36)，与文献报道值[24]在误差范围内完全一致。

4 分析结果

4.1 锆石U–Pb年龄

后山店岩体（DY11–2）和曹娥岩体（DY11–143）花岗斑岩样品的LA–MC–ICP–MS锆石U–Pb同位素结果见表1。锆石阴极发光（CL）图像显示，后山店岩体（DY11–2）的锆石多呈等轴粒状，形态大小不均，部分颗粒破碎，只有少数呈长柱状（图2–a）；而曹娥岩体（DY11–143）的锆石多呈长柱状，长宽比值较大（1.5~3.0）（图2–b）。多数锆石均发育不明显且较窄的振荡环带，暗示为岩浆成因[25]，且样品DY11–143的锆石具有高的Th、U含量而致使阴极发光照片颜色较深（图2–b）。后山店岩体样品（DY11–2）的15颗锆石的Th/U比值为0.68~1.63，所得到的15个数据给出的 $^{206}Pb/^{238}U$ 年龄加权平均值为（149.1± 1.1）Ma（MSWD =1.4）（表1，图3–a）；曹娥岩体（DY11–43）的15颗锆石的Th/U比值为0.65~2.58，所得到的15个数据给出的 $^{206}Pb/^{238}U$ 年龄加权平均值为（150.3± 1.6）Ma（MSWD = 0.89）（表1，图3–b）。可见，本次研究的后山店岩体与曹娥岩体为同时代形成，均为晚侏罗世，属于燕山早期第二阶段岩浆活动的产物。

4.2 岩石地球化学

浙中地区后山店及曹娥晚侏罗世花岗斑岩具有高硅，较富碱，贫Ti、Ca、Mg等特点，其主量元素分析结果见表2。岩石的 SiO_2 含量高，为73.53%~77.21%，富碱（全碱Alk= K_2O +Na_2O，7.79%~8.97%）和略富钾（K_2O /Na_2O 值均>1），里特曼指数介于1.8~2.64，岩体碱度率较高，*AR*介于3.90~5.32，平均为4.52（>0.90），分异指数（*DI*）介于92.35~98.03，反映该时期花岗斑岩在结晶过程中经历了高程度的岩浆分异演化作用。在 SiO_2–(K_2O+Na_2O)图解（图4–a）中，样品均落入亚碱性花岗岩区域；在 SiO_2–K_2O 图解（图4–b）中，所有点均落入高钾钙碱性区域；花岗斑岩的 Al_2O_3 含量为12.57%~13.78%，铝饱和指数A/CNK介于0.96~1.28，在含铝指数图解（图4–c）中，各投影点集中于准铝质–弱过铝质区域；在 K_2O–Na_2O 图解（图4–d）上，样品则均落入A型花岗岩区域，而具体属于哪类花岗岩类型将在后面详述。上述岩石地球化学特征与绍兴地区广山花岗杂岩体特征较为类似[16–17]，也与产于由挤压向拉张转变过程中形成的富钾钙碱性花岗岩（KGG）特征较为相似[26]。

样品的稀土、微量元素分析测试结果列于表2。从稀土元素球粒陨石标准化配分模式图（图5–a）中可以看出，浙中晚侏罗世花岗斑岩稀土总量中等且变化较大（$\Sigma REE=94.81\times10^{-6}\sim327.88\times10^{-6}$），轻、重稀土及轻稀土之间都呈现出一定的分馏特征（LREE/HREE=7.99~11.22，$(La/Yb)_N$ = 6.77~11.22，$(La/Sm)_N$ = 4.62~5.06），而重稀土之间则无或具有弱的分馏（$(Gd/Lu)_N$ =0.91~1.46）特征。两个花岗斑岩岩体稀土配分模式基本相似，其球粒陨石标准化配分模式均为右倾，表明具有一定的稀土分馏现象。样品具明显Eu负异常（δEu=0.1~0.40）（表2，图5–a），配分曲线呈典型的“V”字型特征，表明岩浆的演化过程伴随有斜长石的分离结晶作用。

微量元素方面，该时期花岗斑岩富集Rb、Th、U等大离子亲石元素（LILE）和Nd、Hf、Y等高场强元素（HFSE），明显亏损Ba、Sr、P、Ti等元素（图5–b）。岩石的 10^4Ga/Al值除曹娥岩体样品较高（为3.15）外，后山店岩体样品均介于2.2~2.42，平均值为2.35，均低于A型花岗岩的下限值（2.6）[31]，暗示曹娥岩体可能具有为A型花岗岩的特征，但需要进一步研究的证实，而后山店岩体则应为高分异的I型或S型花岗岩。

4.3 锆石Hf同位素

本次工作在对浙中后山店岩体及曹娥岩体2件样品进行锆石U–Pb测年的基础上，还对其锆石进行了Hf同位素测定，分析结果列于表3。本文共测得30个Hf同位素数据，所测花岗斑岩锆石Lu–Hf同位素均具有高的 $^{176}Hf/^{177}Hf$ 比值（0.282421~0.282621，均值为0.282527）和低的 $^{176}Lu/^{177}Hf$ 比值（0.001035~0.004892，均值为0.003009）组成特征。表明锆石在形成后具有极低的放射性成因Hf积累，因此本文所测定的 $^{176}Hf/^{177}Hf$ 比值可以代表锆石结晶时体系的Hf同位素组成[34]。考虑到所测2件样品的 $f_{Lu/Hf}$ 的变化范围介于−0.9688~−0.8527，平均值为−0.9037，明显小于镁铁质地壳的 $f_{Lu/Hf}$ 值（−0.34）[34]和硅铝质地壳的 $f_{Lu/Hf}$ 值（−0.72）[35]，因此，所测得的二阶段模式年龄更能反映出其源区物质从亏损地幔被抽取的时间或在地壳中存留的平均年龄。

表1 后山店(DY11-2)及曹娥花岗斑岩(DY11-143)锆石U-Th-Pb同位素测定结果

Table 1 U-Th-Pb isotope compositions of zircons in the Houshandian (DY11-2) and Caoe (DY11-143) granite porphyry samples as measured by using LA-MC-ICP-MS technique

