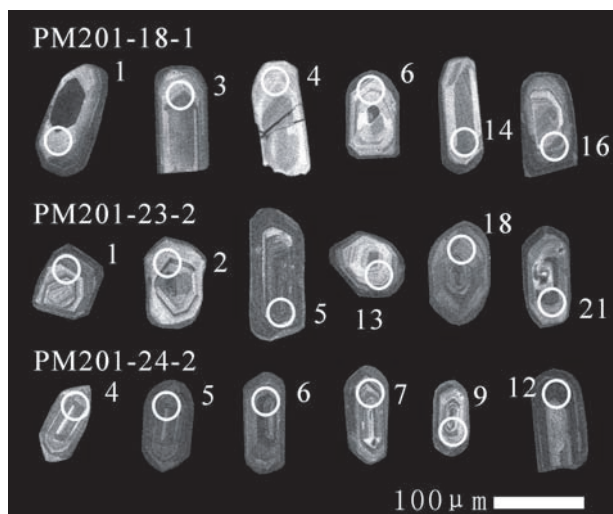


图2 烧锅营子岩体锆石CL显微图像
Fig.2 Zircon CL microscopic images of Shaoguoyingzi intrusion

国土资源部沈阳地质调查中心检测分析中心完成,数据列于表2。

2.2 定年结果

本文对取自烧锅营子花岗岩体的3个样品进行了锆石U-Pb同位素测年,测试结果见表1。由于所测定的岩石形成于中生代,其结果以 $^{206}\text{Pb}/^{238}\text{U}$ 年龄计算,年龄误差为 2σ 。

样品PM201-18-1,岩性为中粗粒黑云母二长花岗岩。从CL阴极发光图像可以看出锆石的晶型好,多为短柱状(长宽比多为4:1),具有较清晰的内部结构,岩浆振荡型环带发育(图2)。锆石的Th/U比值较高,分布在0.64~1.34,这些特征指示锆石为典型的岩浆锆石^[38-40]。该样品共进行了25个锆石颗粒的测定,9号点与11号点调谐度比较高,故在作图中舍掉。其余23个点测试结果位于谐和线上及其附近,数据变化范围小,数据点成群分布,具有很好的谐和度(图3-a),指示这些锆石为同一期岩浆事件形成的。这些锆石的年龄代表了岩石的形成年龄。 $^{206}\text{Pb}/^{238}\text{U}$ 加权平均年龄为 $(159.1\pm 1.5)\text{Ma}$ ($n=23$),MSDW=2.9,代表了样品PM201-18-1岩浆结晶年龄。

样品PM201-23-2,岩性为细粒黑云母二长花岗岩。从分析结果可以看出(表1),此样品的Pb、Th、U含量都很高,锆石的Th/U比值比较低,分布在0.13~0.21,但并没有 <0.1 ,而且锆石晶型良好,多为

柱状,边部为棱角状,具有典型的岩浆振荡型环带,显示其岩浆成因特征^[40-41]。该样品共进行了25个锆石颗粒的测定。由于16个点的调谐度都很高,仅有9个点在谐和曲线上,但是分布稍微有些离散(图3-b)。 $^{206}\text{Pb}/^{238}\text{U}$ 加权平均年龄为 $(160.2\pm 4.4)\text{Ma}$,MSDW=7.7,代表了细粒黑云母二长花岗岩结晶年龄。

样品PM201-24-2,岩性为斑状黑云母二长花岗岩。锆石晶型良好,多为柱状,具有岩浆振荡型环带,锆石的Th/U比值较高(0.21~0.81),显示岩浆成因特征^[38-40]。该样品共进行了25个锆石颗粒的测定,其中3号点调谐度很高故舍掉,2、8、15、17、18、21等6个点数据年龄为 $(1802\pm 19)\text{Ma}$ 、 $(243\pm 3)\text{Ma}$ 、 $(231\pm 3)\text{Ma}$ 、 $(236\pm 3)\text{Ma}$ 、 $(184\pm 2)\text{Ma}$ 和 $(187\pm 3)\text{Ma}$,为捕获锆石(图3-c)。其余18个点均在谐和曲线上或附近(图3-d)。 $^{206}\text{Pb}/^{238}\text{U}$ 加权平均年龄为 $(160.1\pm 1.1)\text{Ma}$,MSDW=1.3,代表了样品PM201-24-2岩浆结晶年龄。

