地球化学

小兴安岭东南部胜利林场地区晚三叠世 A 型花岗岩地球化学特征及构造指示意义

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［摘　要］小兴安岭东南部胜利林场地区晚三叠世花岗岩位于松嫩地块东缘，东部以嘉荫－牡丹江断裂为界与佳木斯地块相接。晚三叠世花岗岩以二长花岗岩和正长花岗岩为主。它具较高的 SiO_2（72.51%～77.83%，平均值 75.70%）、K_2O+Na_2O（7.65%～9.84%，平均 8.58%）及 FeO^*/MgO（5.79～24.43，平均值为 12.81）；较低的 CaO（0.1%～0.87%，平均值 0.55%）、P_2O_5（0.01%～0.03%，平均值 0.02%）；过碱指数 $AI=mol(Na_2O+K_2O)/Al_2O_3$（0.82～1.0，平均值 0.88）；以上各值同 A 型花岗岩值相同。$\delta_{Eu}=0.11$～0.55，平均为 0.31，表现中等－较强的 Eu 负异常。原始地幔标准化蛛网图上，富集 Th、La、Ce、Ta 和 Rb 等元素，而 Ba、Sr、Nb 和 Y 明显亏损。在 A_1、A_2 型花岗岩类的判别图解上，除一个样品外，其它样品均显示了 A_2（后碰撞）花岗岩特征。暗示晚三叠世 A 型花岗岩为造山后伸展拉张环境的产物。

［关键词］　晚三叠世花岗岩　A_2 型花岗岩　后碰撞　伸展拉张
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1　引言

A 型花岗岩最初由 Loiselle and Wones（1979）提出，其含义为碱性的、无水的、非造山环境形成的一类花岗岩。后来不同专家对 A 型花岗岩进行了定义和划分，提出 A 型花岗岩既有过碱性的，亦有偏铝的，还有弱过铝的（Pitcher, 1993; King *et al.*, 1997），其产出环境不仅可以产出于非造山环境，在后造山碰撞阶段同样也可以有 A 型花岗岩产出。Eby（1990，1992）提出将 A 型花岗岩划分为 A_1 型（非造山）和 A_2 型（后碰撞）；Hong *et al*（1996）将 A 型花岗岩划分为 PA 型（非造山）和 AA 型（后碰撞），与 Eby 划分类型基本对应。在构造环境判别中，后碰撞花岗岩往往具多样性，而后碰撞 A_2 型花岗岩却可以作为后碰撞阶段的重要标志（韩宝福，2007）。小兴安岭东南部胜利林场地区出露有大面积的晚三叠世 A_2 型花岗岩，其产出对于该区构造环境演化的研究具有重要的指示意义。

2　地质背景与岩石学特征

小兴安岭胜利林场地区在大地构造位置上位于兴蒙造山带东部的松嫩地块东缘，东部以嘉荫－牡丹江断裂为界与佳木斯地块相接，为小兴安岭－张广才岭巨型花岗岩带的重要组成部分（黑龙江省区域地质志，1988）。该区晚三叠世 A 型花岗岩由中细粒似斑状二长花岗岩及中细粒正长花岗岩组成，岩体整体南北向展布，主要呈大的岩基状产出（图 1），其岩石学特征如下：

晚三叠世细中粒似斑状二长花岗岩：为呈灰白（褐）及浅肉红色，似斑状结构，块状构造。似斑晶为

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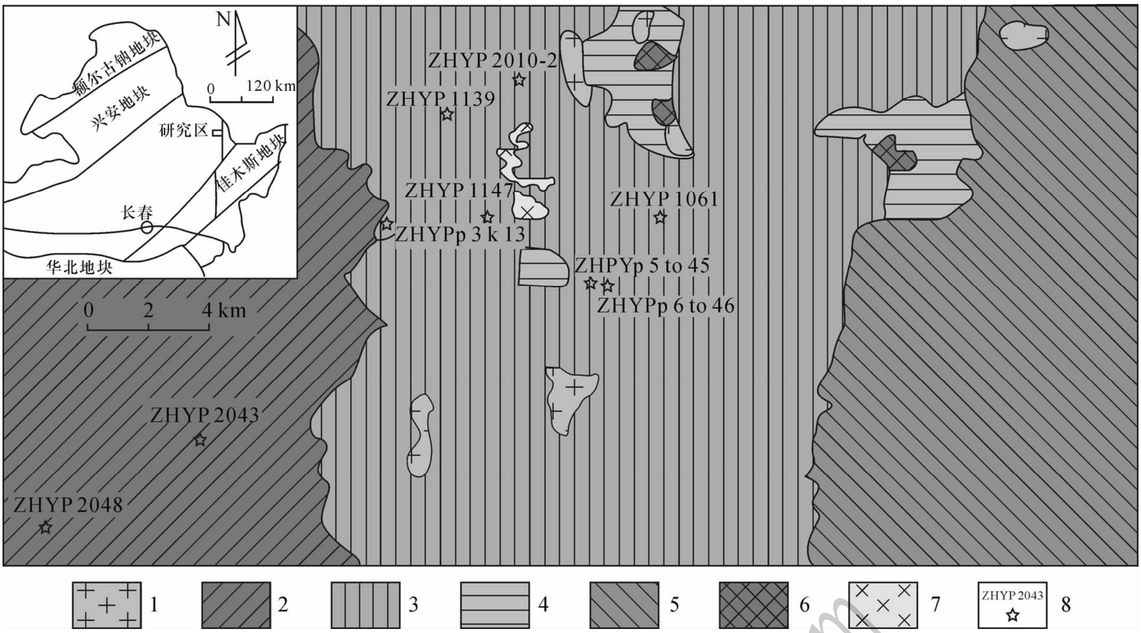

图 1　胜利林场地区地质简图(据武警黄金三支队,2012)