点号	Pb /10^{-6}	Th /10^{-6}	U /10^{-6}	Th/U	$^{207}Pb/^{206}Pb^*$ 比值	$^{207}Pb/^{206}Pb^*$ (±1σ)	$^{207}Pb/^{235}U^*$ 比值	$^{207}Pb/^{235}U^*$ (±1σ)	$^{206}Pb/^{238}U^*$ 比值	$^{206}Pb/^{238}U^*$ (±1σ)	$^{208}Pb/^{232}Th^*$ 比值	$^{208}Pb/^{232}Th^*$ (±1σ)	$^{207}Pb/^{206}Pb$ 年龄 (Ma)	(±1σ)	$^{207}Pb/^{235}U$年龄 (Ma)	(±1σ)	$^{206}Pb/^{238}U$年龄 (Ma)	(±1σ)	$^{208}Pb/^{232}Th$年龄 (Ma)	(±1σ)
DY11-2：花岗斑岩，15个测点，年龄加权平均值为(149.1±1.1) Ma，MSWD = 1.4																				
1	174	210	301	0.70	0.04885	0.00048	0.15274	0.00253	0.02271	0.00036	0.00241	0.00033	139.0	24	144.3	2.2	144.7	2.3	48.7	6.7
2	69	76	113	0.68	0.04957	0.00155	0.15633	0.00491	0.02294	0.00042	0.00356	0.00053	176.0	77	147.5	4.3	146.2	2.7	71.8	11
3	233	298	308	0.97	0.04939	0.00039	0.15816	0.00201	0.02324	0.00027	0.00233	0.00025	164.9	19	149.1	1.8	148.1	1.7	46.9	5.0
4	159	233	195	1.20	0.05099	0.00181	0.16749	0.00706	0.02385	0.00076	0.00197	0.00028	239.0	77	157.2	6.1	152.0	4.8	39.8	5.7
5	461	571	508	1.13	0.04962	0.00032	0.16615	0.00209	0.02427	0.00028	0.00253	0.00021	176.0	15	156.1	1.8	154.6	1.8	51.2	4.3
6	230	318	286	1.11	0.05485	0.00145	0.18078	0.01062	0.02379	0.00107	0.00252	0.00022	405.6	59	168.7	9.1	151.6	6.7	50.8	4.4
7	126	183	199	0.92	0.05069	0.00062	0.16411	0.00354	0.02347	0.00045	0.00268	0.00026	233.4	28	154.3	3.1	149.5	2.8	54.1	5.3
8	410	735	452	1.63	0.05073	0.00039	0.16317	0.00204	0.02334	0.00027	0.00230	0.00016	227.8	23	153.5	1.8	148.7	1.7	46.4	3.2
9	188	385	372	1.03	0.05650	0.00074	0.18016	0.00525	0.02306	0.00054	0.00209	0.00027	472.3	30	168.2	4.5	147.0	3.4	42.2	5.4
10	101	230	244	0.94	0.05068	0.00048	0.16178	0.00209	0.02318	0.00026	0.00192	0.00028	233.4	22	152.3	1.8	147.7	1.6	38.9	5.6
11	95	217	236	0.92	0.05157	0.00061	0.16418	0.00217	0.02315	0.00022	0.00177	0.00031	264.9	28	154.4	1.9	147.5	1.4	35.8	6.2
12	83	182	194	0.94	0.05055	0.00051	0.16294	0.00211	0.02343	0.00026	0.00178	0.00037	220.4	22	153.3	1.8	149.3	1.6	36.0	7.6
13	116	250	262	0.96	0.05130	0.00050	0.16890	0.00191	0.02396	0.00023	0.00182	0.00046	253.8	22	158.5	1.7	152.6	1.5	36.7	9.2
14	421	1090	1096	0.99	0.05683	0.00031	0.18579	0.00498	0.02368	0.00061	0.00128	0.00038	483.4	13	173.0	4.3	150.9	3.8	25.9	7.8
15	159	360	380	0.95	0.05908	0.00061	0.19502	0.00316	0.02399	0.00040	0.00142	0.00051	568.6	22	180.9	2.7	152.8	2.5	28.7	10
DY11-143：花岗斑岩，15个测点，年龄加权平均值为(150.3±1.6) Ma，MSWD = 0.89																				
1	0	26	40	0.65	0.04611	0.01095	0.15693	0.03711	0.02474	0.00070	0.00000	0.00000	400.1	94	148.0	33	157.6	4.4	0.0	0
2	30	37	42	0.87	0.05608	0.01897	0.18639	0.05864	0.02432	0.00065	0.00634	0.00100	457.5	613	173.5	50	154.9	4.1	127.7	20
3	63	224	115	1.94	0.05449	0.00338	0.18603	0.01570	0.02469	0.00066	0.00215	0.00020	390.8	134	173.2	13	157.2	4.2	43.3	4.0
4	57	158	108	1.46	0.05705	0.00491	0.18067	0.00673	0.02306	0.00114	0.00276	0.00022	494.5	186	168.6	5.8	147.0	7.2	55.8	4.0
5	37	186	125	1.49	0.05329	0.00169	0.17162	0.00849	0.02334	0.00042	0.00393	0.00000	342.7	40	160.8	7.4	148.7	2.6	79.2	0
6	33	128	154	0.83	0.04986	0.00105	0.16111	0.00474	0.02343	0.00060	0.00279	0.00055	187.1	48	151.7	4.1	149.3	3.8	56.4	11
7	51	104	74	1.41	0.05172	0.00322	0.16701	0.01101	0.02340	0.00030	0.00373	0.00096	272.3	143	156.8	9.6	149.1	1.9	75.2	19
8	0	27	38	0.72	0.05260	0.00913	0.16665	0.01835	0.02323	0.00151	0.00000	0.00000	322.3	343	156.5	16	148.0	9.5	0.0	0
9	369	1131	438	2.58	0.05459	0.00039	0.17495	0.00184	0.02327	0.00024	0.00237	0.00021	394.5	12	163.7	1.6	148.3	1.5	47.9	4.0
10	59	156	128	1.22	0.04850	0.00254	0.15626	0.00566	0.02344	0.00047	0.00258	0.00095	124.2	119	147.4	5.0	149.4	2.9	52.0	19
11	1	89	77	1.15	0.05144	0.00763	0.16881	0.02127	0.02388	0.00055	0.00000	0.00000	261.2	307	158.4	19	152.1	3.5	0.0	0
12	104	253	155	1.63	0.04678	0.00148	0.15205	0.01620	0.02351	0.00177	0.00280	0.00023	39.0	83	143.7	14	149.8	11	56.6	5.0
13	167	280	197	1.42	0.05152	0.00498	0.17472	0.01056	0.02467	0.00090	0.00404	0.00075	264.9	219	163.5	9.1	157.1	5.7	81.4	15
14	92	41	39	1.06	0.05168	0.00226	0.17293	0.01151	0.02421	0.00059	0.01378	0.00317	272.3	100	162.0	10	154.2	3.7	276.7	63
15	30	61	58	1.05	0.05071	0.00175	0.16521	0.00643	0.02362	0.00048	0.00471	0.00064	227.8	80	155.3	5.6	150.5	3.0	95.0	13

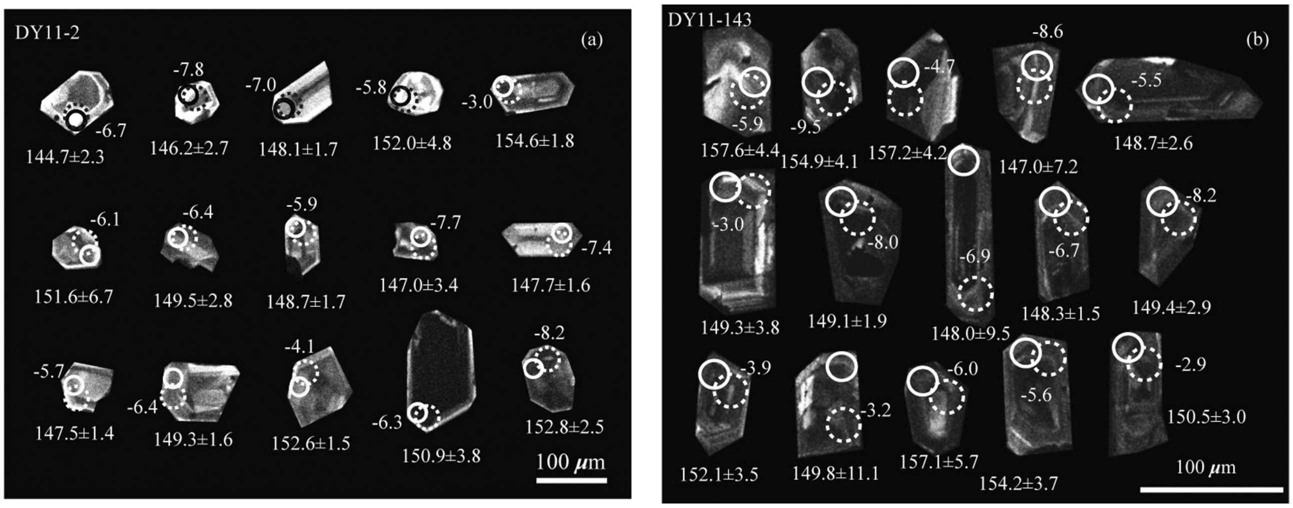

图2 后山店(DY11−2)(a)及曹娥(DY11−143) (b)花岗斑岩阴极发光图像中单个锆石年龄(Ma)及Hf同位素值

Fig.2 Zircon CL images with single zircon U−Pb isochron ages and Hf isotope compositions for the Houshandian (DY11−2) (a) and Caoe (DY11−143) (b) granite porphyries

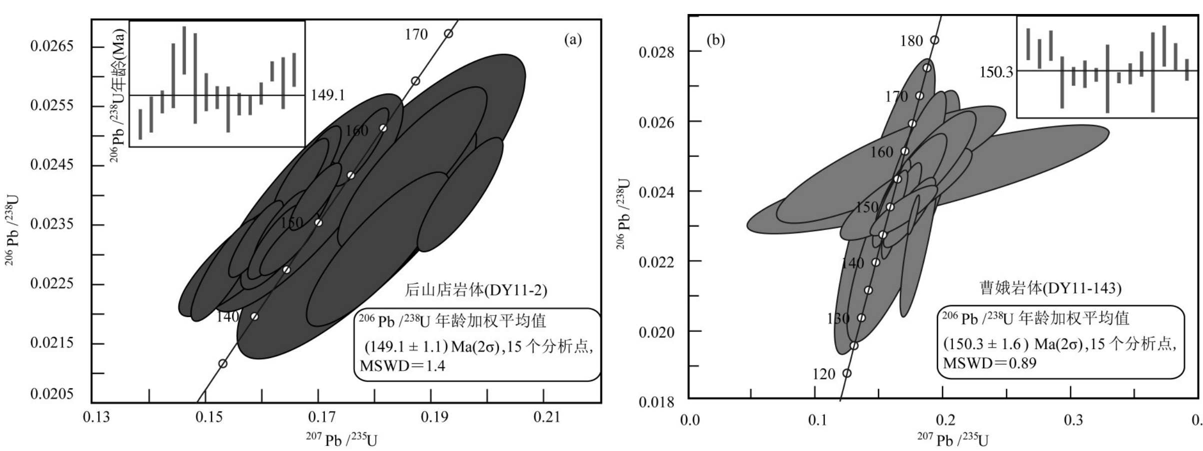

图3后山店(DY11−2)及曹娥岩体(DY11−143)花岗斑岩的锆石U−Pb谐和图及 $^{206}Pb/^{238}U$ 年龄图

Fig. 3 U−Pb Concordia diagrams and $^{206}Pb/^{238}U$ age plots of Houshandian (DY11−2) and Caoe (DY11−143) granite porphyries

锆石Hf同位素分析数据表(表3)显示,后山店花岗斑岩样品(DY11−2)的15颗锆石的 $^{176}Hf/^{177}Hf$ 比值变化范围在0.282468~0.282610,平均值为0.282522;其对应的 $\varepsilon_{Hf}(t)$ 值变化范围为−8.2~−3.0,平均值为−6.3;二阶段模式年龄 t^{C}_{DM} 变化范围在1371~1696 Ma,平均值为1575 Ma。曹娥花岗斑岩样品(DY11−143)的15颗锆石的 $^{176}Hf/^{177}Hf$ 比值变化范围在0.282421~0.282621,平均值为0.282531;其对应的 $\varepsilon_{Hf}(t)$ 值变化范围为−9.5~−2.9,平均值为−5.9;二阶段模式年龄 t^{C}_{DM} 变化范围在1364~1783 Ma,平均值为1552 Ma。

