河北秦皇岛石门寨中生代火山岩的地球化学特征和锆石 LA-ICP-MS U-Pb 年龄

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内容提要:中国东部中生代火山岩比较发育,在冀北—辽西、山东、北淮阳、太行山等地区均有分布。在冀北的秦皇岛石门寨地区存在着一套分布广泛的中生代蓝旗组与孙家梁组火山岩,不整合在侏罗系北票组砾岩之上。蓝旗组与孙家梁组之间为整合关系,蓝旗组主体为碱玄岩和玄武粗安岩,孙家梁组主体为英安岩和流纹岩,前人研究认为其时代为晚侏罗世。本研究对该地区火山岩样品进行了全岩地球化学分析和锆石 U-Pb 定年。蓝旗组火山岩样品总体上以富 K、Na 和 Al 为特征,部分样品有较高的 Mg 和 Fe 含量,在微量元素组成上,粗面岩和玄武粗安岩富集大离子亲石元素和轻稀土元素,亏损高场强元素和重稀土元素,碱玄岩轻微亏损高场强元素,轻重稀土元素分馏较为明显,玄武岩无明显高场强元素异常,轻稀土无明显富集,重稀土不亏损。孙家梁组火山岩样品均为流纹岩,也以富 K、Na 和 Al 为特征,Mg 和 Fe 含量较低,在微量元素组成上,富集轻稀土元素,亏损重稀土元素,具有强烈的 Eu 负异常。蓝旗组火山岩主要为钾玄岩系列,孙家梁组火山岩为高钾钙碱性系列,蓝旗组粗面岩和玄武粗安岩地球化学特征类似岛弧,可能与受上地壳俯冲脱水交代作用有关,碱玄岩地球化学特征类似 HIMU 型 OIB,源区可能为受俯冲洋壳交代所形成的富集型软流圈地幔,玄武岩地球化学特征类似 N-MORB,源区可能为亏损的软流圈地幔。孙家梁组流纹岩可能由早白垩世华北克拉通强烈的伸展作用导致幔源岩浆底侵下地壳,使其部分熔融或古太平洋板块俯冲后撤所导致俯冲洋壳岩石发生部分熔融产生。孙家梁组流纹岩中锆石的 LA-ICP-MS U-Pb 定年获得了 23 个颗粒的加权平均年龄 118.0±1.1 Ma,为早白垩世,可以与辽西地区义县组相对比。河北秦皇岛石门寨地区蓝旗组和孙家梁组火山岩的成因及形成时代对于探讨中生代华北克拉通减薄的机制与时限具有重要意义。