3 岩石地球化学特征

选择了8个样品进行了主量元素、微量元素和稀土元素测定,测试在国土资源部沈阳地质调查中心检测分析中心完成,数据列于表2。

3.1 主量元素

该区花岗岩高 SiO_2 含量(73.99%~77.8%),分异指数DI为89.79~96.03,显示岩石经历了高分异演化; A/CNK 值介于0.91~1.11,属于过铝质到准铝质花岗岩(图4-a);碱含量中等偏低, $\text{K}_2\text{O}+\text{Na}_2\text{O}=7.39\%\sim 8.92\%$, K_2O 含量较高(3.7%~5.1%), $\text{K}_2\text{O}/\text{Na}_2\text{O}$ 介于1.03~1.59;Fe、Mg、Ti氧化物含量相对较低。在 SiO_2 - K_2O 图解(图4-b),8个样品基本落入了中钾—高钾钙碱性系列中。上述特点显示该地区花岗岩具有富硅、略富铝、高钾、低镁、钠、贫钙的特征。

3.2 稀土元素

岩石稀土总量 ΣREE 除1个样品较高(249.84×10^{-6})外,其他稀土总量都较低, $92.06\times 10^{-6}\sim 169.03\times 10^{-6}$,平均含量为 137.61×10^{-6} 。轻重稀土比值为6.06~20.09,在稀土元素球粒陨石标准化图解上(图5-a)可以看出,轻重稀土分馏明显,重稀土呈比较平坦分布。 δEu 为0.08~0.60,具有中等—比较