5 讨 论

5.1 锆石U−Pb年龄的地质意义

一般认为,中国东南部地区燕山期岩浆活动可分为燕山早期(180~140 Ma)和燕山晚期(140~97 Ma)两个主要阶段[36]。前人通过对华南地区晚侏罗世火成岩年代学及岩石地球化学特征进行研究表明,该时期火成岩(163~145 Ma)主要以S型花岗岩为主,少量为I型和A型花岗岩,为加厚地壳伸展下发生部分熔融的产物[17,37−39]。近年来,人们对浙江地区的野外调查结果显示,在浙西北地区也发育有晚

表2 浙中后山店及曹娥岩体主量(%)和微量元素成分(10^{-6})

Table 1 Whole-rock major (%) and trace (10^{-6}) elements compositions of Houshandian and Caoe plutons in central Zhejiang Province

样品	DY11−1	DY11−2	DY11−3	DY11−4	DY11−143
年龄/Ma	149.1±1.1				150.3±1.6
SiO_2	77.21	75.72	74.43	76.67	73.53
TiO_2	0.09	0.09	0.11	0.09	0.11
Al_2O_3	12.57	12.95	12.79	12.94	13.78
TFe_2O_3	0.57	1.52	1.41	1.18	1.83
FeO	0.20	0.18	0.97	0.32	0.20
MnO	0.00	0.01	0.07	0.01	0.02
MgO	0.05	0.04	0.15	0.13	0.18
CaO	0.06	0.07	1.14	0.04	0.33
Na_2O	4.20	3.88	3.98	2.80	3.51
K_2O	4.43	4.71	4.27	4.99	5.46
P_2O_5	0.01	0.02	0.02	0.01	0.01
烧失量	0.63	0.90	1.61	1.01	1.13
总计	99.81	99.89	99.88	99.84	99.87
σ	2.18	2.26	2.17	1.80	2.64
Na_2O+K_2O	8.63	8.59	8.25	7.79	8.97
K_2O/Na_2O	1.06	1.21	1.07	1.78	1.56
AR	5.32	4.88	3.90	4.00	4.49
A/NK	1.07	1.13	1.14	1.29	1.18
A/CNK	1.06	1.11	0.96	1.28	1.12
石英	35.79	34.9	32.41	41.21	31.45
刚玉	0.74	1.31	0	2.87	1.53
正长石	26.42	28.13	25.69	29.85	32.7
钠长石	35.82	33.19	34.25	23.97	30.1
钙长石	0.35	0.47	4.5	0.26	1.63
紫苏辉石	0.29	0.8	1.26	0.9	0.84
磁铁矿	0.38	1	0.49	0.74	1.48
分异指数	98.03	96.22	92.35	95.03	94.25
La	21.01	24.20	46.77	38.28	75.10
Ce	39.24	52.04	85.46	70.45	139.70
Pr	4.64	5.38	9.86	8.03	16.21
Nd	16.29	18.62	34.46	28.95	59.50
Sm	2.77	3.13	5.81	4.98	10.23
Eu	0.32	0.38	0.70	0.51	0.31
Gd	2.33	2.63	4.89	4.23	8.00
Tb	0.42	0.45	0.76	0.68	1.18
Dy	2.68	2.79	4.34	4.07	6.44
Ho	0.58	0.61	0.86	0.84	1.32
Er	1.81	1.94	2.60	2.55	4.04
Tm	0.32	0.34	0.43	0.42	0.66
Yb	2.09	2.37	2.88	2.88	4.51
Lu	0.32	0.34	0.42	0.43	0.68
ΣREE	94.81	115.23	200.23	167.31	327.88
δEu	0.37	0.40	0.39	0.33	0.1
LREE/HREE	7.99	9.04	10.66	9.39	11.22
$(La/Yb)_N$	6.77	6.88	10.96	8.95	11.23
$(La/Sm)_N$	4.77	4.87	5.06	4.84	4.62
$(Gd/Lu)_N$	0.91	0.95	1.46	1.23	1.46
Sc	3.84	3.83	4.20	3.96	3.90
V	6.30	8.60	11.60	9.50	13.00
Cr	5.80	7.80	7.30	8.60	3.60
Ni	1.09	1.58	1.28	2.01	0.86
Cu	2.00	1.76	2.86	1.99	2.20
Zn	11.56	17.65	55.24	36.34	89.00
Ga	14.65	15.52	17.11	16.56	23.00
Rb	146.90	160.60	147.10	201.40	218.00
Sr	66.30	73.60	63.80	46.20	31.00
Zr	144.00	159.90	148.40	138.80	338.00
Y	16.04	16.70	25.90	24.93	36.30
Nb	15.44	16.32	16.27	18.98	23.20
Cs	1.46	1.55	2.55	3.17	8.70
Ba	628.52	882.10	755.51	627.50	117.00
Hf	4.57	4.94	5.43	4.94	9.95
Ta	1.27	1.32	1.31	1.63	1.73
Pb	11.45	11.80	28.21	16.80	31.00
Th	17.24	20.84	21.45	20.24	23.60
U	4.41	4.52	7.04	4.68	2.59
Rb/Sr	2.22	2.18	2.31	4.36	7.03
La/Nb	1.36	1.48	2.87	2.02	3.24
Ba/Nb	40.71	54.05	46.43	33.05	5.04

注:$\sigma = (K_2O+Na_2O)^2/(SiO_2-43)$;$A/NK=Al_2O_3/(Na_2O+K_2O)$;$A/CNK=Al_2O_3/(CaO+Na_2O+K_2O)$;$\delta Eu=2Eu_N/(Sm_N+Gd_N)$。

侏罗世的花岗质岩体,如淳安中西部出露的开岭脚(151 Ma)和里陈家花岗闪长岩体(148 Ma)[13]、栅溪岩体(150 Ma)[14]、结蒙花岗闪长岩体(150 Ma)[15]、广山杂岩体(162~147 Ma)[14,17]等。以上高精度锆石U−Pb年龄结果均证明了在浙江地区中西部地区也的确存在有燕山早期晚阶段(晚侏罗世)的岩浆侵入事件。

在对于中国东部构造体制由古特提斯构造域向古太平洋构造域转换的时间和方式的问题研究上,前人学者也是众说纷纭,争论不休,先后提出过多种不同的观点。但不可否认的是,在上述两大构造域的转换过程中,由古特提斯构造域产生的南北方向挤压应力在逐渐减弱,而古太平洋构造域产生的北西−南东向的作用则逐渐增强,结果就造成了大规模的构造−岩浆活动向东北方向发生了斜向迁移[40]。受此影响,在中国东南部形成了由南岭构造带向东北方向,岩体形成时代逐渐趋于年轻的一系列中侏罗世A型花岗岩带,同时,地幔物质的加入也开始增强[41−42]。至此,北东向的古太平洋的构造体制开始逐渐占据主导地位,所形成的晚侏罗世花岗岩体就应该可以代表两大构造域转换晚期的时间。

5.2 岩石成因类型及物质来源

花岗岩研究中一个重要的基础问题是对花岗岩成因类型的判定,自20世纪70年代以来,以花岗岩物质来源为基础的分类方案受到广大岩石学家们的普遍推崇。前人研究将花岗岩根据物质来源不同划分为I型、S型、M型和A型等类型[43],但值得一提的是,在自然界中真正由地幔岩浆衍生的M型花岗岩可能分布极少,绝大多数花岗岩都为S型、I型和A型,其中尤其是以S型和I型为主[44]。因此,对这三种类型花岗岩的判定就备受岩石学家们的关注,不同学者先后从不同角度提出过多种判别标准[31,43]。现阶段对花岗岩类型的判定,特别是对A型花岗岩的识别也已逐步脱离了岩相学,而越来越侧重于地球化学指纹[45]。其地球化学特征为富SiO_2,高Ga、Zr、Nb和Y,贫Al_2O_3、Sr、Ba、Ti和P等特征,且REE分布具有明显的负铕异常。

分析本文样品的地球化学特征,后山店花岗斑岩虽然也具有高Si,低Al,贫Sr、Ti 、P等主、微量元素特征,但不具有高Ga、Zr、Nb和Y的特征,在REE分布上也不显示较强的负铕异常,其$10^4Ga/Al$值介