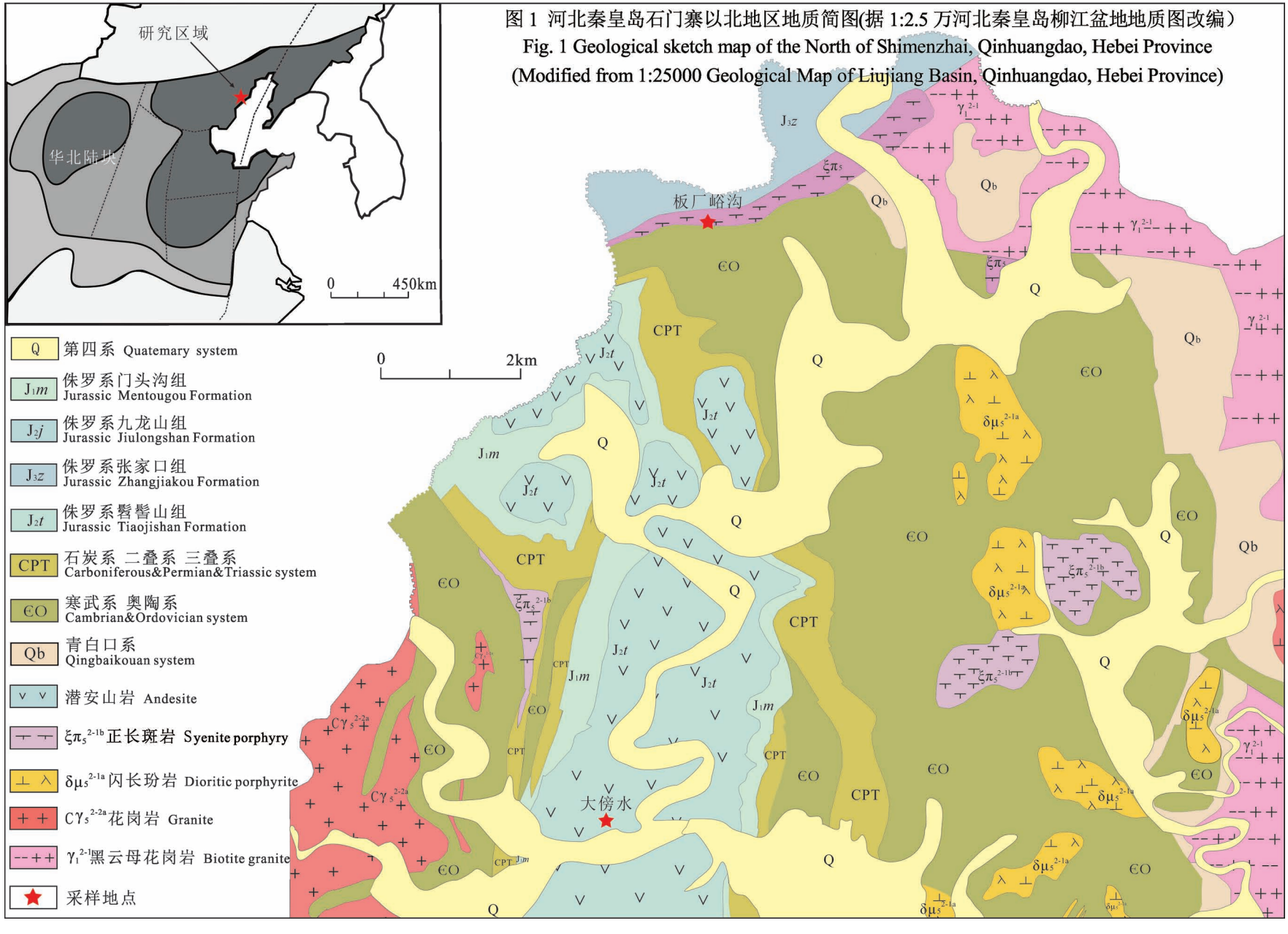
关键词:蓝旗组;孙家梁组;中生代火山岩;中国东部;锆石 U-Pb 年龄

中国东部中生代的岩浆活动十分活跃,规模巨大而且时代集中(吴利仁等,1982; 陈义贤和陈文寄,1997; Zhang Hongfu et al., 2003; Ma Qiang et al., 2015; Wu Fuyuan et al., 2005; Yang Wei and Li Shuguang, 2008; 吴福元等,2008;郑永飞等,2018),中生代岩浆活动广泛分布在北至冀北—辽西,东至山东,南至北淮阳,西至太行山的范围内(Zhang Hongfu, 2007),是中国东部显生宙以来最为人瞩目的岩浆事件之一。华北的辽西冀北地区存在着一套分布广泛的侏罗-白垩纪火山岩,主体为玄武岩—玄武安山岩—安山岩—流纹岩。这套火山岩在辽西地区命名为蓝旗组(北京西山地区称为髫髻山组)和义县组,在冀北地区称为蓝旗组和孙家梁组(滕志宏等,1999)。蓝旗组(髫髻山组)和土城子组火山岩及不整合覆盖之上的孙家梁组(义县组)火山岩和张家口组火山岩,记录了侏罗纪与白垩纪之间动力学调整的信息(任纪舜等,1998)。前人对辽西—冀北地区的蓝旗组和髫髻山组进行了大量的地球化学研究(陈义贤和陈文寄,1997;李伍平等,2001a, 2001b, 2001c, 2007;李伍平和李献华,2004;李伍平,2012;袁洪林等,2005;王蕊等,2007;杨蔚,2007;马强,2013;Ma Qiang et al., 2015; Yang Wei and Li Shuguang, 2008),普遍认为其成因可能与华北克拉通在中生代发生的减薄与破坏作用密切相关。本区蓝旗组火山岩与辽西—冀北地区广泛分布的髫髻山组在层序和岩性上均可以对比,但是多

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图 1 河北秦皇岛石门寨以北地区地质简图(据 1:2.5 万河北秦皇岛柳江盆地地质图改编)

Fig. 1 Geological sketch map of the North of Shimenzhai, Qinhuangdao, Hebei Province (Modified from 1:25000 Geological Map of Liujiang Basin, Qinhuangdao, Hebei Province)



年来一直缺乏系统的地球化学研究。此外,前人对区域内相近时代的辽西义县组地层进行了大量的年代学研究(郭胜哲等,2001;邢德和等,2005;张宏等,2005,2006;杨蔚,2007;孟凡雪等,2008),形成年代均处于早白垩世。但对可能与之相对应的本区孙家梁组火山岩的形成时代前人所做的研究工作极少。

本文对秦皇岛石门寨地区的蓝旗组和孙家梁组火山岩展开地球化学研究和同位素年代学研究,通过全岩主、微量地球化学特征,研究这套中酸性火山岩的物质组成,岩浆作用过程和岩浆源区,讨论中国东部的中生代构造事件在本研究地区的体现,并利用锆石 U-Pb 同位素测年技术测定孙家梁组火山岩的形成时代,对比其与区域内中生代火山岩地层的对应关系。

1　区域地质背景

华北克拉通是世界上最古老的克拉通之一,其地壳演化历史可以追溯到 3.8 Ga(Liu Dunyi et al., 1992, 2007; Song Biao et al., 1996),现今位于太平洋构造域和古亚洲洋构造域的重叠部位,华北克拉通主要由西部块体和东部块体构成(Zhao Guochun et al., 2005; Santosh, 2010; Kusky, 2011; Zhao Guochun and Zhai Mingguo, 2013),于 1.85 Ga 左右沿中部造山带拼合为整体(Zhao Guochun et al., 2001, 2012; Wilde, et al., 2002; Kröner et al., 2005, 2006)。华北克拉通北接中亚造山带(Şengör et al., 1993; Davis et al., 2001; Xiao Wenjiao et al., 2011),南接古生代至三叠纪的秦岭—大别—苏鲁造山带(Li Shuguang et al., 1993; Meng Qingren et al., 2000),东南部以郯庐断裂带为界(Fan Weiming et al., 2000; Xu Yigang, 2001; 吴福元等,2003; Gao Shan et al., 2004)。秦皇岛石门寨地区位于华北克拉通东北部,基底主要由新太古代长英质片麻岩构成,盖层由下部青白口纪—古生代地层和上部中生代地层构成(滕志宏等,1999)。岩浆活动非常强烈,该区火山岩主要集中在柳江向斜核部。该区出露有一套保存完好的侏罗纪-白垩纪中酸性火山岩,包括蓝旗组中性熔岩—火山碎屑岩和孙家梁组的英安岩和流纹岩;岩石新鲜,厚度较大,两组火山岩总厚度超过 1000 m;不整合在侏罗系北票组砾岩之上。蓝旗组与孙家梁组之间为整合关系。(河北省地质矿产局,1989;滕志宏等,1999)。

2　火山岩岩石学特征

本文研究样品中,蓝旗组火山岩样品采自河北秦皇岛石门寨以北的吴庄地区,出露的岩石类型主要为安山质熔岩、火山集块岩和熔结凝灰岩,采集的样品为玄武质和安山质熔岩;孙家梁组火山岩样品采自板厂峪地质公园东门至九道缸瀑布之间,岩石类型主要为流纹岩。采样位置见图 1。

(1)玄武岩:岩石具斑状结构,基质具玻晶交织结构。斑晶含量为 20%,主要为单斜辉石,斜长石。单斜辉石为淡黄色,多色性明显,自形粒状,发育熔蚀结构。斜长石为无色,半自形板状。基质含量为 80%,主要为斜长石微晶和玻璃质,以及少量磁铁矿,构成玻晶交织结构。斜长石微晶无色,为细小板条状。