Fig. 1 Simplified geological map of the Shengli forestry centre area(after No. 3 Gold Geological Party of CAPF, 2012)

1 - 早白垩世花岗岩;2 - 晚三叠世正长花岗岩;3 - 晚三叠世二长花岗岩;4 - 中二叠世弱片麻状二长花岗岩;5 - 中二叠世二长花岗岩;6 - 中二叠世花岗闪长岩;7 - 中二叠世角闪辉长岩;8 - 样品采集位置

1 - early Cretaceous granite; 2 - late Triassic granite; 3 - Late Triassic adamellite; 4 - Middle Permian weakly gneissic adamellite; 5 - Middle Permian adamellite; 6 - Middle Permian granodiorite; 7 - middle Permian hornblende gabbro; 8 - sample col lection location

碱性长石,以条纹长石为主、微斜长石次之,为灰褐色 - 浅肉红色,大小 7 ~ 10 mm,占 10% ~ 15%;基质主要有碱性长石,大小 1 ~ 4 mm,含量 20% ~ 30%;斜长石,大小 0.7 ~ 4.0 mm,占 25 ~ 40%;石英为灰白色、烟灰色,它形粒状或集合体,波状消光,粒径 0.5 ~ 4.0 mm,大多 0.5 ~ 2.5 mm,含量 25% ~ 30%;黑云母,大小 0.25 ~ 1.0 mm,占 1% ~ 5%;角闪石,为绿 - 深绿色,柱状,粒径 0.5 ~ 3.5 mm,含量 1% ~ 3%。

晚三叠世细中粒正长花岗岩:呈黄褐色 - 肉红色,具细粒或细中粒花岗结构,块状构造。碱性长石呈肉红色半自形宽板状,主要为条纹长石及微斜条纹长石,包含斜长石小晶体及交代净边结构,粒径 2 ~ 3.2 mm,含量 40% ~ 50%;斜长石呈灰白色、浅肉红色,半自形板状,镜下环带清晰,聚片双晶发育,Np′ ∧ (010) = 10° ~ 18°, An = 28 ~ 32,主要为更长石,少量为中长石,粒径 1 ~ 3 mm,含量 15% ~ 20%;石英为灰白色、烟灰色,自形或近圆粒状,波状消光,粒径 2 ~ 3.2 mm,含量 30% ~ 35%;暗色矿物黑云母为黑色,不规则片状,较新鲜,0.6 ~ 4 mm,含量 3% 左右。

3　年代学特征

3.1　年代学分析方法

本次工作在晚三叠世二长花岗岩中采集锆石 U-Pb 测年样品一件,样品在河北省廊坊市区域地质调查研究所用常规方法进行粉碎,并用浮选和磁选方法进行分选。在双目镜下挑选出晶形和透明度较好、无明显裂痕和包裹体的锆石颗粒,将其粘在环氧树脂表面,固化后打磨抛光,并进行透射光和反射光图象的采集,最后在国土资源部华北矿产资源监督检测中心进行锆石阴极发光(CL)图像的采集。锆石 LA-ICP-MS U-Pb 同位素分析在国土资源部华北矿产资源监督检测中心的 LA-MC-ICP-MS 仪器按标准测定程序进行,使用标准锆石 91500 进行分馏校正。激光束束斑为 30 μm。实验获得的数据采用 Andersen(2002)的方法进行同位素比值的校正,以扣除普通 Pb 的影响,然后用 ISOPLOT 宏程序进行年龄谐和图的生成和处理,所给定的同位素比值和年龄的误差(标准误差)在 1σ 水平(表 1)。