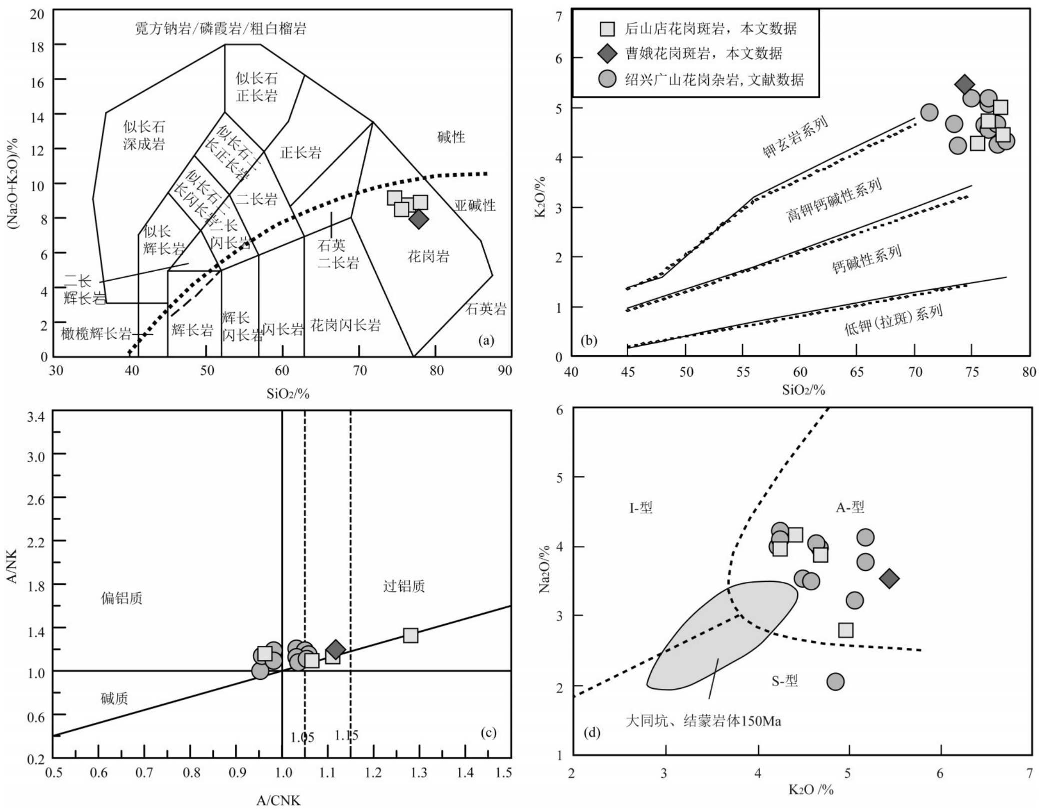

图4 浙中后山店及曹娥晚侏罗世花岗斑岩主量元素成分图(文献数据引自文献❶,[16−17])

a—硅−碱图(底图据文献[27]);b—硅−钾图(底图据文献[28]);c—A/CNK−A/NK图(底图据文献[29]);

d—K_2O-Na_2O图(底图据文献[30])

Fig. 4 Plots of major element compositions on total alkalis versus silica (a, after reference [27]), potassium versus silica (b, after reference [28]), A/NK versus A/CNK (c, after reference [29]) and Na_2O-K_2O(d, after reference [30]) diagrams for Late Jurassic granite porphyries from Houshandian and Caoe area of central Zhejiang Province (data after reference❶, [16−17])

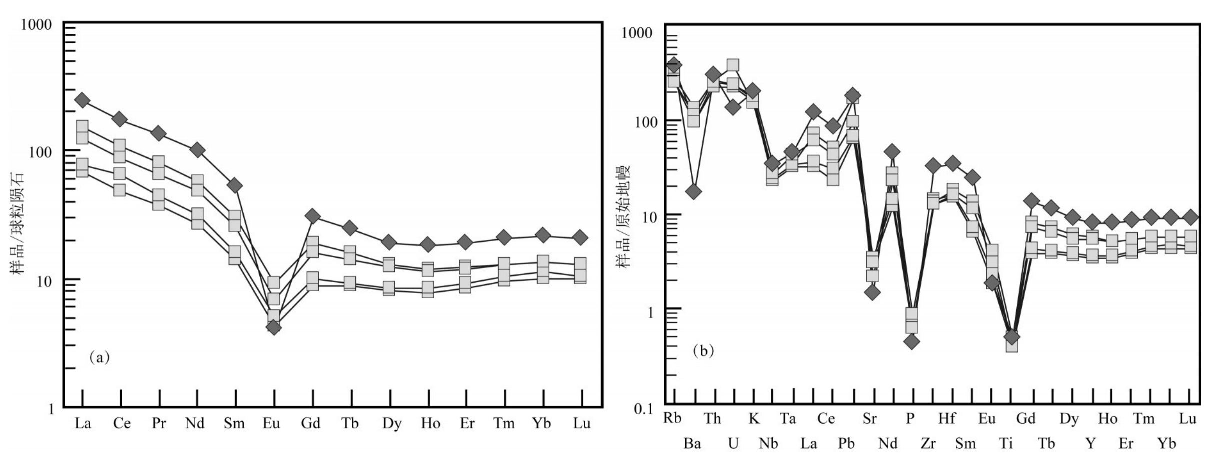

图5 后山店及曹娥岩体花岗斑岩稀土元素(a,球粒陨石标准化值据文献[32])和微量元素(b,原始地幔标准化值据文献[33])成分图(图例同图4)

Fig. 5 Chondrite−normalized REE patterns (a, chondrite−normalized data after reference [32]) and primitive mantle−normalized trace−element spidergrams (b, primitive mantle−normalized data after reference [33]) of Houshandian and Caoe granite porphyry plutons

❶浙江省地质职工大学. 1∶5 万漓渚幅区域地质调查报告. 1981.

表3 后山店及曹娥花岗斑岩体样品的锆石Hf同位素分析结果

Table 3 Zircon Hf isotope compositions of Houshandian and Caoe granitic porphyries

点号	年龄/Ma	$^{176}Yb/^{177}Hf$	$^{176}Lu/^{177}Hf$	$^{176}Hf/^{177}Hf$	2σ	$^{176}Hf/^{177}Hf_i$	$\varepsilon_{Hf}(0)$	$\varepsilon_{Hf}(t)$	T_{DM}/Ma	T_{DM}^{C}/Ma	$f_{Lu/Hf}$
DY11－2，花岗斑岩，年龄加权平均值：(149.1±1.1) Ma											
1	145	0.146081	0.002438	0.282512	0.000023	0.282505	−9.2	−6.7	1090	1596	−0.93
2	146	0.134111	0.002472	0.282480	0.000020	0.282473	−10.3	−7.8	1138	1667	−0.93
3	148	0.137406	0.002563	0.282502	0.000019	0.282495	−9.6	−7.0	1108	1618	−0.92
4	152	0.212718	0.003916	0.282538	0.000021	0.282527	−8.3	−5.8	1096	1543	−0.88
5	156	0.137043	0.002506	0.282610	0.000018	0.282603	−5.7	−3.0	947	1371	−0.92
6	152	0.204965	0.003750	0.282529	0.000020	0.282519	−8.6	−6.1	1104	1562	−0.89
7	150	0.151514	0.002882	0.282518	0.000020	0.282510	−9.0	−6.4	1094	1583	−0.91
8	149	0.204811	0.003606	0.282535	0.000018	0.282525	−8.4	−5.9	1091	1549	−0.89
9	147	0.147353	0.002735	0.282482	0.000020	0.282474	−10.3	−7.7	1142	1663	−0.92
10	148	0.186497	0.003474	0.282493	0.000022	0.282483	−9.9	−7.4	1150	1644	−0.90
11	148	0.247446	0.004328	0.282543	0.000023	0.282531	−8.1	−5.7	1101	1536	−0.87
12	149	0.200466	0.003727	0.282520	0.000020	0.282509	−8.9	−6.4	1118	1584	−0.89
13	153	0.212282	0.003945	0.282584	0.000019	0.282573	−6.6	−4.1	1026	1440	−0.88
14	151	0.169370	0.003193	0.282520	0.000023	0.282511	−8.9	−6.3	1100	1579	−0.90
15	153	0.179532	0.003369	0.282468	0.000020	0.282458	−10.8	−8.2	1184	1696	−0.90
DY11－143，花岗斑岩，年龄加权平均值为(150.3±1.6) Ma											
1	158	0.117476	0.002112	0.282527	0.000030	0.282520	−8.7	−5.9	1058	1555	−0.94
2	155	0.055183	0.001035	0.282421	0.000024	0.282418	−12.4	−9.5	1176	1783	−0.97
3	157	0.218695	0.004035	0.282565	0.000029	0.282553	−7.3	−4.7	1058	1482	−0.88
4	147	0.120854	0.002186	0.282455	0.000026	0.282449	−11.2	−8.6	1164	1719	−0.93
5	149	0.143182	0.002650	0.282545	0.000029	0.282537	−8.0	−5.5	1048	1522	−0.92
6	149	0.265677	0.004892	0.282621	0.000030	0.282607	−5.4	−3.0	998	1366	−0.85
7	149	0.221098	0.003848	0.282476	0.000027	0.282465	−10.5	−8.0	1188	1682	−0.88
8	148	0.264950	0.004520	0.282511	0.000027	0.282498	−9.2	−6.9	1157	1609	−0.86
9	148	0.138418	0.002505	0.282510	0.000025	0.282503	−9.3	−6.7	1095	1600	−0.92
10	149	0.103941	0.001885	0.282465	0.000025	0.282460	−10.9	−8.2	1140	1694	−0.94
11	152	0.141714	0.002565	0.282586	0.000025	0.282579	−6.6	−3.9	984	1427	−0.92
12	150	0.122044	0.002455	0.282608	0.000026	0.282601	−5.8	−3.2	950	1379	−0.93
13	157	0.081767	0.001494	0.282520	0.000021	0.282516	−8.9	−6.0	1050	1565	−0.95
14	154	0.065898	0.001170	0.282535	0.000022	0.282531	−8.4	−5.6	1021	1532	−0.96
15	151	0.220404	0.004015	0.282619	0.000031	0.282608	−5.4	−2.9	975	1364	−0.88