(2)安山岩:岩石具斑状结构,基质具玻晶交织

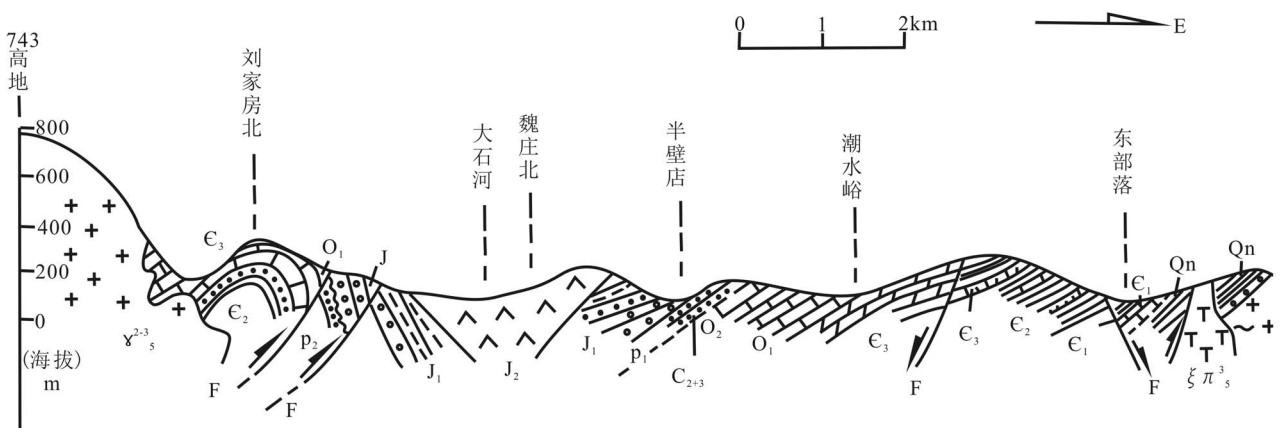


图 2 河北秦皇岛柳江盆地地区剖面图

Fig. 2 The section map of Liujiang Basin in Qinhuangdao, Hebei Province

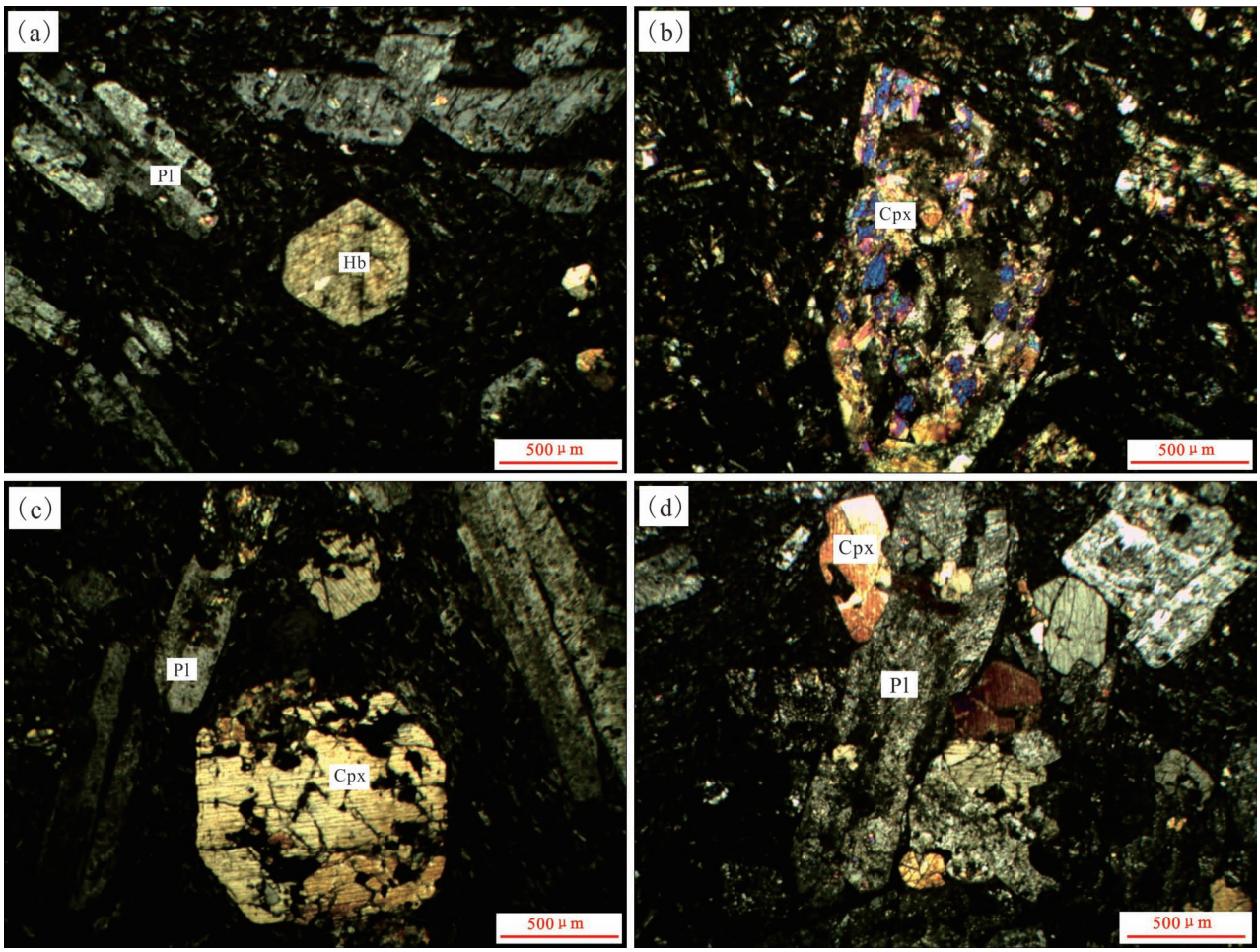


图 3 秦皇岛石门寨蓝旗组代表性火山岩显微照片

Fig. 3 Representative microphotograghs of volcanic rocks of the Lanqi Formation in Shimenzhai, Qinhuangdao

Cpx—单斜辉石;Pl—斜长石;Hb—角闪石

Cpx—clinopyroxene; Pl—plagioclase; Hb—hornblende

结构。斑晶含量为 15%,主要为斜长石、角闪石。角闪石为褐黄色—棕色,多色性明显,自形粒状,粒径大小不等,发育熔蚀结构和暗化边结构。斜长石为无色,半自形板状,具简单双晶和聚片双晶,具绢云母化。基质含量为 85%,主要为斜长石微晶和玻璃质,以及少量磁铁矿,构成玻晶交织结构。斜长石微晶无色,为细小板条状。玻璃质灰黑色,有脱玻化现象(图 3a—d)。

(3)流纹岩:岩石具斑状结构,流纹构造。斑晶为石英、斜长石以及少量黑云母,占岩石总量 10%。石英占斑晶的 70%。斜长石呈自形—半自形,占斑晶的 20%。黑云母呈自形—半自形,含量占斑晶的 5%。可见少量角闪石,呈半自形,具暗化边结构。基质为隐晶长英质以及少量不透明矿物,具流动构造。

3 分析方法

本文选择了蓝旗组和孙家梁组有代表性的岩石样品进行主量元素,微量元素分析(见表 1)。样品无污染碎样、主量元素 X 射线荧光分析、微量元素的 ICP-MS 分析,均在西北大学大陆动力学国家重点实验室进行。主量元素利用碱熔玻璃片在日本理学 RIX2100X 荧光光谱仪(XRF)上测定,分析相对误差一般小于 2%,测试时由 BCR-2、GBW07105 标样和重复样监控。微量元素分析采用美国 Perkin Elmer 公司 Elan6100DRC 型电感耦合等离子质谱仪(ICP-MS),分析相对误差一般小于 2%~5%,测试时由 AGV-1、BCR-1、BHVO-1 国际标样和空白样监控。

锆石分选在河北省区域地质矿产调查研究所完

成,锆石的制靶和阴极发光图像的拍摄均在西北大学大陆动力学国家重点实验室完成。LA-ICP-MS 锆石 U-Pb 原位定年分析在西北大学大陆动力学国家重点实验室进行。分析中,使用 Agilent 7500a 型四级杆 ICP-MS,激光剥蚀系统为 GeoLas 200M 193nm ArF 准分子(excmer)激光剥蚀系统,激光斑束直径是 30 μm,激光剥蚀深度是 20~40 μm,激光脉冲是 10Hz,能量是 34~40 mJ,以^{29}Si 作为内标,哈佛大学标准锆石 91500 作为外标校正。同位素比值数据处理采用 GLITTER(4.0 版)软件,年龄计算和成图采用 ISOPLOT(3.23 版)软件进行,详细的分析步骤以及数据处理方法见参考文献(Yuan Honglin et al., 2004)。