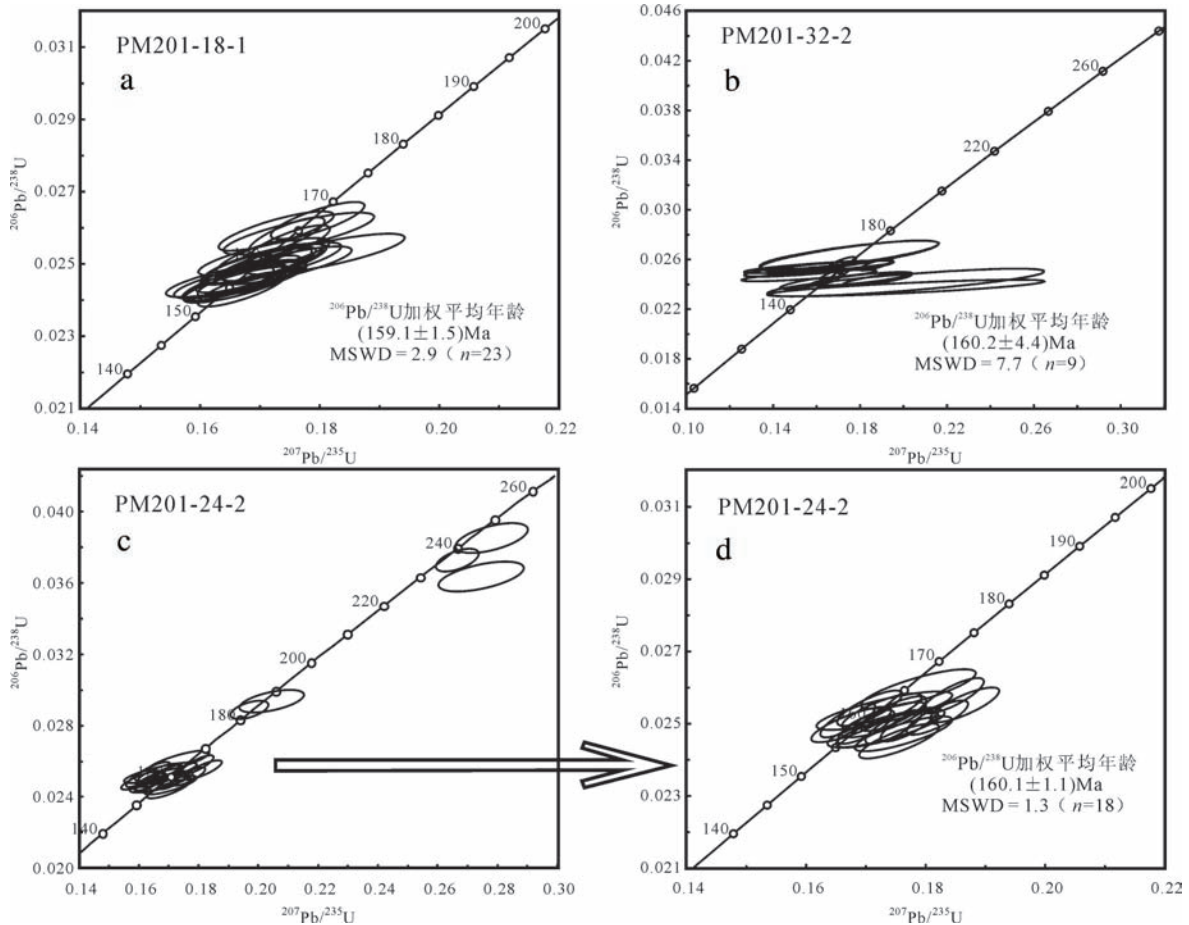


图3 烧锅营子岩体花岗岩锆石U-Pb年龄谐和图
Fig.3 U-Pb concordia diagram of zircons from granites in Shaoguoyingzi intrusion

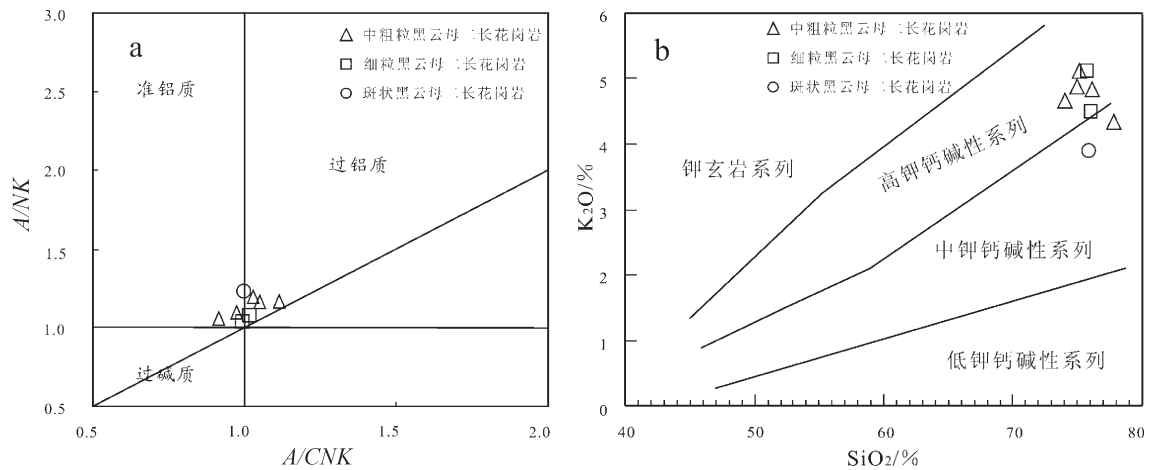


图4 烧锅营子岩体的A/CNK-A/NK(a)及SiO₂-K₂O(b)图解
Fig.4 A/CNK-A/NK (a) and SiO₂-K₂O (b) patterns of Shaoguoyingzi intrusion