于2.20~2.53，平均值为2.35，均小于A型花岗岩的最小值(2.60)[31]，故不应为A型花岗岩，而更可能是I型或S型花岗岩；曹娥花岗斑岩样品表现出富SiO_2，高Ga、Zr、Nb和Y，贫Al_2O_3的特征，其10^4Ga/Al值为3.15，大于A型花岗岩的下限值(2.60)[31]，且在稀土元素球粒陨石标准化配分曲线图上表现出较强负铕异常的“海鸥型”展布，在微量元素蛛网图上也显示出Sr、Ba、Ti和P值的明显低谷，这些均为A型花岗岩的特征标志[45]，而岩石中锆石Th的含量较高也可作为判定A型花岗岩的标志之一[46]，故曹娥岩体应为A型花岗岩。在以10^4Ga/Al比值为基础的花岗岩类型判别图解上(图6−a、b、c)，后山店花岗岩斑岩样品均落入I型和S型花岗岩区域，而曹娥花岗斑岩则落入A型花岗岩区域。在花岗岩ACF图解(图6−d)上，后山店花岗斑岩样品多落入S型花岗岩区域，其岩石类型应为S型花岗岩。

在火成岩的物质来源判定方面，Hf同位素的示踪研究已经被广泛应用于一些重要地球化学储库(如亏损地幔、球粒陨石和地壳等)源区的判别[47]。本文对后山店及曹娥岩体Hf同位素的研究表明，后山店及曹娥花岗斑岩单颗粒锆石Hf同位素组成均比较均一，且具有相似的$\varepsilon_{Hf}(t)$值及二阶段模式年龄。地壳模式年龄t^{C}_{DM}和εHf(t)直方图(图7)显示，$\varepsilon_{Hf}(t)$主要集中在−9.5~−2.9，均为负值t^{C}_{DM}主要集中于1364~1783 Ma。岩体二阶段模式年龄范围主要在1.3~ 1.7 Ga，说明岩体的源区物质主要来自于中

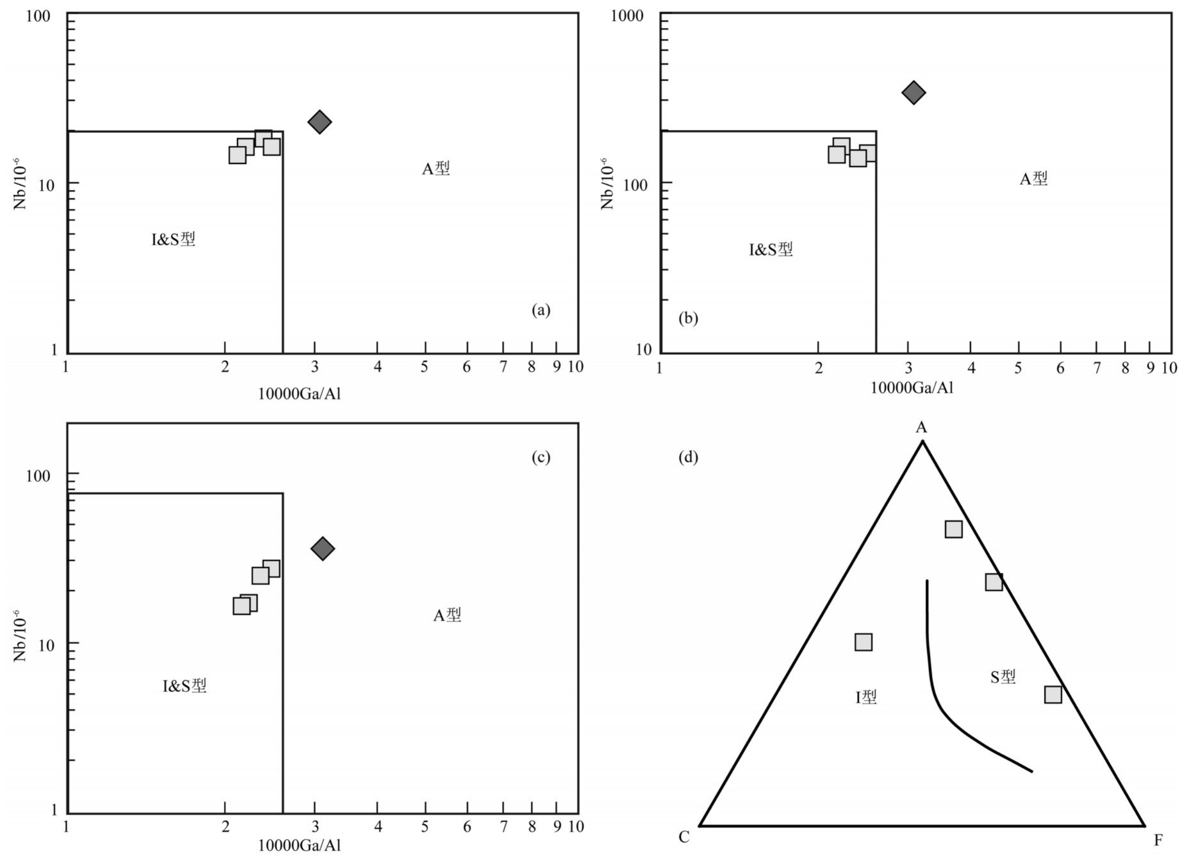

图6 后山店和曹娥花岗斑岩花岗岩类型判别图解(a，b，c底图据文献[31])(图例同图4)

Fig. 6 Granite types of discrimination diagrams of Houshandian and Caoe granite porphyries (a, b, c after reference [31])

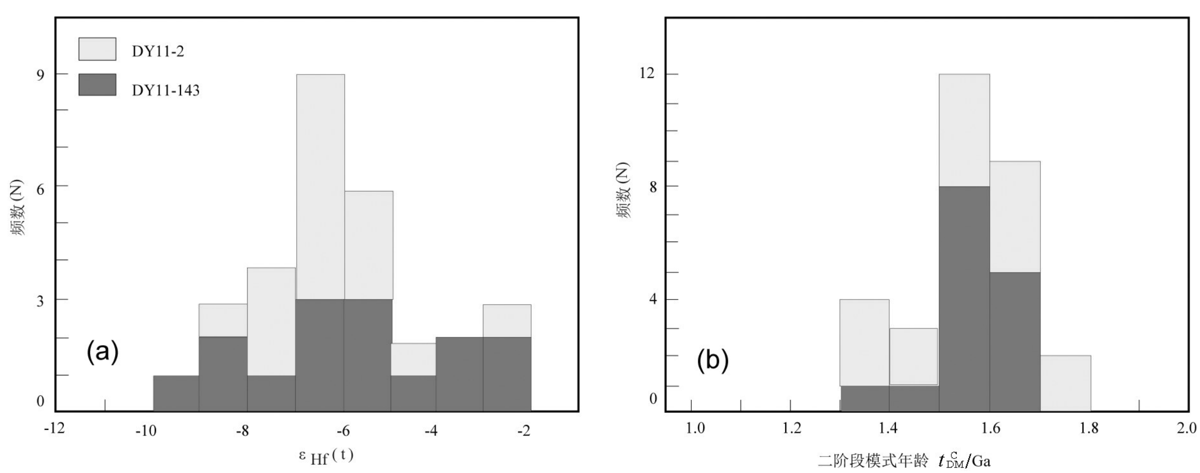

图7 后山店和曹娥花岗斑岩锆石$\varepsilon_{Hf}(t)$值(a)和Hf同位素地壳模式年龄t^{C}_{DM} (b)直方图

Fig. 7 Zircon $\varepsilon_{Hf}(t)$ histogram of $\varepsilon_{Hf}(t)$ values (a) and Hf isotope model ages (b) of Houshandian and Caoe granitic porphyries

元古代地壳。两个岩体$\varepsilon_{Hf}(t)$值均为负值，总体呈现相对亏损的特征，并在$t-\varepsilon_{Hf}(t)$图解(图8)上，样品投影点均分布于亏损地幔与下地壳之间区域，且较靠近于下地壳，也说明岩体的物质均来源于中元古代下地壳的结晶基底。