4　分析结果

4.1　岩石化学和微量元素地球化学特征

蓝旗组火山岩样品主要氧化物的含量变化范围较大,SiO_2含量范围在 43.84%~64.50%之间,Al_2O_3含量(12.64%~17.19%)较高,CaO 含量范围在 2.59%~10.11%之间,大部分样品有较高的 TFe_2O_3(7.32%~16.57%),只有 LQ-16 的 TFe_2O_3含量较低(3.52%),大部分样品有中等至较高的 MgO(3.87%~9.29%),只有 LQ-16 的 MgO 含量较低(1.26%),$Mg^{\#}$(45.4~63.5)较高;样品总体上具有较高的碱质含量,Na_2O 含量 2.18%~4.67%,K_2O 含量 0.50%~3.78%,大多数样品具有碱性岩的特征,在 TAS 图解中(图 4a)主要落入碱玄岩、玄武粗安岩区域,个别点落入玄武岩、粗面岩区域。碱玄岩(LQ21、LQ22)SiO_2含量在 43.84%~44.56%,Al_2O_3含量(12.64%~12.84%)较高,MgO 含量(9.08%~9.29%)较高,Na_2O 含量(2.18%~2.20%)较高;玄武粗安岩(LQ17、LQ18)SiO_2含量范围在 53.90%~53.99%之间,Al_2O_3含量(16.80%~16.97%)较高,MgO 含量(3.87%~3.93%)较高,Na_2O含量(4.12%~4.17%)较高。

孙家梁组火山岩样品均为流纹岩,主要氧化物

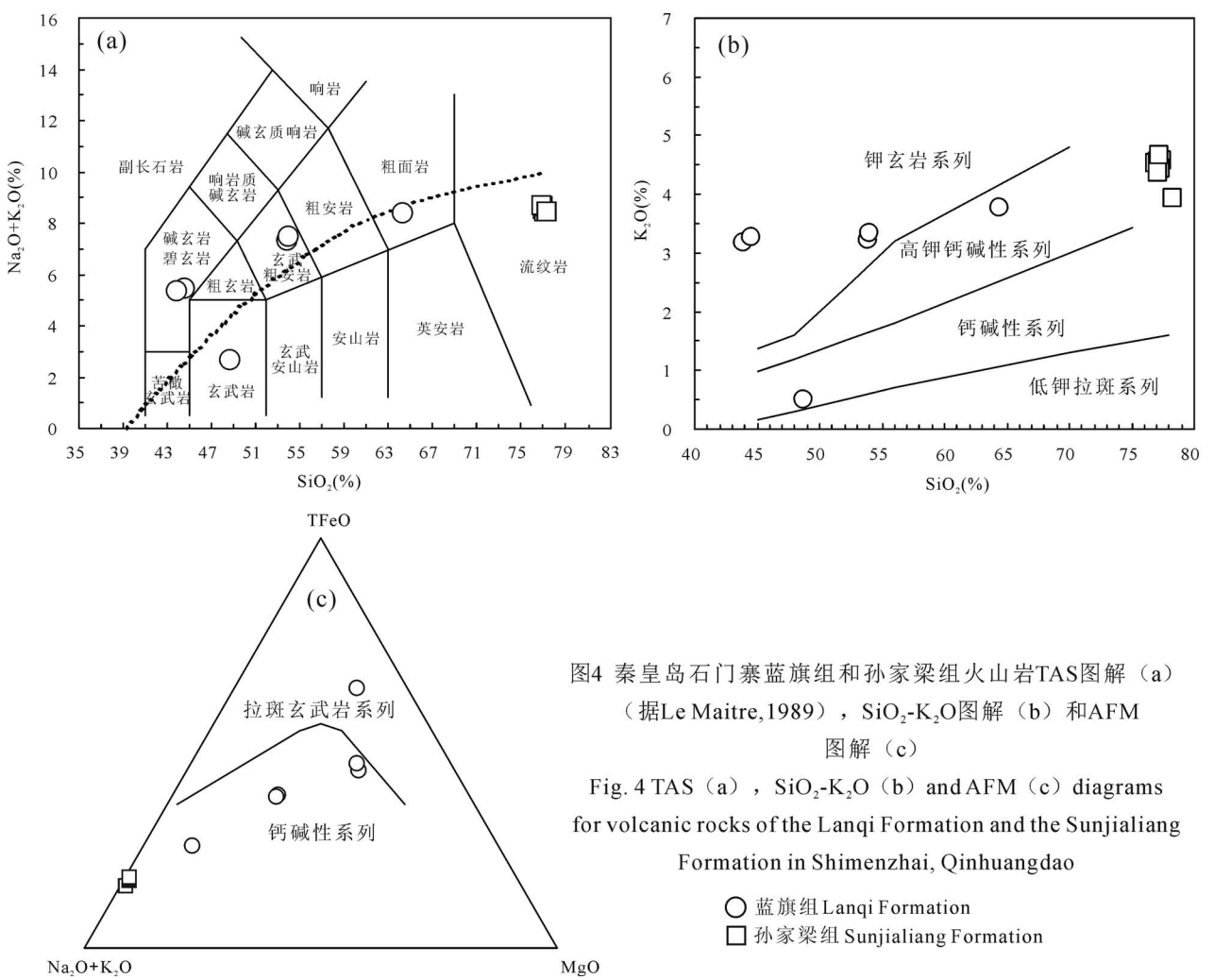


图4 秦皇岛石门寨蓝旗组和孙家梁组火山岩TAS图解（a）（据Le Maitre,1989），SiO_2-K_2O图解（b）和AFM图解（c）

Fig. 4 TAS（a），SiO_2-K_2O（b）and AFM（c）diagrams for volcanic rocks of the Lanqi Formation and the Sunjialiang Formation in Shimenzhai, Qinhuangdao

○ 蓝旗组 Lanqi Formation
□ 孙家梁组 Sunjialiang Formation

表 1 秦皇岛石门寨蓝旗组和孙家梁组火山岩样品主量元素(%)和微量元素($\times10^{-6}$)分析结果

Table 1 Major elements (%) and trace elements ($\times10^{-6}$) data for volcanic rocks of the Lanqi Formation and the Sunjialiang Formation in Shimenzhai, Qinhuangdao