强烈的负锆异常。

3.3 微量元素

在原始地幔蛛网图上可以看出(图5-b),烧锅

营子岩体具有富集高场强元素Th、Zr、Nd和Rb、K,相对亏损大离子亲石元素Nb、Sr和P、Ti,显示在岩浆演化过程中存在长石类矿物或Fe-Ti氧化物等矿物

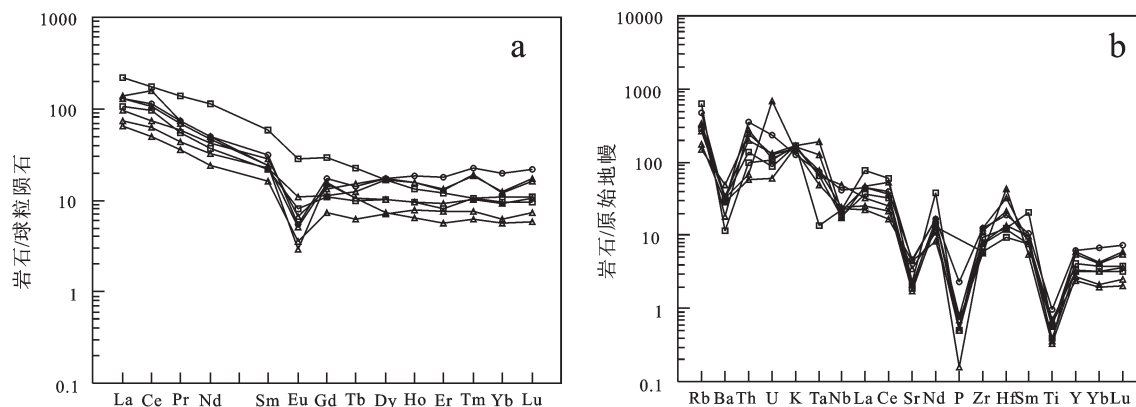


图5 烧锅营子花岗岩稀土元素配分曲线(a)和微量元素蛛网图(b)(图例同图4)

Fig.5 Chondrite-normalized REE patterns (a) and primitive mantle-normalized trace elements spidergrams (b) of Shaoguoyingzi intrusion

的强烈结晶分异。具有低的Sr含量($36.97 \times 10^{-6} \sim 99.74 \times 10^{-6}$)、低Yb($0.94 \times 10^{-6} \sim 3.36 \times 10^{-6}$)含量,显示出强烈的负Sr异常。

4 讨 论

4.1 花岗岩的形成年龄及其对成矿作用时代的制约

通过锆石U-Pb测试结果可以看出烧锅营子岩体3个年龄在误差范围内一致,由此可知,烧锅营子地区侏罗纪不同结构的二长花岗岩均形成于160 Ma左右,时代为晚侏罗世早期。前人通过总结认为金成矿作用通常大体同时或稍晚于各自区内最后一次花岗质岩浆作用的时间^[14,42]。烧锅营子岩体周边的金矿化与烧锅营子岩体于时间、空间及成因上呈现出同源联系^[34],因此,烧锅营子岩体周边金矿床(点)的形成时代为160 Ma或稍晚。

朝阳—赤峰金矿区其他金矿床研究结果显示,金矿成矿时代主要为早白垩世。区内代表性的金矿床金厂沟梁—二道沟金矿田内金矿化作用发生在123~116 Ma^[14],安家营子金矿田形成年龄为132~126 Ma^[9]。在华北地台北缘其他金矿的重要成矿时代也是这个时期^[43~45]。从表3和图6可以看出,朝阳—赤峰地区金矿大规模成矿作用发生在245~237 Ma、132~123 Ma两个时间段。

本文研究的烧锅营子岩体时代为晚侏罗世,其周边的金矿点也是此时代形成,而在华北地台北缘还未见此时期的金矿床。但在整个中国东部,此时期与金矿有关的花岗岩体分布比较多。胶东地区

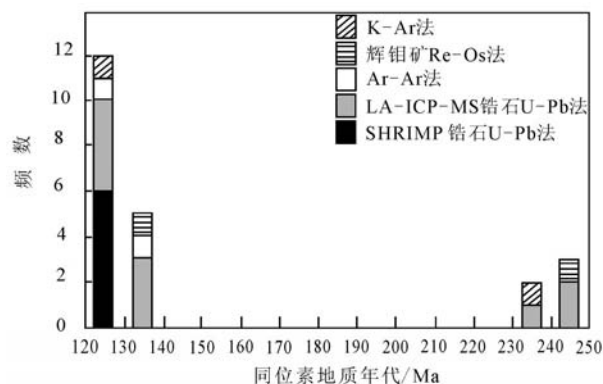


图6 赤峰—朝阳地区主要金矿床同位素年龄直方图

Fig.6 Histogram of the geochronological data of the major gold deposits in Chifeng-Chaoyang area