5.3 成岩构造背景判别

研究认为，花岗岩的微量元素组成明显受其成岩构造环境的制约，因此，利用某些微量元素的组

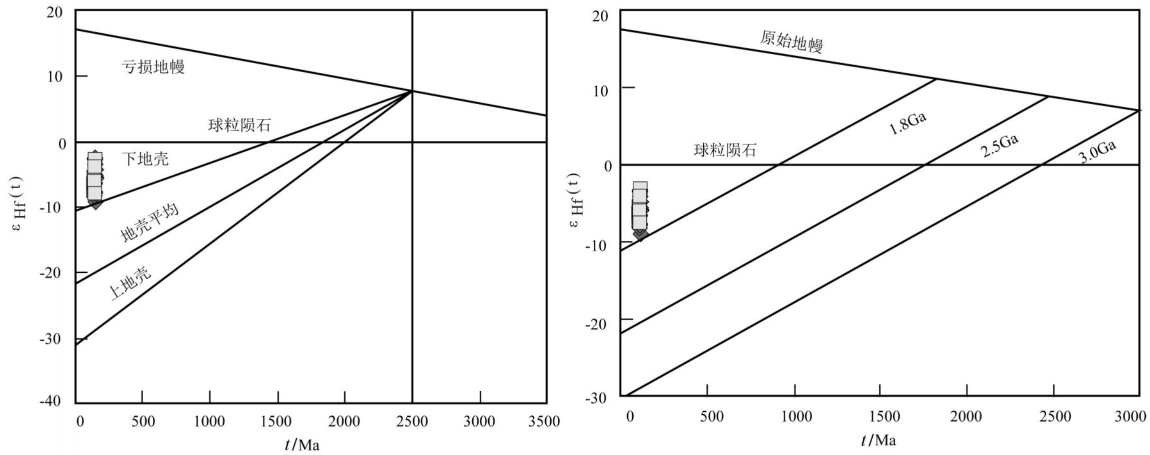

图8 后山店和曹娥花岗斑岩Hf同位素演化图解(图例同图4)

Fig. 8 Hf isotope diagrams of Houshandian and Caoe granitic porphyries

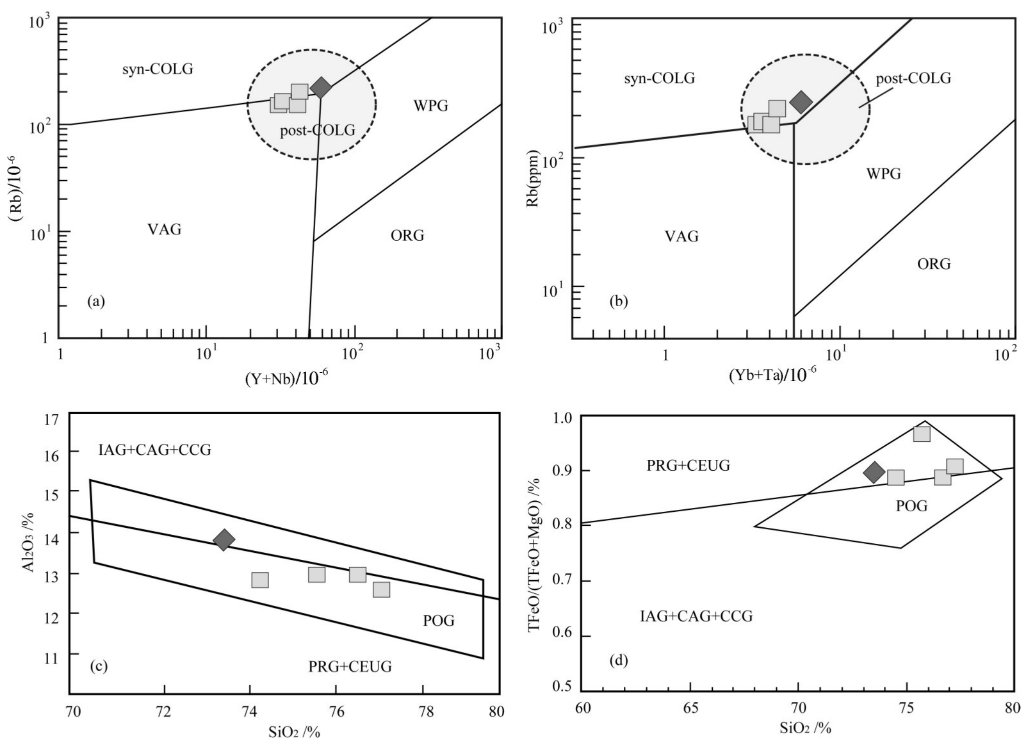

图9后山店及曹娥花岗斑岩体构造环境判别图解 (a、b底图据文献[48];c、d底图据文献[29])(图例同图4)

Syn-COLG—同碰撞花岗岩;WPG—板内花岗岩;Post-GOLG—后碰撞花岗岩;VAG—火山弧花岗岩;ORG—洋脊花岗岩;IAG-岛弧花岗岩类;CAG-大陆弧花岗岩类;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-与大陆的造陆抬升有关的花岗岩类

Fig. 9 Discrimination diagrams of tectonic setting for Houshandian and Caoe granitic porphyries (a, b after reference [48] and c, d after reference [29])

Syn-COLG-syn-collision granite; WPG-Intraplate granite; Post-GOLG-Post-collision granite; VAG-Volcanic-arc granite; ORG-Ocean-ridge granite; IAG-Island-arc granites; CAG-Continent-arc granite; CCG-Continent-collision granite; POG-Post-orogenic granite; RRG-Granite related to rift; CEUG-Continent emergence-uplift granite

成特征来反映花岗岩体的形成环境是可行的。在经典微量元素Rb−(Y+Nb)、Rb−(Yb+Ta)构造环境判别图解[48]中(图9−a、b),后山店及曹娥花岗斑岩体所有样品均投影于同碰撞花岗岩、火山弧花岗岩及板内花岗岩相交的后碰撞花岗岩区域,表明岩体形成于后碰撞构造环境,这种构造环境有利于幔源岩浆的底侵,形成A型花岗岩[49],本文中曹娥A型花岗斑岩体及邻区广山A型花岗杂岩体[17]均印证了这一结论。在$SiO_2-Al_2O_3$、SiO_2−TFeO/(TFeO+MgO)花岗岩构造环境判别图解[29]中(图9−c、d),浙中地区晚侏罗世花岗斑岩样品的投影点也均落入后造山环境区域。

对于华南地区燕山早期花岗岩大地构造背景的研究,一直以来也都是国内外地质学家所关注的热点,前人学者对其提出过诸多不同的观点,也存在着较大的分歧:如受古太平洋板块俯冲作用所控制的大陆边缘环境;岩石圈减薄拆沉、后造山、弧后伸展环境;板内伸展、裂谷环境以及陆内俯冲、地幔柱等观点[40,50−54]。前人研究认为,华南地区在印支期晚期已经具有后造山伸展构造环境的特征[55],但华南与华北两大陆块在该时期发生拼合后,构造−岩浆活动及造山运动却始终没有停止过[4]。结合本文所研究的晚侏罗世花岗斑岩特征,其在经典花岗岩环境判别图解上,样品均落入后造山环境区域,印证了至少在早—中侏罗世时期,花岗质岩浆活动就已经进入到后造山阶段[40]。到中侏罗世时期,古太平洋板块开始向华南大陆发生北西向的俯冲作用[56],这种俯冲作用导致的挤压应力通过华南的刚性板块快速传到内陆地区,诱发了元古宙形成的深断裂(如江绍断裂带、政和—大埔断裂带)的复活,进而导致华南板块内部发生局部的板内伸展运动,软地壳物质发生减压熔融,形成花岗质岩浆。

6　结　论

(1)后山店及曹娥岩体花岗斑岩LA−ICP−MS锆石U−Pb年龄分别为(149.1±1.1) Ma和(150.3±1.6) Ma,在误差范围内近于一致,显示其为同一期岩浆活动的产物,为燕山早期晚阶段形成。

(2)样品地球化学特征显示后山店岩体岩石类型为S型花岗岩,但具有A型花岗岩的特征,这可能与后期发生较强的岩浆分异作用有关;而曹娥岩体为A型花岗岩。两个岩体的Nb、Sr、P和Ti强烈亏损,暗示其可能来自壳源或有来自与俯冲有关的物质,是地壳物质在板内造山后伸展的构造环境下发生部分熔融的产物。较低的$\varepsilon_{Hf}(t)$值及老的二阶段模式年龄也指示了其物质来源可能为中元古界上地壳结晶基底发生部分熔融而成。

(3)后山店及曹娥岩体均为后碰撞构造环境下的岩浆产物,属于后造山花岗岩,可能是在中—晚侏罗世时期,由于受到古太平洋板块向华南板块俯冲的影响,产生的东西向挤压应力诱发早期存在的深断裂(如江绍断裂带、政和—大埔断裂带等)发生复活,进而导致板块内部发生局部的板内伸展作用,软地壳物质发生减压熔融,形成花岗质岩浆。浙中晚侏罗世A型花岗岩的存在也证实了在燕山早期晚阶段,华南板块东北缘构造环境已为伸展环境,其成岩时间即代表了古特提斯构造域向古太平洋构造域转换的晚阶段。

致谢:中国地质科学院矿产资源研究所国土资源部成矿作用与资源评价重点实验室侯可军博士、郭春丽博士在锆石U−Pb测年及Lu−Hf同位素的测定中给予了大力帮助,在此表示诚挚的感谢;衷心感谢匿名审稿人和责任编辑李亚萍老师给予的中肯而细致的审稿意见。

参考文献(References):

[1] 陈培荣, 孔兴功, 倪琦生, 等. 赣南燕山早期双峰式火山岩的厘定及意义[J]. 地质论评, 1999, 45(7): 734−741.
Chen Peirong, Kong Xinggong, Ni Qisheng, et al. Ascertainment and implication of the Early Yanshanian bimodal volcanic associations from south Jiangxi Province[J]. Geological Review, 1999, 45(7): 734−741(in Chinese with English abstract).