样品号	LQ-16	LQ-17	LQ-18	LQ-20	LQ-21	LQ-22	SL-2	SL-3	SL-4	SL-5	SL-6	SL-7	SL-8	SL-9	SL-10
岩性	粗面岩	玄武粗安岩		玄武岩	碱玄岩		流纹岩								
SiO_2	64.37	53.90	53.99	48.70	43.84	44.56	77.42	77.26	77.05	76.91	77.08	77.13	77.09	77.20	78.23
TiO_2	0.26	0.86	0.85	1.83	2.66	2.55	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.12	0.08
Al_2O_3	17.14	16.97	16.80	13.01	12.64	12.84	11.31	11.39	11.56	11.58	11.47	11.38	11.36	11.62	11.66
TFe_2O_3	3.52	7.47	7.32	16.57	13.16	12.44	1.83	1.92	1.90	1.88	1.90	1.84	1.91	1.85	1.60
MnO	0.08	0.11	0.12	0.25	0.17	0.16	0.04	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03
MgO	1.26	3.93	3.87	5.92	9.08	9.29	0.07	0.05	0.05	0.05	0.05	0.06	0.05	0.07	0.07
CaO	2.59	6.22	6.01	10.11	8.44	8.42	0.21	0.25	0.24	0.23	0.22	0.13	0.25	0.11	0.07
Na_2O	4.63	4.12	4.17	2.18	2.18	2.20	3.87	4.07	4.15	4.17	4.18	4.00	4.16	3.79	4.25
K_2O	3.78	3.23	3.33	0.50	3.18	3.26	4.58	4.44	4.51	4.52	4.48	4.56	4.38	4.67	3.93
P_2O_5	0.17	0.39	0.39	0.15	0.93	0.90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
烧失	1.82	2.88	3.01	0.66	3.42	3.20	0.38	0.45	0.29	0.39	0.44	0.48	0.48	0.44	0.37
总量	99.62	100.08	99.86	99.88	99.70	99.82	99.82	99.96	99.89	99.86	99.95	99.71	99.81	99.91	100.29
$Mg^{\#}$	45.5	55.1	55.2	45.4	61.7	63.5	8.18	5.72	5.78	5.84	5.78	7.06	5.75	8.10	9.25
A/CNK	1.04	0.79	0.79	0.58	0.56	0.57	0.97	0.95	0.95	0.95	0.95	0.97	0.94	1.01	1.03
Li	11.4	13.1	13.3	9.94	38.7	31.6	32.5	66.8	59.9	28.8	56.9	48.1	52.4	27.5	9.63
Be	1.86	1.39	1.34	0.56	2.99	2.85	6.69	8.60	8.29	7.73	7.61	7.07	7.92	5.38	3.77
Sc	2.59	17.8	17.2	43.9	18.1	17.2	0.88	0.82	0.82	0.82	0.86	0.96	0.89	0.99	0.81
V	22.5	165	156	463	231	221	0.31	0.29	0.29	0.30	0.36	0.50	0.55	0.63	0.93
Cr	7.93	90.1	93.7	102	248	236	1.30	0.94	0.70	1.26	0.87	2.16	1.07	1.13	2.16
Co	3.68	21.9	20.5	53.8	53.8	48.9	0.19	0.15	0.22	0.17	0.16	0.21	0.20	0.33	0.39
Ni	3.88	38.6	36.8	60.9	207	196	0.66	0.39	0.31	0.58	0.31	1.46	0.45	1.80	1.41
Cu	7.38	43.5	42.2	72.5	43.9	52.9	2.49	3.05	2.97	3.11	2.77	2.82	2.96	2.81	2.45
Zn	89.5	88.0	85.2	117	139	109	109	126	125	116	126	113	125	96.3	86.9
Ga	19.4	21.1	20.8	19.6	22.0	22.1	24.8	24.6	23.8	23.6	25.2	25.8	24.2	24.1	23.4
Ge	0.97	1.08	1.06	1.64	1.63	1.57	1.21	1.24	1.79	1.74	1.20	1.36	1.77	1.43	0.89
Rb	76.8	60.0	61.8	15.5	144	142	197	240	236	219	245	210	229	171	159
Sr	1120	1490	1455	169	1268	1319	7.01	5.60	4.55	5.05	7.32	5.35	7.19	9.63	11.4
Y	10.6	13.2	13.5	35.5	29.8	29.4	58.1	61.3	55.7	54.2	63.9	58.9	64.0	33.7	41.9
Zr	178	111	108	105	330	331	401	446	444	437	448	416	453	386	316
Nb	6.62	5.43	5.26	5.93	63.1	63.4	57.5	71.1	69.9	65.2	71.3	58.1	70.5	49.0	55.5
Cs	1.62	1.06	1.07	0.32	15.1	14.8	1.54	2.89	2.22	1.85	4.35	1.69	2.05	1.03	0.85
Ba	2380	1706	1675	81.3	1227	1128	23.5	10.6	11.2	15.3	15.7	37.6	15.1	53.2	44.7
Hf	4.38	2.94	2.89	2.91	7.12	7.07	12.5	14.9	14.6	14.0	14.7	13.0	14.8	11.2	11.1
Ta	0.39	0.29	0.28	0.38	3.62	3.66	3.80	4.90	4.77	4.38	4.81	3.99	4.78	3.11	3.86
Pb	11.5	11.9	11.1	1.12	6.87	7.72	32.1	40.2	38.0	34.2	38.1	33.1	38.7	25.0	22.2
Th	8.25	4.29	4.22	0.52	7.29	7.39	14.5	17.3	16.8	15.9	17.4	15.2	17.1	13.0	14.5
U	2.47	1.21	1.18	0.15	1.99	2.22	3.94	5.12	5.02	4.36	5.05	3.91	5.01	2.70	2.78
La	44.4	35.7	35.3	7.98	77.8	78.4	54.6	45.3	47.2	51.3	46.4	50.8	47.5	35.5	5.27
Ce	84.7	72.7	72.6	19.3	163	164	110	102	105	109	101	101	103	91.3	73.9
Pr	8.98	8.46	8.51	2.96	20.4	20.2	12.8	11.0	11.3	11.9	11.4	12.1	11.5	7.59	1.55
Nd	31.6	33.9	33.7	14.7	79.2	78.7	46.1	40.3	40.9	43.5	41.8	44.1	42.2	25.5	5.96
Sm	4.46	5.82	5.87	4.37	14.3	14.2	10.2	9.54	9.25	9.71	9.87	9.75	9.82	4.87	2.27
Eu	1.43	1.78	1.75	1.50	3.96	3.96	0.19	0.15	0.15	0.17	0.17	0.20	0.17	0.14	0.077
Gd	3.40	4.70	4.73	5.38	11.7	11.5	9.92	9.70	9.18	9.49	10.0	9.60	10.0	4.56	3.46
Tb	0.39	0.56	0.56	0.96	1.42	1.39	1.69	1.71	1.59	1.60	1.78	1.67	1.77	0.82	0.86
Dy	2.10	2.94	2.94	6.34	6.98	6.88	10.4	10.9	10.0	10.0	11.4	10.6	11.4	5.65	6.61
Ho	0.38	0.51	0.52	1.33	1.12	1.10	2.09	2.24	2.04	1.99	2.34	2.18	2.32	1.23	1.51
Er	1.13	1.36	1.37	3.85	2.73	2.68	6.17	6.64	6.00	5.80	6.89	6.53	6.87	4.03	4.85
Tm	0.17	0.18	0.19	0.57	0.34	0.33	0.92	0.99	0.89	0.86	1.04	0.99	1.02	0.67	0.77
Yb	1.15	1.14	1.15	3.64	1.89	1.86	5.86	6.35	5.80	5.52	6.68	6.55	6.58	4.70	5.17

样品号	LQ-16	LQ-17	LQ-18	LQ-20	LQ-21	LQ-22	SL-2	SL-3	SL-4	SL-5	SL-6	SL-7	SL-8	SL-9	SL-10
岩性	粗面岩	玄武粗安岩		玄武岩	碱玄岩		流纹岩								
Lu	0.18	0.16	0.17	0.54	0.26	0.26	0.84	0.89	0.82	0.78	0.93	0.95	0.94	0.71	0.75
∑REE	184.44	169.89	169.36	73.40	385.51	385.55	271.94	248.18	250.53	261.27	251.65	256.66	255.36	187.33	113.04
Eu/Eu *	1.12	1.04	1.02	0.94	0.94	0.95	0.06	0.05	0.05	0.05	0.05	0.06	0.05	0.09	0.08
$(La/Yb)_N$	27.66	22.54	21.95	1.57	29.58	30.16	6.69	5.11	5.84	6.67	4.98	5.56	5.17	5.42	0.73
Sr/Y	105.33	113.10	108.07	4.77	42.47	44.87	0.12	0.09	0.08	0.09	0.11	0.09	0.11	0.29	0.27
Sm/Nd	0.14	0.17	0.17	0.30	0.18	0.18	0.22	0.24	0.23	0.22	0.24	0.22	0.23	0.19	0.38
Gd/Yb	2.96	4.13	4.10	1.48	6.21	6.18	1.69	1.53	1.58	1.72	1.50	1.47	1.53	0.97	0.67
U/Pb	0.22	0.10	0.11	0.14	0.29	0.29	0.12	0.13	0.13	0.13	0.13	0.12	0.13	0.11	0.12