表 1 晚三叠世二长花岗岩(1139)LA-ICP MS U-Pb 分析结果表

Table 1 LA-ICP-MS zircon U-Pb dating data of the Late Triassic monzogranites

样品号	含量($\times10^{-6}$)		同位素比值				年龄(Ma)		
RZ1139	Pb	U	$^{206}Pb/^{238}U\pm1\sigma$	$^{207}Pb/^{235}U\pm1\sigma$	$^{207}Pb/^{206}Pb\pm1\sigma$	$^{232}Th/^{238}U\pm1\sigma$	$^{206}Pb/^{238}U\pm1\sigma$	$^{207}Pb/^{235}U\pm1\sigma$	$^{207}Pb/^{206}Pb\pm1\sigma$
1	29	850	0.0335 ± 0.0003	0.2317 ± 0.0043	0.0502 ± 0.0009	0.3103 ± 0.0004	212 ± 2	212 ± 4	205 ± 41
2	73	1851	0.0335 ± 0.0002	0.4605 ± 0.0068	0.0998 ± 0.0014	0.4411 ± 0.0078	212 ± 1	385 ± 6	1620 ± 26
3	25	672	0.0335 ± 0.0002	0.2325 ± 0.0056	0.0503 ± 0.0012	0.5932 ± 0.0044	212 ± 1	212 ± 5	209 ± 55
4	21	410	0.0335 ± 0.0002	0.7643 ± 0.0114	0.1657 ± 0.0023	1.1452 ± 0.0076	212 ± 1	577 ± 9	2514 ± 24
5	45	1312	0.0335 ± 0.0002	0.2329 ± 0.0041	0.0504 ± 0.0008	0.3232 ± 0.0004	213 ± 2	213 ± 4	212 ± 36
6	27	746	0.0336 ± 0.0003	0.2328 ± 0.0049	0.0503 ± 0.001	0.4181 ± 0.0011	213 ± 2	213 ± 4	210 ± 46
7	30	667	0.0335 ± 0.0002	0.5871 ± 0.0232	0.1273 ± 0.0045	0.8804 ± 0.0243	212 ± 2	469 ± 19	2060 ± 62
8	79	2262	0.0335 ± 0.0002	0.2328 ± 0.0029	0.0503 ± 0.0006	0.3391 ± 0.0011	213 ± 1	213 ± 3	211 ± 28
9	20	531	0.0335 ± 0.0002	0.2326 ± 0.0057	0.0504 ± 0.0012	0.5367 ± 0.0022	212 ± 1	212 ± 5	212 ± 54
10	74	2082	0.0335 ± 0.0002	0.2327 ± 0.003	0.0504 ± 0.0006	0.3964 ± 0.0009	212 ± 1	212 ± 3	214 ± 29
11	40	1080	0.0335 ± 0.0002	0.2324 ± 0.0038	0.0503 ± 0.0008	0.4786 ± 0.0062	212 ± 1	212 ± 3	209 ± 35
12	17	482	0.0336 ± 0.0002	0.2339 ± 0.0069	0.0506 ± 0.0015	0.3948 ± 0.001	213 ± 1	213 ± 6	221 ± 68
13	27	723	0.0335 ± 0.0002	0.2323 ± 0.0048	0.0504 ± 0.001	0.5621 ± 0.0075	212 ± 1	212 ± 4	211 ± 47
14	24	678	0.0336 ± 0.0002	0.2325 ± 0.0072	0.0502 ± 0.0015	0.4482 ± 0.0004	213 ± 1	212 ± 7	206 ± 68
15	24	711	0.0335 ± 0.0002	0.2324 ± 0.0043	0.0503 ± 0.0009	0.317 ± 0.0006	212 ± 1	212 ± 4	209 ± 42
16	24	638	0.0338 ± 0.0002	0.2317 ± 0.0053	0.0497 ± 0.0011	0.579 ± 0.0091	214 ± 1	212 ± 5	181 ± 52
17	65	1721	0.0337 ± 0.0003	0.2332 ± 0.0045	0.0502 ± 0.0012	0.552 ± 0.0114	214 ± 2	213 ± 4	202 ± 55
18	19	559	0.0335 ± 0.0002	0.2318 ± 0.0065	0.0501 ± 0.0013	0.3169 ± 0.0031	213 ± 2	212 ± 6	201 ± 60
19	13	357	0.0336 ± 0.0002	0.2332 ± 0.01	0.0504 ± 0.0021	0.5235 ± 0.0034	213 ± 2	213 ± 9	213 ± 94
20	10	267	0.0335 ± 0.0002	0.2322 ± 0.0099	0.0503 ± 0.0021	0.5199 ± 0.0037	212 ± 1	212 ± 9	208 ± 96
21	15	490	0.0335 ± 0.0002	0.2335 ± 0.006	0.0505 ± 0.0013	0.0628 ± 0.001	213 ± 1	213 ± 6	220 ± 59
22	33	938	0.0336 ± 0.0002	0.2316 ± 0.004	0.05 ± 0.0009	0.3605 ± 0.0008	213 ± 1	212 ± 4	195 ± 40
23	15	433	0.0335 ± 0.0002	0.2325 ± 0.0064	0.0503 ± 0.0014	0.507 ± 0.0029	213 ± 2	212 ± 6	208 ± 66
24	11	314	0.0335 ± 0.0002	0.232 ± 0.0086	0.0502 ± 0.0018	0.3557 ± 0.0066	213 ± 1	212 ± 8	202 ± 84
25	31	929	0.0335 ± 0.0002	0.2322 ± 0.004	0.0503 ± 0.0008	0.2853 ± 0.0023	212 ± 1	212 ± 4	207 ± 39

3.2 锆石特征及分析结果

本次采集的二长花岗岩样品(RZ1139)共测锆石 25 粒,锆石呈自形晶,多呈长柱状,少数为短柱状,透射光下可见到锆石内部发育少量的裂纹和包裹体,阴极发光(CL)图像(图 2)显示,锆石具清晰、致密的韵律环带结构。Th/U 比值一般介于 0.2583 ~1.1452 之间,仅有 21 号测点为 0.0628,所测锆石具岩浆成因特征。25 个测点中,2、4、7 号测点的 $^{207}Pb/^{235}U$ 年龄值分别为 385 ±6 Ma、577 ±9 Ma、469 ±19 Ma,明显高于其它测点值,可能为捕获锆石年龄,其余 1、3、5、6、8 ~25 点 $^{206}Pb/^{238}U$ 表面年龄加权平均值 212.70 ±0.60 Ma(图 3),该年龄为二长花岗岩的结晶年龄,即岩体的形成时代应为晚三叠世。

4 地球化学特征

常量元素和痕量元素分析均在地科院廊坊物化探所中心实验室完成,主量元素采用 X 荧光光谱法(XRF)分析;痕量元素采用电感耦合等离子质谱法(ICP-MS)分析。

4.1 主量元素特征

常量元素分析结果(表 2)表明:研究区晚三叠世花岗岩具较高的 SiO_2(72.51% ~77.83%,平均值 75.70%)、$K_2O + Na_2O$(7.65% ~9.84%,平均 8.58%)及 FeO^*/MgO(5.79 ~ 24.43,平均值为 12.81);较低的 CaO(0.1% ~ 0.87%,平均值 0.55%)、P_2O_5(0.01% ~0.03%,平均值 0.02%);过碱指数 A.I = mol($Na_2O + K_2O$)/Al_2O_3(0.82 ~1.0,

表 2　晚三叠世花岗岩主量元素含量分析表

Table 2　Major element compositions of the Late Triassic granite from the Shengli forestry centre area