[2] 董树文, 张岳桥, 陈宣华, 等. 晚侏罗世东亚多向汇聚构造体系的形成与变形特征[J]. 地球学报, 2008, 29(3): 306−317.
Dong Shuwen, Zhang Yueqiao, Chen Xuanhua, et al. The formation and deformational characteristics of East Asia multi−direction convergent tectonic system in Late Jurassic[J]. Acta Geoscientica Sinica, 2008, 29(3): 306− 317(in Chinese with English abstract).

[3] 徐夕生.华南花岗岩−火山岩成因研究的几个问题[J].高校地质学报, 2008, 14(3): 283−294.
Xu Xisheng. Several problems worthy to be noticed in the research of granites and volcanic rocks in SE China[J].Geological Journal of China Universities, 2008, 14(3): 283− 294(in Chinese with English abstract).

[4] 毛建仁, 叶海敏, 厉子龙, 等. 中国东南部及邻区中新生代岩浆作用与成矿[M]. 北京: 科学出版社, 2013: 1−478.
Mao Jianren, Ye Haimin, Li Zilong, et al. Mesozoic to Cenozoic Magmatism and Mineralization in the Southeastern China and Adjacent Areas[M]. Beijing: Science Press, 2013: 1− 478(in Chinese).
[5] 顾知微.浙江侏罗系和白垩系研究 [C]// 中国科学院南京地质古生物研究专著.浙皖中生代火山沉积岩地层的划分及对比.北京:地质出版社, 1980: 2−68.
Gu Zhiwei. Jurassic and Cretaceous Research in Zhejiang [C]// Geology and Palaeontology, Chinese Academy of Sciences, Nanjing Research Monographs. Zhejiang and Anhui Mesozoic Volcano− Sedimentary Strata Division and Contrast. Beijing: Geological Publishing House, 1980: 2−68 (in Chinese).
[6]浙江省地质矿产局.浙江省区域地质志[M].北京: 地质出版社, 1989: 138−164.
Bureau of Geology and Mineral Resources of Zhejiang Province. Regional Geology of Zhejiang Province [M]. Beijing: Geological Publishing House, 1989: 138 − 164 (in Chinese with English abstract).
[7] 俞国华, 方柄兴, 马武平, 等.浙江省岩石地层[M].武汉: 中国地质大学出版社, 1996: 136−143.
Yu Guohua, Fang Bingxing, Ma Wuping, et al. Stratigraphy (Lithostratic) of Zhejiang Province [M] . Wuhan: China University of Geosciences Press, 1996: 136−143 (in Chinese).
[8] 俞云文, 徐步台.浙江中生代晚期火山−沉积岩系层序与时代[J].地层学杂志, 1999, 4: 136−145.
Yu Yunwen, Xu Butai. Strati graphical sequence and geochronology of the Upper Mesozoic volcano−sedimentary rock series in Zhejiang[J]. Journal of Stratigraphy, 1999, 4: 136−145 (in Chinese with English abstract).
[9] 陶奎元, 邢光福, 杨祝良, 等.浙江中生代火山岩时代厘定和问题讨论[J].地质评论, 2000, 1: 14−21.
Tao Kuiyuan, Xing Guangfu, Yang Zhuliang, et al. Determination of and discussion on the ages of Mesozoic volcanic rocks in Zhejiang[J]. Geological Review, 2000, 1: 14−21 (in Chinese with English abstract).
[10] 汪庆华.试论浙江建德群和磨石山群时代[J].火山地质与矿产, 2001, 22(3): 163−169.
Wang Qinghua. Discussion of ages of the Jiande Group and the Moshishan Group in Zhejiang[J]. Volcanology & Mineral Resources, 2001, 22(3): 163−169 (in Chinese).
[11] 邢光福. 中国东南部中生代火山岩地层调查研究新进展[C]//南京地质矿产研究所编.华东地区地质调查成果论文集.北京: 中国大地出版社, 2006: 11−17.
Xing Guangfu. Mesozoic volcanic rocks in southeastern China Research Progress [C]// Nanjing Research Institute of Geology and Mineral Resourcs. The Outcome of Proceedings in East China Geological Survey. Beijing: China Land Press, 2006: 11−17 (in Chinese).
[12] 陈丕基.中国陆相侏罗—白垩系划分对比述评[J].地层学杂志, 2000, 24(2): 114−119.
Chen Piji. Chinese terrestrial Jurassic − Cretaceous division and correlation commentary[J]. Journal of Stratigraphy, 2000, 24(2): 114−119 (in Chinese with English abstract).
[13] 汪建国, 汪隆武, 陈小友, 等.浙西开岭脚和里陈家花岗闪长岩锆石 SHRIMP U−Pb 年龄及其地质意义[J]. 中国地质, 2010, 37 (6): 1559−1565.
Wang Jianguo, Wang Longwu, Chen Xiaoyou, et al. SHRIMP U− Pb ages of zircons from Kailingjiao and Lichenjia granodiorites in western Zhejiang and their geological implications[J]. Geology in China, 2010, 37(6): 1559−1565 (in Chinese with English abstract).
[14] 顾明光, 冯立新, 胡艳华, 等.浙江绍兴地区广山—栅溪岩体LA−ICP−MS锆石U−Pb定年: 对漓渚铁矿成矿时代的限定[J].地质通报, 2011, 30(8): 1212−1219.
Gu Mingguang, Feng Lixin, Hu Yanhua, et al. LA−ICP−MS U−Pb dating of zircons from Guangshan and Zhaxi plutons in Shaoxing area, Zhejiang Province: constraint on the ore−forming epoch of the Lizhu iron deposit[J]. Geological Bulletin of China, 2011, 30(8): 1212− 1219 (in Chinese with English abstract).
[15] Li P J, Yu X Q, Li H Y, et al. Jurassic− Cretaceous tectonic evolution of southeast China: geochronological and geochemical constraints of Yanshanian granitoids[J]. International Geology Review, 2013, 55(10): 1202−1219.
[16] 张建芳, 解怀生, 许兴苗, 等.浙江漓渚地区栅溪—广山岩体地质地球化学特征, 构造及找矿意义[J].中国地质, 2013, 40(2): 403−413.
Zhang Jianfang, Xie Huaisheng, Xu Xingmiao, et al. Geological and geochemical characteristics and tectonic and prospecting significance of the Shanxi− Guangshan intrusions in Lizhu area, Zhejiang Province[J]. Geology in China, 2013, 40(2): 403−413 (in Chinese with English abstract).
[17]贾德龙, 严光生, 叶天竺, 等.浙江绍兴地区广山花岗杂岩体的锆石 U−Pb 年代学, 锆石 Hf 同位素, 岩石地球化学特征及其地质意义[J].岩石学报, 2013, 29(12): 4087−4103.
Jia Delong, Yan Guangsheng, Ye Tianzhu, et al. Zircon U−Pb dating, Hf isotopic compositions and petrochemistry of the Guangshan granitic complex in Shaoxing area of Zhejiang Province and its geological significance[J]. Acta Petrologica Sinica, 2013, 29(12): 4087− 4103 (in Chinese with English abstract).
[18] 宋彪, 张玉梅, 万渝生, 等.锆石SHRIMP样品靶制作、年龄测定及有关现象讨论[J].地质论评, 2002, (48): 26−30.
Song Biao, Zhang Yuhai, Wan Yusheng, et al. Mount making and procedure of the SHRIMP dating[J]. Geological Review, 2002, (48): 26−30 (in Chinese with English abstract).

[19] Liu X M, Gao S, Di wu C R, et al. Simultaneous in-situ determination of U-Pb age and trace elements in zircon by LA-ICP-MS in 20 μm spot size[J]. Chinese Science Bulletin, 2007, 52(9): 1257-1264.

[20] Liu Y S, Hu Z C, Gao S, et al. In situ analysis of major and trace elements of anhydrous minerals by LA-ICP-MS without applying an internal standard[J]. Chemical Geology, 2008, 257: 34-43.

[21] Liu Y S, Hu Z C, Zong K Q, et al. Reappraisement and refinement of zircon U-Pb isotope and trace element analyses by LA-ICP-MS[J]. Chinese Science Bulletin, 2010, 55(15): 1535-1546.

[22] 侯可军, 李延河, 田有荣.LA-MC-ICP-MS锆石微区原位U-Pb定年技术[J].矿床地质, 2009, 28(4): 481-492.
Hou Kejun, Li Yanhe, Tian Yourong. In situ U-Pb zircon dating using laser ablation-multi ion counting-ICP-MS[J]. Mineral Deposits, 2009, 28(4): 481-492(in Chinese with English abstract).

[23] Ludwig K R. ISOPLOT 3.00: A Geochronological Toolkit for Microsoft Excel[M]. Berkeley: Berkeley Geochronology Center, California. 2003.

[24] 侯可军, 李延河, 邹天人, 等.LA-MC-ICP-MS 锆石 Hf 同位素的分析方法及地质应用[J].岩石学报, 2007, 23(10): 2595-2604.
Hou Kejun, Li Yanhe, Zou Tianren, et al. Laser ablation-MC-ICP-MS technique for Hf isotope microanalysis of zircon and its geological applications[J]. Acta Petrologica Sinica, 2007, 23 (10): 2595-2604 (in Chinese with English abstract).