注:$Mg^{\#}=\frac{n(Mg)}{n(Mg)+n(Fe)}$; $A/CNK=\frac{n(Al_2O_3)}{n(CaO)+n(Na_2O)+n(K_2O)}$; Eu/Eu^{*} 为球粒陨石标准化后 $\sqrt{\frac{Eu}{Sm\times Gd}}$ (邓晋福等,2015)。

的含量变化范围较小,SiO_2 含量范围在 76.91%~78.23%之间,Al_2O_3 含量(11.31%~11.66%)较高,MgO 含量(0.05%~0.07%)较低,$Mg^{\#}$较低(5.72~9.25),TFe_2O_3含量(1.44%~1.73%)较低,Na_2O 含量(3.79%~4.25%)较高,K_2O 含量(3.93%~4.67%)较高。

在 SiO_2—K_2O 图解中(图 4b),蓝旗组四个样品(LQ-17、18、21、22)落入钾玄岩系列区域,一个样品(LQ-16)落入高钾钙碱性系列区域,一个样品(LQ-20)落入钙碱性系列区域,孙家梁组全部样品落入高钾钙碱性系列区域。

在 AFM 图解中(图 4c),只有 LQ-20 玄武岩样品落入拉斑玄武岩系列区域,其余全部样品落入钙碱性系列区域。结合 SiO_2—K_2O 图解(图 4b),说明 LQ-21、LQ-22(碱玄岩)、LQ-17、LQ-18(玄武粗安岩)均为钾玄岩系列岩石。

在哈克图解中(图 5),蓝旗组火山岩中 TiO_2、MgO、TFe_2O_3、CaO、P_2O_5含量与 SiO_2呈负相关关系,Al_2O_3、Na_2O、K_2O 含量与 SiO_2呈正相关关系。孙家梁组火山岩数据较为集中,样品之间的分异较弱。

蓝旗组、孙家梁组大部分样品的铝饱和指数 A/CNK <1,在 0.56~1.04 之间,主要属于准铝质类型。

4.2　锆石 U-Pb 年龄测定结果

测年样品 SL-1 中的锆石,晶形较完好,多为短柱状,长轴在 100~200 μm 之间,个别锆石粒径达 450 μm,长短轴比为 1.3~3.4,CL 图像中显示出典型的岩浆成因震荡环带结构(图 6)。采用 LA-ICP-MS 方法对这些锆石进行 U-Pb 定年,分析结果见表 2。测定结果中,Th、U 含量变化较大,Th = 29.7×10^{-6}~822.29×10^{-6},U = 44.74×10^{-6}~989.03×10^{-6},Th/U = 0.43~1.08,Th/U 值均大于 0.4(除测点 21 的 Th/U = 0.33 以外),属于典型的岩浆成因锆石(Belousova et al., 2002; 吴元保和郑永飞,2004)。一共有 25 个测点,除去远离 $n(^{206}Pb)/n(^{238}U)$—$n(^{207}Pb)/n(^{235}U)$的 U-Pb 谐和线和加权平均值的两个测点 14 和 23,其余测点的谐和性较好(图 7),这 23 个锆石测点的 $n(^{206}Pb)/n(^{238}U)$加权平均年龄为 118.0±1.1 Ma(MSWD = 2.2),属于早白垩世,该年龄值应代表岩石的结晶年龄。

5　讨论

5.1　秦皇岛石门寨蓝旗组和孙家梁组火山岩岩浆源区特征与岩浆演化过程

5.1.1　蓝旗组

前人对北京西山髫髻山组,冀北髫髻山组和辽西蓝旗组的研究中,部分学者认为其火山岩源于古老的玄武质下地壳部分熔融(李伍平等,2001a,2001b,2001c,2007;葛小月等,2002;赵越等,2004;李伍平和李献华,2004;李伍平,2012),其中具有高 Sr/Y 和 La/Yb 值特征的火山岩,被认为是 Adakitic 岩石(即高锶低钇中酸性岩,也有人译为埃达克质岩)。王蕊等(2007)在对北京西山髫髻山组火山岩的研究中,得出其在相同硅含量条件下,具有比玄武岩熔融实验熔体(Rapp et al., 1995)明显高的含镁指数,说明髫髻山组火山岩可能不是形成于基性下地壳的部分熔融,可能需要幔源岩浆的混合。Chen Bin 等(2013)对这类高镁 Adakitic 岩石进行了岩石学和 Sr—Nd—Os 同位素研究,提出交代幔源玄武质岩浆与重熔地壳的混合成因。Gao Yongfeng 等(2012, 2013)提出髫髻山组火山岩的产生可能经历了 MASH 模型的过程,富集的岩石圈地幔熔融,玄武质幔源岩浆底侵,使下地壳部分熔融,之后发生了分离结晶与岩浆混合。段超等(2016)对太行山北