晚侏罗世是重要的金矿形成时代^[46],例如玲珑花岗岩形成时间为158.5 Ma^[47];在中国东北部160 Ma左右也是金矿重要成矿时代^[48],夹皮沟金矿斑状二长花岗岩158~168 Ma^[49]、花岗闪长岩153 Ma^[48],海沟岩体二长花岗岩167 Ma^[50],海沟金矿成矿年龄为165~170 Ma^[51]。韩世炯等总结中国东北部陆缘的金矿成矿时代分为170~160 Ma、130~110 Ma、110~90 Ma 3个时间段^[48],这段与胶东地区成矿时代(160~141 Ma、130~110 Ma、105~81 Ma)^[46]十分耦合,说明中国东部地区金矿主要的成矿时期除早白垩世外^[52],还存在一期160 Ma左右的金的成矿作用。

因此,结合前人资料总结认为朝阳—赤峰地区金矿成矿时代除了245~237 Ma、132~123 Ma两个时间段外,可能在160 Ma左右也存在一期金的富集

表3 朝阳—赤峰地区金矿成矿年龄统计
Table 3 Statistics of metallogenic ages of gold deposits in Chifeng-Chaoyang area

矿床名称	测试样品	测试方法	年龄/Ma	资料来源
金厂沟梁	对面沟辉钼矿 ⁺	辉钼矿 ⁺ Re-Os	131.45±0.93	候万荣 [53]
	西矿区辉钼矿 ⁺	辉钼矿 ⁺ Re-Os	243.5±1.3	
	与 58 号脉相互穿插的 黑云粗安岩脉	LA-ICP-MS 锆石 U-Pb	131.7±1.1	孙珍军 [42]
	与成矿关系密切的大庙岩体	LA-ICP-MS 锆石 U-Pb	245±1	
	与金矿关系密切闪长斑岩墙	LA-ICP-MS 锆石 U-Pb	126~124	苗来成 [45]
二道沟	蚀变矿物绢云母	Ar-Ar	140±2.8	庞奖励 [54]
	成矿区闪长玢岩脉	SHRIMP 锆石 U-Pb	126±1	苗来成 [14]
撰山子	与成矿关系密切撰山子岩体	K-Ar	123	魏存弟 [55]
	与矿化同期的撰山子岩体	LA-ICP-MS 锆石 U-Pb	245.8±3.1	孙珍军 [42]
东风	赋矿围岩-梅林岩体	SHRIMP 锆石 U-Pb	1699.6±6.9	内部数据
奈林沟	赋矿围岩安山岩	LA-ICP-MS 锆石 U-Pb	125.5±0.87	
	赋矿围岩安山岩	LA-ICP-MS 锆石 U-Pb	124.7±1.2	
红花沟	与成矿有关的闪长岩脉	K-Ar	237	余宏全 [56]
小塔子沟		LA-ICP-MS 锆石 U-Pb	239±2/233±4	宋维民 [57]
安家营子	赋矿围岩-安家营子岩体	LA-ICP-MS 锆石 U-Pb	132~138	李永刚 [9]
	穿切矿体的流纹斑岩脉	LA-ICP-MS 锆石 U-Pb	124.9~126.5	Trumbul [58]
排楼山			124~122	
	粗粒似斑状二长花岗岩体	LA-ICP-MS 锆石 U-Pb	132±5~126±1	孙珍军 [42]
	前变形的闪长玢岩脉	SHRIMP 锆石 U-Pb	126±2	罗镇宽 [44]
	变形花岗斑岩脉	SHRIMP 锆石 U-Pb	124±1	
	成矿后的闪长玢岩脉	SHRIMP 锆石 U-Pb	125±1	
	大石头沟黑云母花岗岩	SHRIMP 锆石 U-Pb	124±1	
	矿石中蚀变黑云母	Ar-Ar	124.4±0.4	骆辉等 [59]