样品编号	岩石类型	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOT	Total	$\frac{FeO^*}{MgO}$	A.R	AI	A/CNK
ZHYP2023	正长花岗岩	76.88	0.1	11.91	0.56	0.25	0.04	0.14	0.59	3.76	5.23	0.02	0.26	99.75	5.79	6.12	1.00	0.922
ZHYP2043		75	0.14	13.22	1.03	0.55	0.08	0.18	0.74	3.29	5.22	0.03	0.22	99.71	8.91	4.13	0.84	1.065
ZHYP2048		75.18	0.24	12.71	1.41	0.5	0.05	0.18	0.87	3.24	5.13	0.03	0.2	99.74	10.98	4.21	0.86	1.02
ZHYP3tc13		77.83	0.08	11.94	0.38	0.52	0.042	0.07	0.42	3.28	4.82	0.017	0.41	99.8	14.30	4.81	0.89	1.049
ZHYP1139		76.3	0.09	12.56	0.23	1.23	0.09	0.13	0.72	3.19	5.1	0.02	0.1	99.74	11.89	1.35	0.86	1.04
ZHYP5tc45	二长花岗岩	72.99	0.12	13.9	1.56	0.62	0.026	0.1	0.1	4.63	5.03	0.022	0.76	99.86	22.22	0.85	0.94	1.05
ZHYP5tc46		72.51	0.14	14.22	1.31	0.84	0.032	0.09	0.1	4.7	5.14	0.022	0.67	99.78	24.43	0.76	0.94	1.055
ZHYP2010-2		75.94	0.11	12.72	0.67	0.9	0.07	0.2	0.74	3.06	5	0.03	0.27	99.71	8.37	2.03	0.82	1.079
ZHYP1061		77.25	0.08	12.28	0.64	0.35	0.05	0.09	0.46	2.99	5.35	0.01	0.25	99.79	11.32	0.97	0.87	1.063
ZHYP1147		77.09	0.09	12.25	0.58	0.84	0.07	0.15	0.81	3.34	4.31	0.03	0.2	99.75	9.92	1.66	0.83	1.053

图 2　胜利林场地区晚三叠世二长花岗岩锆石阴极发光照片

Fig. 2　Cathode Luminescence image of the Late Triassic monzogranite zircon from Shengli forestry centre area

平均值 0.88);同 A 型花岗岩值基本相同(Eby, 1990;Whalen *et al.*, 1987)。K_2O/Na_2O(1.09% ~ 1.79%,平均为 1.45%)、Al_2O_3(11.91% ~ 14.22%,平均值为 12.77%),以上各值也均接近于 A 型花岗岩值(罗红玲等,2009)。在 Na_2O-K_2O 图解(图 4a)及 SiO_2-Zr 图解上(图 4b),所有样品都落入 A 型花岗岩的范围, Eby(1990)指出,对于高硅($SiO_2>74\%$)花岗岩,$FeO^*/MgO-SiO_2$ 图解最能把大多数 A 型花岗岩与 I 型与 S 型花岗岩区别开来,研究区晚三叠世花岗岩在该图解中也都落入 A 型花岗岩区(图 5)。同时铝饱和指数 A/CNK = 0.92 ~ 1.05,平均为 1.04,属于弱过铝质花岗岩; King *et al.* (1997)和 Pitcher(1993)提出,除过碱性 A 型花岗岩外,还应有一种铝质(偏铝 - 弱过铝)A 型花岗岩,即虽然含有碱性暗色矿物的过碱性花岗岩是典型的 A 型花岗岩,然而,一部分不含碱性暗

色矿物的偏铝、甚至弱过铝的花岗岩亦可属于 A 型花岗岩。因此研究区晚三叠世花岗岩应为高硅、富碱、弱过铝质 A 型花岗岩。

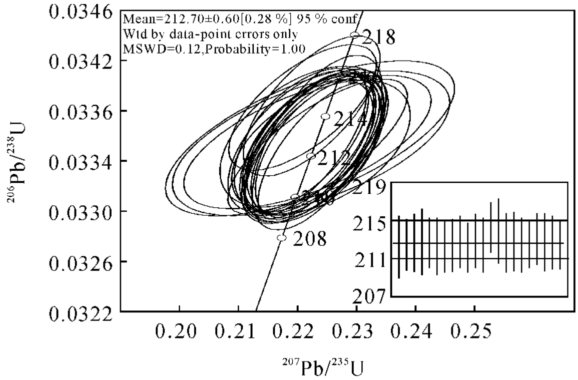

图 3 胜利林场地区晚三叠世二长花岗岩锆石 U-Pb 谐和图

Fig. 3 Zircon U-Pb concordian diagrams of the Late Triassic monzogranite from the Shengli forestry centre area

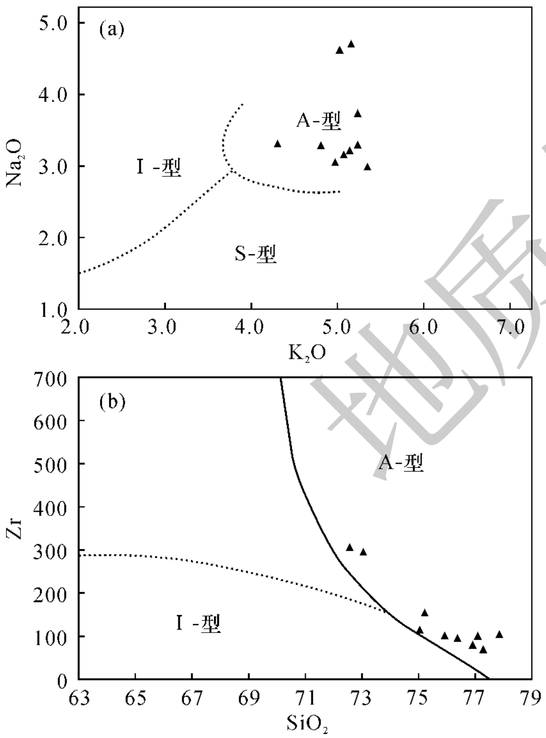

图 4 胜利林场地区晚三叠世花岗岩 Na_2O-K_2O(a)、SiO_2-Zr(b)图解(据 Collins *et al*,1982)