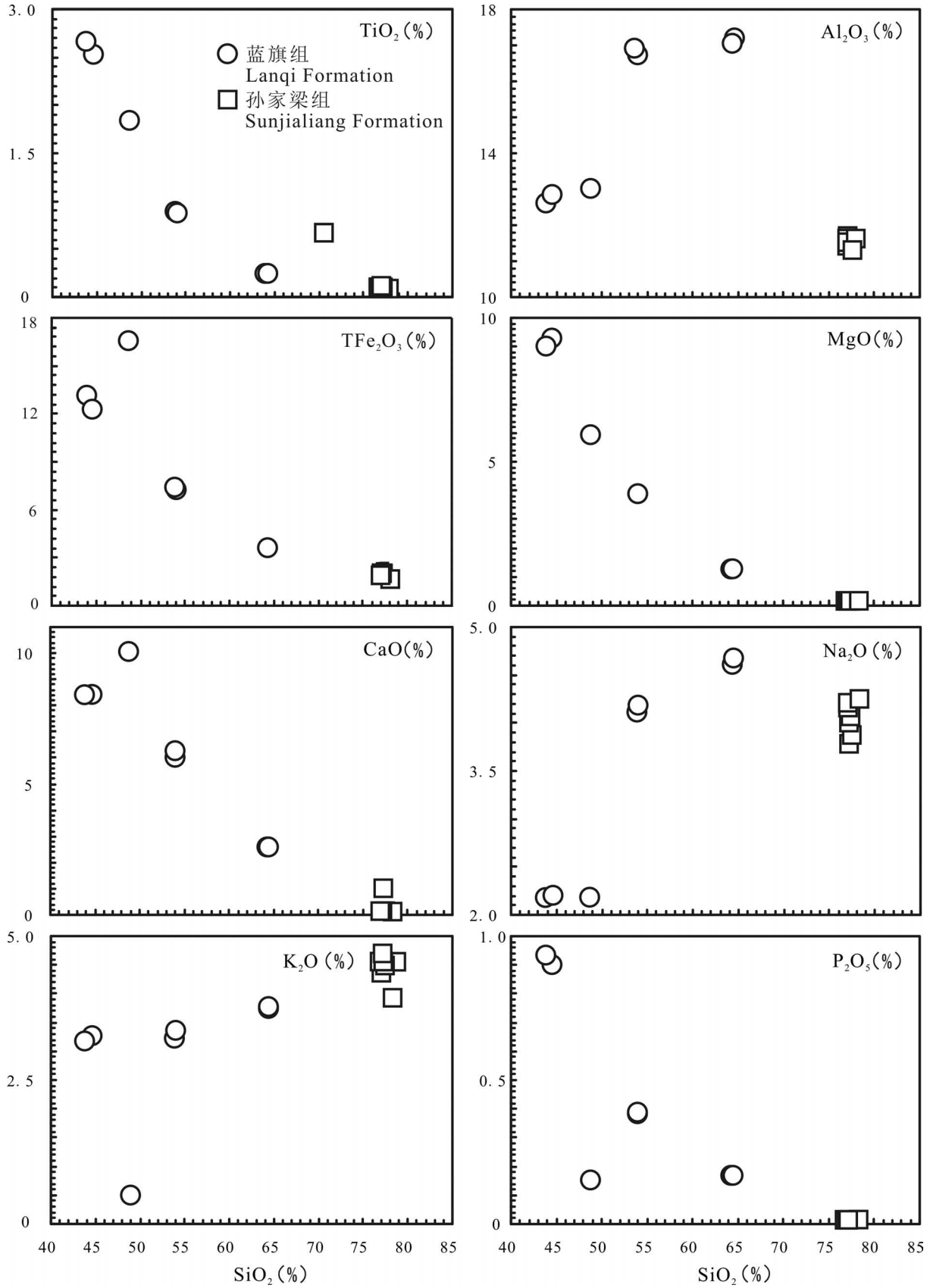


图 5 秦皇岛石门寨蓝旗组和孙家梁组火山岩岩石化学成分哈克图解

Fig. 5 Harker diagrams for volcanic rocks of the Lanqi Fm. and the Sunjialiang Fm. in Shimenzhai, Qinhuangdao



图 6 秦皇岛石门寨孙家梁组流纹岩锆石阴极发光图像(CL)

Fig. 6 CL images of zircons from rhyolite of the the Sunjialiang Formation in Shimenzhai, Qinhuangdao

段髫髻山组火山岩的锆石 Hf 同位素研究表明,其产生于富集地幔的部分熔融,在岩浆上升过程中同化混染了华北克拉通的古老地壳物质,之后又经历了分离结晶作用。

蓝旗组火山岩样品总体上具有较高的碱质含量,具备碱性岩的特征,样品主要为碱玄岩、玄武粗安岩、粗面岩,说明它们由地幔源区岩石低程度部分熔融产生。蓝旗组火山岩的稀土总量变化范围很宽($73.40\times10^{-6}\sim385.55\times10^{-6}$),大部分样品 REE 分布特征为 LREE 相对富集,HREE 相对亏损的配分型式(图 8a)。轻重稀土分馏明显($(La/Yb)_N=21.95\sim30.16$),只有 LQ-20 的$(La/Yb)_N$低至 1.57,轻重稀土分馏很弱,部分样品有明显的重稀土相对中稀土的亏损(Gd/Yb = 4.10 ~ 6.21),说明岩石起源于含石榴子石的地幔源区,石榴子石对重稀土的富集导致了熔体中重稀土元素的相对亏损,只有 LQ-16(Gd/Yb = 2.96)和 LQ-20(Gd/Yb = 1.48)较低。蓝旗组样品基本无 Eu 异常($Eu/Eu^*=0.94\sim1.12$),可能与岩浆演化过程中斜长石的结晶分异较弱或岩浆源区残留相中无斜长石有关。蓝旗组样品 $Sr>1120\times10^{-6}$(除 LQ-20 $Sr=169\times10^{-6}$),$Y<35.5\times10^{-6}$,Sr/Y(42.47 ~ 113.10,除 LQ-20 Sr/Y = 4.77)较高,$U<2.47\times10^{-6}$,$Th<8.25\times10^{-6}$,Sm/Nd<0.18(除 LQ-20 Sm/Nd = 0.30),Nb/Y < 2.16,且 Ba、Pb、Sr 含量较高,与正常岛弧火山岩有区别。Ba 在 LQ-20、LQ-21、LQ-22 中无明显异常,在 LQ-16、LQ-17、LQ-18 中均为正异常。Sr 在 LQ-21、LQ-22 中无明显异常,在 LQ-16、LQ-17、LQ-18 中均为正异常,在 LQ-20 中为负异常。

在微量元素蛛网图中(图 9a),蓝旗组火山岩样品可根据不同的微量元素分布特征分为三类:

第一类:包括样品 LQ-16(粗面岩)、LQ-17 和

表 2 秦皇岛石门寨孙家梁组流纹岩 LA-ICP-MS 锆石 U-Pb 分析结果

Table 2 Zircon LA-ICP-MS U-Pb dating results from rhyolite of the Sunjialiang Formation in Shimenzhai, Qinhuangdao