成矿。这3个时间段与赤峰—朝阳地区中生代3期岩浆作用在时间上耦合^[42]。

4.2 岩体成因及源区特征

主量元素特征显示烧锅营子岩体花岗岩具有富硅、略富铝、高钾、低镁、钠、磷、贫钙的特征,铝饱和指数(A/CNK)仅有一个大于1.1,其余为0.92~1.05,因此不具备S型花岗岩特征,而中低碱含量,低钠含量,也不具备A型花岗岩特征。岩体显示出高钾特征(图4-a),稀土元素表现出轻、重稀土元素的明显分异且均具有Eu负异常,稀土元素配分曲线显示出右倾V字型波谷状特征,结合其矿物组合特征判断出烧锅营子岩体为高钾钙碱性I型花岗岩^[60]。烧锅营子岩体具有富集高场强元素Th、Zr、Nd和Rb、K,相对亏损大离子亲石元素Nb、Sr和P、Ti,显示在岩浆演化过程中存在长石类矿物或Fe—

Ti氧化物等矿物的强烈结晶分异。明显的Sr负异常及负Eu异常,表明源区具有斜长石残留,或可能在岩浆演化结晶过程中发生明显的斜长石分离结晶作用。

Sr对于石榴石和辉石是强不相容元素,而HREE和Y对于石榴石是强相容元素,因此与石榴石平衡的花岗岩富Sr,相应的Sr/Yb和Sr/Y比值高,形成于高压环境^[61-63]。Hollocher and Robinson的模拟计算也表明,低Sr花岗岩的源岩无石榴石出现,形成在相对低的压力下(<10 kbar)^[64]。张旗等^[65-66]总结认为从非常低Sr高Yb型→低Sr高Yb型→低Sr低Yb型→高Sr低Yb型花岗岩,其源区深度可能是增加的。烧锅营子侏罗系花岗岩体具有低Sr、低Yb、Y(表2)含量的特点,在Yb-Sr(图7)演化图解上,处于低Sr低Yb区,说明岩体形成于低压环境,

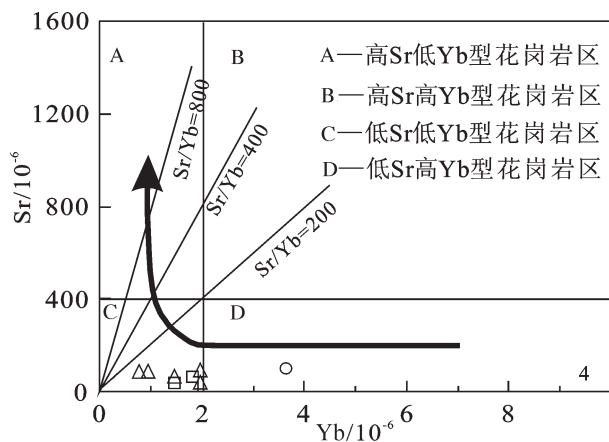


图7 烧锅营子岩体 Sr-Yb 图(图例同图4)

Fig.7 Sr-Yb diagram of Shaoguoyingzi intrusion (legends as for Fig. 4)

花岗岩岩体源区较浅,深度可能为 30 km 左右^[65]。

4.3 岩体形成的动力学背景

目前对冀北—辽西地区中—晚侏罗世的构造背景存在争议,一种观点认为中生代本区受古太平洋板块俯冲作用影响^[3, 67-69];而近些年另一种观点认为本区此时是受蒙古—鄂霍茨克构造体系影响^[70-72]。本区域在二叠纪末—三叠纪初,古亚洲洋关闭,华北地块与南蒙古复合地体最终碰撞拼合^[73],中三叠世—早侏罗世进入后造山地壳伸展环境,产生一系列幔源及壳源岩浆活动,并可能持续到早侏罗世^[74]。随后进入构造转折期,构造线由近东西向变为东北及北北东向,构造体制由挤压为主转变为以伸展为

主体^[75]。张连昌对西拉木伦铜铅成矿带研究也显示,在本区 180~150 Ma 为构造体系转折期^[68]。但贾三石通过对冀北—辽西金矿集区地质特征研究认为 200~145 Ma 为板内挤压隆升期,其动力来源于太平洋板块的俯冲^[3]。也就是说此时已经开始受到太平洋板块俯冲作用的影响。晚中生代以来,华北边缘及中国东部经历了强烈的岩石圈减薄与伸展^[76],张拴宏^[77]认为晚侏罗世—早白垩世以来,华北地块北缘侵入体的隆升及剥露应与本区及中国东部地壳强烈伸展有关^[76],并且本区中侏罗世—早白垩世(163~125 Ma)岩浆活动发育在伸展构造背景中,与岩石圈减薄存在密切的成因联系^[78],这种减薄是在太平洋板块俯冲的背景下形成的。