[25]Hoskin PWO, Schaltegger U. The composition of zircon and igneous and metamorphic petrogenesis[J]. Reviews in mineralogy and geochemistry, 2003, 53(1): 27-62.

[26] Barbarin B. A review of the relationships between granitoid types, their origins and their geodynamic environments[J]. Lithos, 1999, 46: 605-626.

[27] Middlemost EAK. Naming materials in the magma/igneous rock system[J].Earth Sci.Rev., 1994, 37: 215-224.

[28] Rickwood P C. Boundary lines within petrologic diagrams which use oxides of major and minor elements[J]. Lithos, 1989, 22: 47-263.

[29] Maniar P D, Piccoli P M. Tectonic discrimination of granitoids[J]. Geological Society of America Bulletin, 1989, 101: 635-643

[30] Collins WJ, Beams SD, White AJ, et al. Nature and origin of A-type granite with particular reference to southeastern Australia[J]. Contributions to Mineralogy and Petrology, 1982, 80: 189-200.

[31] Whalen J B, Currie K L and Chappell B W. A-type granites: geochemical characteristics, discrimination and petrogenesis[J]. Contributions to Mineralogy and Petrology, 1987, 95(4): 407-419.

[32] Boynton W V. Geochemistry of the rare earth elements: meteorite studies[M]. Rare Earth Element Geochemistry, 1984: 63-114.

[33] Sun SS and McDonough WF. Chemical and isotope systematics of oceanic basalts: implications for mantle composition and processes[C]//Saunders A D(ed.). Magmatism in Ocean Basins. Special Publication, Geological Society of London, 1989, 42: 313-345.

[34] Amelin Y, Lee D C, Halliday A N. Early-Middle Archaean crustal evolution deduced from Lu-Hf and U-Pb isotopic studies of single zircon grains[J]. Geochimica et Cosmochimica Acta, 2000, 64(24): 4205-4225.

[35] Vervoort J D, Pachelt P J, Gehrels GE, et al. Constraints on early Earth differentiation from hafnium and neodymium isotopes[J]. Nature, 1996, 379(6566): 624-627.

[36] Zhou X M and Li W X. Origin of Late Mesozoic igneous rocks in southeast China: implications for lithosphere subduction and underplating of mafic magmas[J]. Tectonophysics, 2000, 326 (3/4): 269-287.

[37] Sun T, Zhou X M, Chen P R, et al. The genesis and significance of Mesozoic strong aluminum granites in eastern Nanling[J]. Science in China(Siries D), 2005, 48(2): 165-174.

[38] Collins W J and Richards S W. Geodynamic significance of Stype granites in circum-Pacific orogens[J]. Geology, 2007, 36(7): 559-562.

[39] 徐先兵, 张岳桥, 贾东, 等.锆石 LA-ICP-MS U-Pb 与白云母 $^{40}Ar/^{39}Ar$ 年代学及其对中国东南部早燕山事件的制约[J].地质科技情报, 2010, 29(2): 87-94.
Xu Xianbing, Zhang Yueqiao, Jia Dong, et al. Geochronology of Zircon LA-ICP-MS U-Pb and Muscovite $^{40}Ar/^{39}Ar$: Constrains to Early Yanshanian Event in Southeast China[J].Geological Science and Technology Information, 2010, 29(2): 87-94 (in Chinese with English abstract).

[40] Chen Peirong, Hua Renmin, Zhang Bangtong, et al . Early Yanshanian post-orogenic granitoids in the Nanling region: Petrological constraints on and geodynamic settings[J] . Science in China(Series D) , 2002, 45(8) : 756-768.

[41] 蒋少涌, 赵葵东, 姜耀辉, 等.十杭带湘南—桂北段中生代 A 型花岗岩带成岩成矿特征及成因讨论[J]. 高校地质学报, 2008, 4 (4): 496-509.
Jiang Shaoyong, Zhao Kuidong, Jiang Yaohui, et al. Characteristics and genesis of Mesozoic A-type granites and associated mineral deposits in the southern Hunan and northern Guangxi Provinces along the Shi-Hang belt, South China[J]. Geological Journal of China Universities, 1999, 5(2): 164-169 (in Chinese with English abstract).

[42] Zhao K D, Jiang S Y, Yang S Y, et al. Mineral chemistry, trace elements and Sr-Nd-Hf isotope geochemistry and petrogenesis of Cailing and Furong granites and mafic enclaves from the Qitianling batholith in the Shi-Hang zone, South China[J]. Gondwana Research, 2012, 22(1): 310-324.

[43] Chappell B W and White AJR. Two contrasting granite types[J]. Pacific Geology, 1974, 8: 173−174.

[44] 邱检生, 肖娥, 胡建, 等.福建北东沿海高分异I型花岗岩的成因: 锆石U−Pb年代学、地球化学和Nd−Hf同位素制约[J].岩石学报, 2008, 24: 2468−2484.

Qiu Jiansheng, Xiao E, Hu Jian, et al. Petrogenesis of highly fractionated I− type granites in the coastal area of northeastern Fujian Province: Constraints from zircon U− Pb geochronology, geochemistry and Nd− Hf isotopes[J]. Acta Petrologica Sinica, 2008, 24: 2468−2484 (in Chinese with English abstract).

[45] 吴锁平, 王梅英, 戚开静. A型花岗岩研究现状及其述评[J].岩石矿物学杂志, 2007, 26(1): 57−66.

Wu Suoping, Wang Meiying, Qi Kaijing. Present situation of researches on A−type granites: a review[J]. Acta Petrologica ET Mineralogica, 2007, 26(1): 57− 66 (in Chinese with English abstract).

[46] Xie L, Wang R, Chen X, et al. Th−rich zircon from peralka line A− type granite: Mineralogical features and petrological implications[J]. Chinese Science Bulletin, 2005, 50(8): 809−817.

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

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

[48] Pearce J A. Source and settings of granitic rocks[J]. Episodes, 1996, 19: 120−125.

[49]肖庆辉, 王涛, 邓晋福, 等. 中国典型造山带花岗岩与大陆地壳生长研究[M].北京: 地质出版社, 2009: 1−107.

Xiao Qinghui, Wang Tao, Deng Jinfu, et al. Granitoids and Continent Growth of Key Orogen in China[M]. Beijing: Geological Publishing House, 2009: 1−107(in Chinese).

[50] 邓晋福, 赵海玲, 莫宣学, 等.中国大陆根−柱构造——大陆动力学的钥匙[M].北京: 地质出版社, 1996: 1−110.

Deng Jinfu, Zhao Hailing, Mo Xuanxue, et al. Continental Roots− plume Tectonics of China——Key to the Continental Dynamics[M]. Beijing: Geological Publishing House, 1996: 1−110 (in Chinese).

[51] 毛景文, 李红艳, 王登红, 等.华南地区中生代多金属矿床形成与地幔柱关系[J].矿物岩石地球化学通报, 1998, 17(2): 63−65.

Mao Jingwen, Li Yanhong, Wang Denghong, et al. Ore − Forming of Mesozoic polymetallic deposits in South China and its relationship with mantle plume[J]. Bulletin of Mineralogy, Petrology and Geochemistry, 1998, 17(2): 63− 65 (in Chinese with English abstract).

[52] 李武显, 周新民.中国东南部晚中生代俯冲带探索[J].高校地质学报, 1999, 5(2): 164−169.

Li Wuxian, Zhou Xinmin. Late Mesozoic seduction zone of southeastern China[J]. Geological Journal of China Universities, 1999, 5(2): 164−169 (in Chinese with English abstract).

[53] 张旗, 钱青, 王二七, 等.燕山中晚期的"中国东部高原": 埃达克岩的启示[J] .地质科学, 2001, 36(2): 248−255.

Zhang Qi, Qian Qing, Wang Erqi, et al. An east China plateau in mid− late Yanshanian period: implication from adakites[J]. Chinese Journal of Geology, 2001, 36(2): 248−255 (in Chinese with English abstract).

[54]陈志刚, 李献华, 李武显, 等.赣南全南正长岩SHRIMP锆石U−Pb年龄及其对华南燕山早期构造背景的制约[J].地球化学, 2003, 32(3): 223−229.

Chen Zhigang, Li Xianhua, Li Wuxian, et al. SHRIMP U− Pb zircon age of the Quannan syenite, southern Jiangxi: Constraints on the early Yanshanian tectonic setting of SE China[J]. Geichimica, 2003, 32(3): 223− 229 (in Chinese with English abstract).

[55] 徐岩, 胡艳华, 顾明光, 等.浙江东南印支晚期的构造伸展事件: 来自诸暨大爽岩体的证据[J].岩石学报, 2013, 29(9): 3131−3141.

Xu Yan, Hu Yanhua, Gu Mingguang, et al. The tectonic extensional event during the Late Indosinian Period in the southeastern Zhejiang Province: Evidence from the Dashuang pluton in Zhuji County[J]. Acta Petrologica Sinica, 2013, 29(9): 3131−3141 (in Chinese with English abstract).

[56]Maruyama S, Isozaki Y, Kimura G et al. Paleogeographic maps of the Japanese Islands: Plate tectonicsynthesis from 750 Ma to the present[J]. Island Arc, 1997, 6(1): 121−142.