Fig. 4 Diagrams of the Na_2O-K_2O(a) and SiO_2-Zr(b) of the Late Triassic granite from the Shengli forestry centre area (after Collins *et al*, 1982)

4.2 微量元素特征

根据微量元素分析结果表(表 3),晚三叠世花

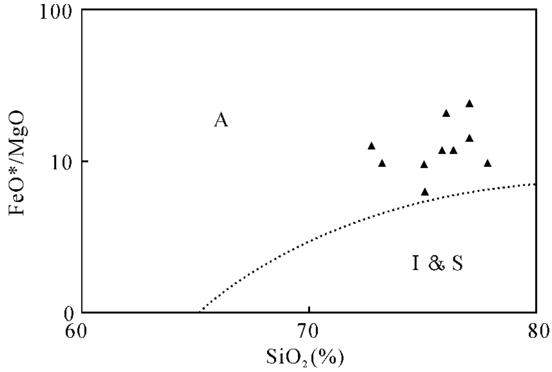

图 5 胜利林场地区晚三叠世花岗岩 FeO*/MgO-SiO_2 图解(据 Eby,1990)

Fig. 5 Diagram of FeO*/MgO-SiO_2 of the Late Triassic granite from the Shengli forestry centre area(after Eby,1990)

岗岩岩石微量元素以低 Ba、Sr 和高 Rb/Sr 为特征,其中 Rb($122.9\times10^{-6}\sim223\times10^{-6}$,平均值为 189.72×10^{-6})、Sr($30.4\times10^{-6}\sim62.7\times10^{-6}$,平均值为 48.7×10^{-6})、Rb/Sr 比值(1.96~6.55,平均为 4.20),接近于 A 型花岗岩平均值(Rb/Sr=3.52);Ga 总量较高($14\times10^{-6}\sim21.3\times10^{-6}$),并具较高的 Ga/Al 比值(1.86~3.37,平均值 2.5),接近于 A 型花岗岩下限值(2.6)(Whalen *et al.*,1987);高于 I 型花岗岩和 S 型花岗岩的平均值(2.1 和 2.28)(Whalen *et al.*,1987);在微量元素蛛网图上(图 6b)上,高场强元素 Th、La、Ce、Zr 和大离子亲石元素 Rb 等元素呈明显的尖峰状,而 Ba、Sr、Nb 和 Y 呈明显低谷,具 A 型花岗岩特征。微量元素锶(Sr)的明显负异常有两种可能,一种是源区长石类矿物的分离,因为根据矿物/溶体分配系数,锶主要进入长石类矿物,特别是斜长石(杨学明等,2000);另一种是源区本身锶含量低。从研究区晚三叠世花岗岩的情况看,长石是主要造岩矿物,不可能出现第一种情况,只能是后一种情况。因此,可以推断晚三叠世花岗岩源区很深,可能来源于下地壳(下地壳锶含量低)。

4.3 稀土元素特征

据稀土元素分析结果表(表 4),岩石稀土总量($\sum$REE)介于 $51.34\times10^{-6}\sim241.03\times10^{-6}$之间,平均值为 109.43×10^{-6},稀土总量相对典型的碱性 A 型花岗岩较低,但接近铝质 A 型花岗岩$\sum$REE 值(91.41~160.50)(邱检生等,2000);$(La/Yb)_N$=3.74~30.87,平均值为 8.64;LREE/HREE 比值介于 4.31~22.42,平均值为 8.35,轻稀土元素(LREE)相

表3　晚三叠世花岗岩微量元素含量分析表

Table 3　Trace element compositions of the Late Triassic granite from the Shengli forestry centre area

样品编号	岩性	Rb	Sr	Ba	Th	Nb	Ta	Zr	Hf	Sc	Ga	Be	Nd	Ce	Y/Nb	Rb/Sr	Ga/Al (×104)
ZHYP2023	正长花岗岩	185.2	59.1	487.6	11.96	8.18	0.75	81.8	2.58	2.99	14.63	2.61	11.79	36.75	1.42	3.13	2.32
ZHYP2043		219.2	58.2	488.5	23.43	17.84	1.7	114.2	3.65	3.98	17.25	4.19	19.86	80.08	1.27	3.77	2.46
ZHYP2048		122.9	62.7	476.5	13.67	7.31	0.61	157	4.7	3.4	15.31	2.1	38.57	109.7	1.81	1.96	2.28
ZHYP3tc13		189	37	233	15.6	18.2	1.3	105	3.4	2.8	21.3	3.54	12.1	41	0.87	5.11	3.37
ZHYP1139		223	44.9	190.3	29.56	14.35	2.03	95.6	3.32	3.29	16.73	4.47	15.14	41.15	1.89	4.97	2.52
ZHYP5tc45	二长花岗岩	193	32	135	15.8	17.3	1.3	298	9.8	3.1	20.5	2.63	21.6	30	1.94	6.03	2.79
ZHYP5tc46		190	47	145	12.3	6.5	0.7	311	11.3	2.8	14	2.63	18.2	30	5.03	4.04	1.86
ZHYP2010-2		211.4	61.6	346.8	18.23	11.86	1.82	102.3	3.3	3.22	15.17	3.64	8.46	20.52	1.50	3.43	2.25
ZHYP1061		199.2	30.4	253.9	18.56	9.89	1.23	70.8	2.27	4.43	15.52	2.69	9.3	16.73	1.38	6.55	2.39
ZHYP1147		164.3	54.1	293.3	26.12	11.35	1.41	101.3	3.57	3.15	15.66	3.62	11.2	37.11	1.51	3.04	2.41

表4　晚三叠世花岗岩稀土元素含量分析表

Table 4　REE element compositions of the Late Triassic granite from the Shengli forestry centre area