烧锅营子花岗岩的形成时代为 160 Ma,地球化学特征显示烧锅营子岩体源区形成深度可能在 30 km 左右,深度比较浅,与此时区域上的地壳强烈伸展的构造背景有关。在 Y-Nb 图解上(图 8-a)烧锅营子岩体处于火山弧和同碰撞的区域,而在 (Y+Nb)-Rb 图解上(图 8-b)烧锅营子岩体为火山弧区域,也说明烧锅营子岩体形成于伸展拉张的背景下。在晚侏罗世—早白垩世是东北地区火山岩的主要喷发阶段,而此时的火山活动是受太平洋板块俯冲作用影响^[67, 69],并且烧锅营子岩体 NE 向展布也符合太平洋构造域的构造方向(图 1)。综上所述,烧锅营子岩体形成于太平洋板块俯冲背景下的弧后伸展环境。

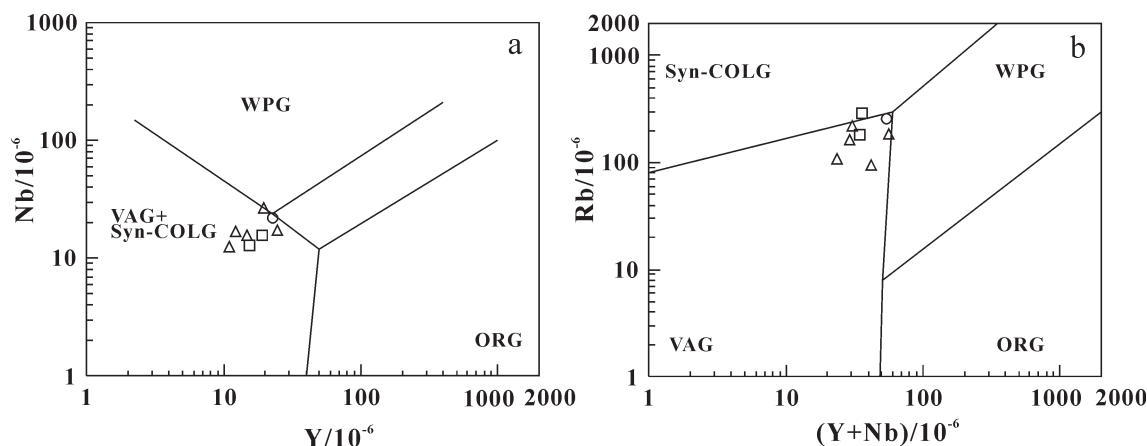


图8 烧锅营子岩体的 Y-Nb(a)和 (Y+Nb)-Rb(b) 图解(图例同图4)

Fig.8 Nb-Y and Rb-Y+Nb patterns of Shaoguoyingzi intrusion (legends as for Fig. 4)

5 结 论

(1)通过锆石 LA-ICP-MS U-Pb 定年,确定了烧锅营子花岗岩的结晶年龄为 160 Ma 左右,为晚侏罗世早期,而非早侏罗世。代表了烧锅营子岩体周围金矿(点)形成于此时或稍晚于此时,为华北地台北缘金矿成矿时代研究提供了新资料。结合前人研究成果将朝阳—赤峰地区金矿成矿时代分为 245~237 Ma、160 Ma、132~123 Ma 三期。

(2)地球化学特征研究表明,富硅、略富铝、高钾、低镁、钠、磷、贫钙的特征,铝饱和指数(A/CNK)中等,轻、重稀土元素的明显分异且均具有 Eu 负异常等地球化学特征显示烧锅营子岩体为高钾钙碱性 I 型花岗岩。富集高场强元素 Th、Zr、Nd 和 Rb、K,相对亏损大离子亲石元素 Nb、Sr 和 P、Ti,明显的 Sr、Eu 负异常,其岩浆形成于 30 km 左右深度。

(3)综合区域地质背景及地球化学特征分析,烧锅营子岩体形成于古太平洋板块俯冲背景下的伸展环境。

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