样品编号	岩石类型	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y	ΣREE	LREE	HREE	LREE/HREE	La_N/Yb_N	δEu
ZHYP2023	正长花岗岩	30.89	36.75	3.97	11.79	1.67	0.3	1.59	0.27	1.81	0.35	1.13	0.2	1.36	0.23	11.61	92.3	85.37	6.93	12.31	15.31	0.55
ZHYP2043		33.95	80.08	6.18	19.86	3.21	0.37	3.12	0.52	3.61	0.74	2.46	0.43	2.98	0.49	22.58	158.01	143.65	14.36	10	7.69	0.35
ZHYP2048		64.92	109.7	12.32	38.57	4.66	0.57	3.45	0.47	2.53	0.48	1.46	0.23	1.42	0.25	13.24	241.03	230.74	10.29	22.42	30.87	0.41
ZHYP3tc13		22	41	3.8	12.1	2.1	0.2	2	0.38	2.51	0.5	1.73	0.32	2.31	0.38	15.9	91.05	80.93	10.12	8	6.43	0.29
ZHYP1139		22.31	41.15	4.52	15.14	3.05	0.18	2.96	0.58	4.05	0.84	2.77	0.5	3.45	0.59	27.19	102.09	86.35	15.75	5.48	4.37	0.18
ZHYP5tc45	二长花岗岩	32	30	6.5	21.6	3.9	0.14	3.7	0.78	5.26	1.11	3.56	0.68	4.62	0.72	33.5	114.77	94.31	20.46	4.61	4.67	0.11
ZHYP5tc46		27.4	30	5.5	18.2	3.4	0.12	3.2	0.71	5.17	1.07	3.57	0.67	4.52	0.74	32.7	104.31	84.68	19.63	4.31	4.09	0.11
ZHYP2010-2		13.82	20.52	2.58	8.46	1.78	0.23	1.76	0.35	2.61	0.55	1.9	0.35	2.47	0.42	17.75	57.8	47.39	10.42	4.55	3.77	0.39
ZHYP1061		11.67	16.73	2.79	9.3	1.81	0.17	1.5	0.3	2.22	0.46	1.59	0.31	2.11	0.37	13.66	51.34	42.47	8.87	4.79	3.74	0.31
ZHYP1147		17.42	37.11	3.31	11.2	2.11	0.26	1.99	0.36	2.59	0.53	1.81	0.33	2.15	0.39	17.16	81.55	71.4	10.15	7.03	5.48	0.38

对富集；$(La/Sm)_N = 6.45 \sim 18.50$，轻稀土较重稀土分馏明显；$\delta Eu = 0.11 \sim 0.55$，平均为 0.31，表现中等－较强的 Eu 负异常，δEu 值是判断物质来源及地质作用的重要的地球化学参数（Rogers *et al.*，2001），壳源岩浆具有较小的 δEu 值（0.45 左右），表现强负异常，幔源岩浆 δEu 值接近于 1，壳幔型花岗岩 δEu 值介于二者之间（0.84 左右），碱性花岗岩 δEu 值小于 0.30，由此可以看出，本期晚三叠世花岗岩 δEu 值接近于碱性花岗岩值，但从地球化学特征分析，其为弱过铝质花岗岩，说明晚三叠世花岗岩岩浆源可能不是单一来源；在稀土球粒陨石标准化图解上（图 6a）呈现近右倾的“海鸥式”的稀土元素配分模式，符合铝质 A 型花岗岩特征。同时所有元素稀土模式图和微量元素蛛网图特征，也均显示了岩浆具壳幔混合源岩浆的特征（罗红玲等，2009）。

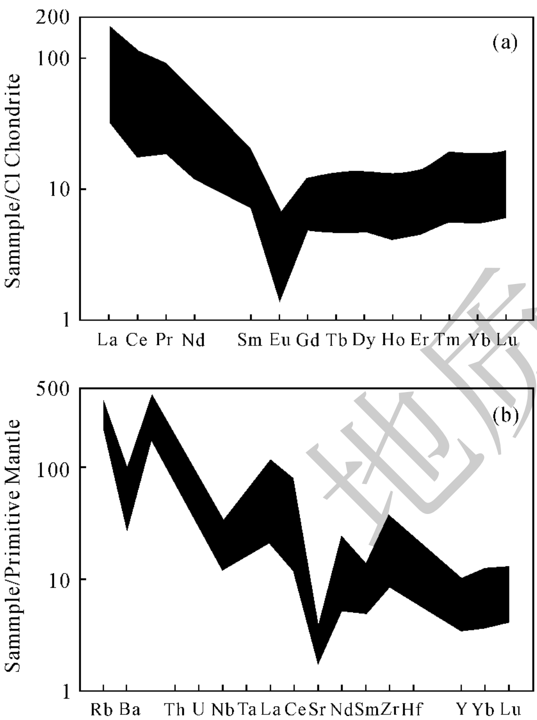

图 6　胜利林场地区晚三叠世花岗岩稀土配分曲线（a）和微量元素蛛网图（b）

Fig. 6　Chonrdrite-normalized REE pattern (a) and primitive mantle-normalized trace element spidergram (b) of the Late Triassic granite from the Shengli forestry centre area

5　构造环境及成因

5.1　构造环境

研究区晚三叠世 A 型花岗岩具有较低的 Sr 含量（$30.4 \times 10^{-6} \sim 62.7 \times 10^{-6}$），较高的 Yb 含量（$1.42 \times 10^{-6} \sim 4.62 \times 10^{-6}$），以及中－较强的 Eu 负异常（0.11 ~ 0.55），这同张旗等（2008）提出的形成于造山后地壳减薄阶段的花岗岩基本相似。

在花岗岩各类判别图解上，胜利林场地区晚三叠世花岗岩所有样品比较一致的显示了造山期后 A 型花岗岩的特征。在 $R_1 - R_2$ 多阳离子构造环境判别图解中（图 7），多数样品均落入造山期后 A 型花岗岩区及其附近；w(Y)/w(Nb) 比值是判别 A_1 和 A_2 型花岗岩的重要依据之一，研究区 w(Y)/w(Nb) = 0.87 ~ 5.03，平均值 1.86，除一个样品外，其它样品 w(Y)/w(Nb) 值均大于 1.2，据 Bonin *et al.*（1998）认为，当 w(Y)/w(Nb) > 1.2 时为 A_2 型花岗岩，当 w(Y)/w(Nb) < 1.2 时为 A_1 型花岗岩，也就是说，高铌者为 A_1 型，与板内或裂谷型的岩浆作用吻合，低铌者为 A_2 型，与造山型总体吻合。在 A_1 和 A_2 型花岗岩类的判别图解中（图 8），所有样品也均落入了 A_2 区（后碰撞），说明研究区晚三叠世花岗岩为后碰撞造山阶段形成的 A_2 型花岗岩。

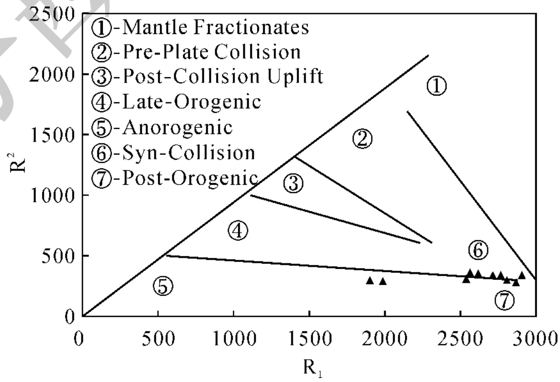

图 7　花岗岩类 $R_1 - R_2$ 多阳离子图解（据 Batchelor and Bowden，1985）

Fig. 7　$R_1 - R_2$ multication diagram of the granitoids (after Batchelor and Bowden, 1985)

①－幔斜长花岗岩；②－破坏性活动板块边缘（板块碰撞前）花岗岩；③－板块碰撞后隆起花岗岩；④－晚造山期花岗岩；⑤－非造山区 A 型花岗岩；⑥－同碰撞（S 型）花岗岩；⑦－造山期后 A 型花岗岩

① – mantle plagioclase granite; ② – pre-plate collision granite; ③ – granite of post-collision uplift; ④ – late orogenic granite; ⑤ – anorgenic A-type granite; ⑥ – syn-collision granite; ⑦ – post – orogenic A-type granite

以往对松嫩地块与佳木斯地块碰撞拼合的时间观点不一，一种观点认为其拼合时间为早古生代末期（尹冰川等，1997）；第二种观点认为两地块拼合

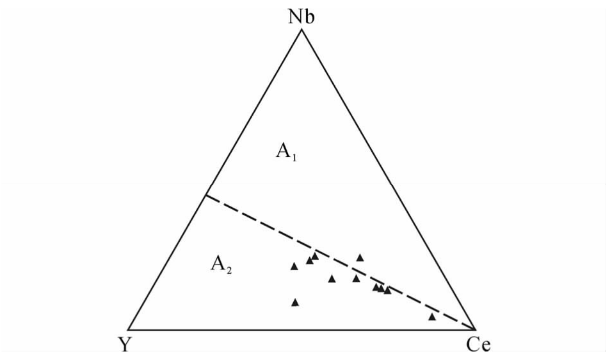

图8　A_1 和 A_2 型花岗岩类的三角形判别图解(据 Eby,1992)

Fig.8　Triangular plot for distinguishing between A_1 and A_2 (after Eby,1992)

A_1 -非造山型;A_2 -后碰撞型

的标志应为黑龙江群构造混杂岩,其蓝片岩变质年龄为165~195 Ma之间(叶惠文等,1994;李锦铁等,1999;Wu *et al*,2004),反映两地块碰撞闭合的时间为三叠纪末-侏罗纪初期。目前国际上对后造山 A_2 型花岗岩与主造山事件时间间隔的研究成果显示,其间隔时间一般为40 Ma或75~25 Ma(Dewey J F,1988;Turter S P *et al*,1992),通过本次锆石LA-ICP-MS U-Pb同位素测年结果(212.70±0.60 Ma),以时间间隔75~25 Ma上限及下限为界,推断产生本期造山后A型花岗岩的主造山时间应在237~289 Ma之间,对应的主造山期时代为早二叠世-中三叠世。而对研究区中二叠世花岗岩的年代学(260.72±0.72 Ma、261.62±0.74 Ma、259.86±0.69 Ma)、地球化学研究表明,本区中二叠世时正处于同碰撞造山、挤压的构造环境,同上述推断的主造山期时间(237~289 Ma)吻合,说明松嫩地块与佳木斯地块拼合时期应为中二叠世。从而证明研究区从中二叠世到晚三叠世所处的大地构造环境应为碰撞挤压—伸展拉张转换的构造演化时期。

5.2　花岗岩的成因

由以上讨论可以看出,小兴安岭东南部胜利林场地区晚三叠世花岗岩岩石化学特征显示了其具下地壳和富集地幔的特征,因地幔岩熔融不能直接生成花岗岩(张旗等,2007),因此晚三叠世花岗源区可能来源于下地壳,但可能受到了富集地幔的影响。

研究区晚三叠世花岗岩具A型花岗岩的地球化学特征,A型花岗岩生成的主要有以下两种观点:①部分熔融模式,即由中下地壳高钾、贫水的岩石部分熔融而成(Collins *et al.*,1982;Whalen *et al.*,1987;Landenberger and Collins,1996;Patino Douse,1997);②分异模式,即由地幔来源的玄武岩浆分异作用产生(Loiselle and Wones,1979;Eby 1990,1992;Turner *et al.* 1992;King *et al.*,2001);因晚三叠世花岗岩 SiO_2 含量较高且变化范围较窄(72.51%~77.83%),因此其不可能直接由结晶分离作用形成(张旗等,2007),同时陆壳岩石的熔融实验也表明其可以产生偏铝的A型花岗岩,但不能产生过碱性的A型花岗岩,因此由中下地壳的部分熔融可能是胜利林场地区晚三叠世弱过铝质花岗岩形成的主要原因。本期花岗岩 K_2O+Na_2O(7.65%~9.84%,平均8.58%,同巴西Queimadas碰撞后A型花岗岩 K_2O+Na_2O 值平均为8.95%基本一致,AImeida *et al.*,2002),在花岗岩类构造环境判别图解(Maniar and Piccoli 1989)中(图9),也显示了晚三叠世花岗

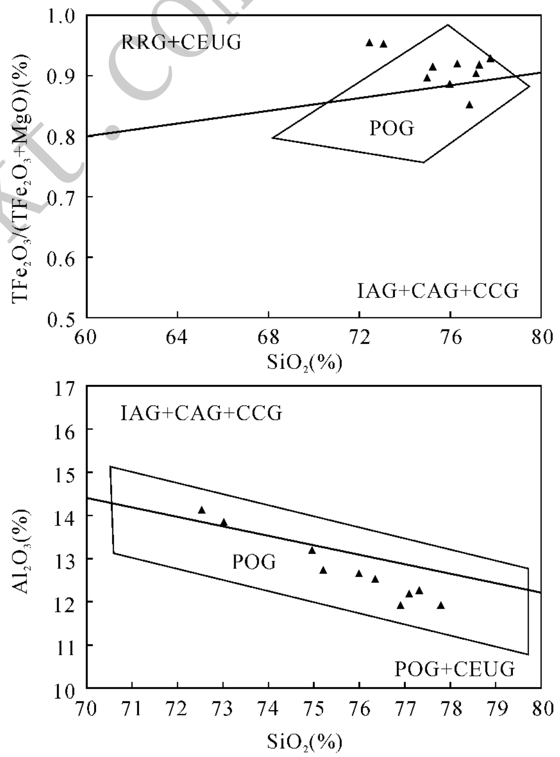

图9　胜利林场地区晚三叠世花岗岩类构造环境判别图解(据 Maniar and Piccoli,1989)

Fig.9　Tectonic discrimination diagram of granitoids of the Late Triassic granite in the Shengli forestry centre area(after Maniar and Piccoli,1989)

IAG-岛弧型花岗岩类;CAG-大陆弧型花岗岩类;CCG-大陆碰撞花岗岩类;POG-后造山花岗岩类;RRG-与裂谷有关的花岗岩类;CEUG-与造山抬升有关的花岗岩类

IAG-island-arc type granites; CAG-continental-arc type granites; CCG-continental collision type granites; POG-post-orogenic granites; RRG-rift-related granites; CEUG-granites related to orogenic uplift

岩具后造山花岗岩(POG)的特征。由此可以得出,胜利林场地区晚三叠世 A 型花岗岩可能的成因是后碰撞环境下岩石圈伸展减薄,幔源岩浆底侵促使上覆的下地壳发生部分熔融并与幔源岩浆混合的产物。

6 结论

(1)小兴安岭东南部胜利林场地区晚三叠世花岗岩组合不是典型的 A 型花岗岩,应是 King *et al.*(1997)和 Pitcher(1993)提出的弱过铝质 A 型花岗岩,其成因可能是研究区在造山后由挤压向拉伸转换的构造背景下,岩石圈伸展减薄,幔源岩浆底侵促使上覆的先存地壳发生部分熔融的产物。

(2)晚三叠世花岗岩所反映的具壳幔混源的地球化学特征,可能是受地幔岩浆底侵并受地幔挥发份稀释作用下的下地壳的物质部分熔融结果的反映(Harris *et al.*,1986)。

(3)本次工作 LA-ICP-MS U-Pb 锆石测年龄为 212.70±0.60 Ma,暗示本区在晚三叠世已进入造山后岩石圈伸展背景下的构造演化阶段。结合研究区中二叠世花岗岩研究成果,表明从中二叠世到晚三叠世研究区所处的大地构造环境应为碰撞挤压—伸展拉张转换的构造演化阶段。

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Geochemical Characteristics of the Late Triassic A-Type Granite in the Shengli Forestry Centre Area, Southeastern Xiao Hinggan Ling and Their Tectonic Implications

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Abstract: The Shengli forestry centre district is in the southeast of the Xiao Hinggan Ling Mountains. Late Triassic granites in this district are located in the east of the Songnen crustal block, which is bounded by the Jiayin-Mudanjiang fault adjoining the Jiamusi crustal block in east. These Late Triassic granites are comprised of the monzonitic granite and the syenite granite. They have high contents of SiO_2 (72.51% ~77.83% average of 75.7%), $K_2O + Na_2O$ (7.65% ~9.84%, 8.58%) and FeO^*/MgO (5.79 ~24.43, average 12.81), and low contents of CaO (0.1% ~0.87%, average 0.55%) and P_2O_5 (0.01% ~0.03%, average 0.02%). Their alkali index which ranges from 0.82 to 1.0, average 0.88, is identical with the A-type granite. The Eu element exhibits moderate-stronger negative anomalies (δEu = 0.11 ~ 0.55, average 0.31). It is clear from the preliminary mantle-normalized trace element pattern that the elements of Th, La, Ce, Ta, and Rb are enriched, while Ba, Sr, Nb, and Y are depleted. Except one sample, all the other samples demonstrate characters of the A_2 (post-collision) granite implying that this Late Triassic A type granite was produced by an extensional environment of post-orogenesis.

Key words: Late Triassic granite; A_2 type granite; post-collision; extensional environment