测点号	元素含量($\times10^{-6}$)			Th/U	同位素比值						同位素年龄(Ma)						谐和度(%)
	Pb	Th	U		$n(^{207}Pb)/n(^{206}Pb)$		$n(^{207}Pb)/n(^{235}U)$		$n(^{206}Pb)/n(^{238}U)$		$n(^{207}Pb)/n(^{206}Pb)$		$n(^{207}Pb)/n(^{235}U)$		$n(^{206}Pb)/n(^{238}U)$		
					测值	1σ	测值	1σ	测值	1σ	测值	1σ	测值	1σ	测值	1σ	
流纹岩(样品号 SL-1)																	
1	1.95	34.68	78.43	0.44	0.0540	0.0039	0.1376	0.0095	0.0185	0.0003	372.5	154.3	130.9	8.4	117.9	1.9	111
2	1.43	41.36	56.89	0.73	0.0539	0.0085	0.1363	0.0210	0.0183	0.0005	365.0	319.7	129.7	18.8	117.2	2.9	111
3	1.67	36.40	63.03	0.58	0.0658	0.0053	0.1715	0.0132	0.0189	0.0004	799.5	160.6	160.8	11.5	120.7	2.4	133
4	2.57	71.43	94.45	0.76	0.0580	0.0049	0.1542	0.0125	0.0193	0.0004	530.0	175.2	145.6	11.0	123.1	2.3	118
5	14.30	301.04	586.33	0.51	0.0503	0.0018	0.1297	0.0039	0.0187	0.0002	210.6	80.5	123.8	3.5	119.3	1.3	104
6	4.79	82.86	180.97	0.46	0.1131	0.0066	0.2817	0.0151	0.0181	0.0004	1850.1	102.3	252.0	11.9	115.3	2.3	219
7	24.74	688.39	989.03	0.70	0.0502	0.0014	0.1268	0.0028	0.0183	0.0002	205.2	64.5	121.2	2.5	117.0	1.2	104
8	4.03	91.15	173.23	0.53	0.0478	0.0030	0.1213	0.0073	0.0184	0.0003	88.5	144.5	116.2	6.6	117.5	1.8	99
9	6.65	132.28	267.57	0.49	0.0696	0.0031	0.1787	0.0072	0.0186	0.0003	916.3	90.1	167.0	6.2	118.9	1.6	140
10	18.74	340.50	527.14	0.65	0.0987	0.0048	0.2785	0.0122	0.0205	0.0003	1600.1	88.4	249.4	9.7	130.5	2.1	191
11	11.08	288.47	409.97	0.70	0.0477	0.0018	0.1224	0.004	0.0186	0.0002	9.0	87.8	117.2	3.6	118.9	1.3	99
12	1.50	32.17	44.74	0.72	0.0896	0.0090	0.2351	0.0227	0.0190	0.0005	1416.5	181.2	214.4	18.7	121.5	3.1	176
13	2.26	43.03	99.12	0.43	0.0465	0.0045	0.1161	0.0110	0.0181	0.0004	23.1	218.4	111.5	10.0	115.7	2.2	96
14 *	2.76	59.50	104.73	0.57	0.0621	0.0043	0.1580	0.0104	0.0185	0.0003	677.1	142.3	148.9	9.2	117.9	2.0	126
15	15.26	344.18	580.35	0.59	0.0562	0.0018	0.1451	0.0039	0.0187	0.0002	458.6	71.0	137.6	3.5	119.7	1.3	115
16	19.04	670.16	761.95	0.88	0.0609	0.0020	0.1414	0.0037	0.0168	0.0002	635.1	68.1	134.3	3.3	107.6	1.2	125
17	9.28	182.80	364.33	0.50	0.0470	0.0022	0.1190	0.0050	0.0184	0.0002	46.5	106.5	114.2	4.5	117.4	1.5	97
18	10.54	252.35	408.59	0.62	0.0578	0.0021	0.1500	0.0048	0.0188	0.0002	522.6	79.6	141.9	4.2	120.2	1.4	118
19	4.51	82.53	185.76	0.44	0.0525	0.0028	0.1329	0.0064	0.0184	0.0003	308.1	114.7	126.7	5.8	117.2	1.6	108
20	1.83	36.25	77.32	0.47	0.0427	0.0053	0.1080	0.0132	0.0183	0.0004	0.1	98.9	104.1	12.1	117.2	2.4	89
21	2.12	29.70	88.95	0.33	0.0443	0.0042	0.1112	0.0102	0.0182	0.0003	0.1	119.6	107.1	9.3	116.5	2.1	92
22	20.77	822.29	759.19	1.08	0.0498	0.0016	0.1234	0.0032	0.0180	0.0002	186.6	71.9	118.2	2.9	114.8	1.2	103
23 *	13.26	297.97	593.90	0.50	0.0495	0.0019	0.1218	0.0040	0.0179	0.0002	171.2	86.6	116.7	3.7	114.0	1.3	102
24	1.67	35.20	68.48	0.51	0.0535	0.0063	0.1354	0.0156	0.0184	0.0004	351.4	247.5	129.0	14.0	117.2	2.7	110
25	5.44	86.33	147.11	0.59	0.1385	0.0056	0.3745	0.0129	0.0196	0.0003	2208.3	68.4	323.0	9.6	125.2	1.9	258

注:加 * 的测点为计算加权平均年龄、谐和图成图时除去的测点。

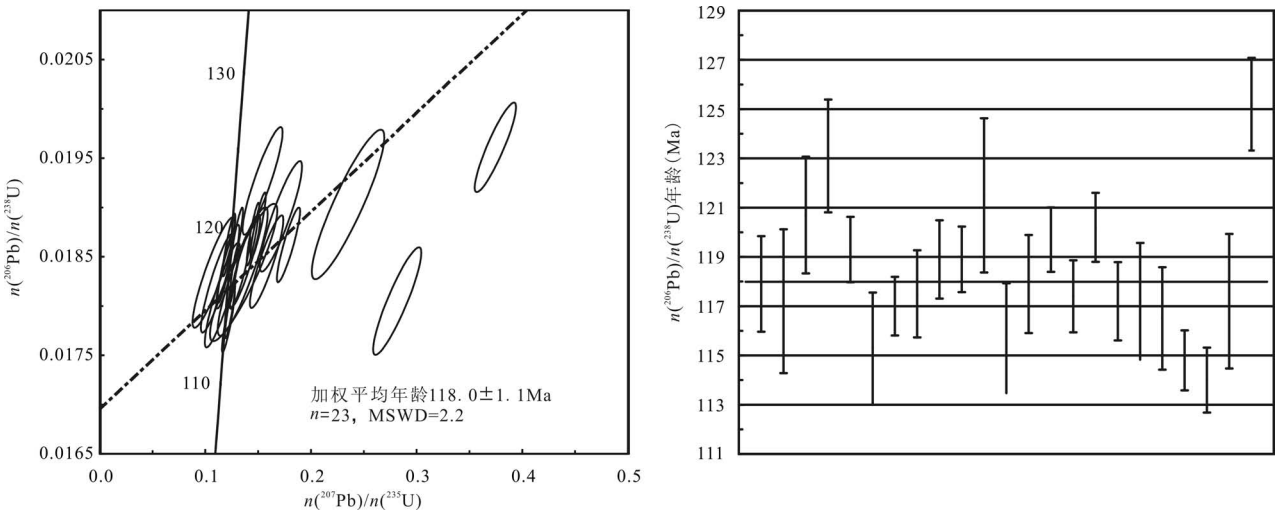


图 7 秦皇岛石门寨孙家梁组流纹岩 LA-ICP-MS 锆石 U-Pb 谐和图

Fig. 7 Concordia diagram of LA-ICP-MS zircon from rhyolite of the Sunjialiang Formation in Shimenzhai, Qinhuangdao

LQ-18(玄武粗安岩)。这类样品 SiO_2>53%,Na_2O/K_2O>1.22,Al_2O_3 含量(16.80%~17.14%)较高,MgO 含量(1.26%~3.93%)较低。高场强元素 Nb、Ta、Zr、Hf 均呈明显的负异常,大离子亲石元素 Ba、Pb、Sr、U 具有明显的正异常,富集轻稀土元素,亏损重稀土元素,粗面岩重稀土相对中稀土的亏损不明显(Gd/Yb=2.96),玄武粗安岩有较为明显的重稀土相对中稀土的亏损(Gd/Yb=4.10~4.13),Yb<1.15×10^{-6},$(La/Yb)_N$(>21.95)较高,无明显 Eu 异常(Eu/Eu*>1),Sr>1120×10^{-6},Y 含量(<13.5×10^{-6})较低,Sr/Y(>105.33)较高。其地球化学特征类似岛弧(图 9a),受交代作用的地幔橄榄岩在经历部分熔融时所形成的玄武质岩浆岩会继承陆壳岩石的岛弧微量元素特征(Zhao Zifu et al., 2013; 赵子福等,2015)。郑永飞等(2018)根据华北中生代岛弧型镁铁质岩浆岩的$^{206}Pb/^{204}Pb$ 与 Nb/La 之间的负相关关系得出其地幔源区的地壳组分中,上地壳贡献占主导,下地壳拆沉可能不是华北克拉通岛弧型镁铁质岩浆岩的地幔源区中地壳组分再循环的主导机制,因此本文蓝旗组的玄武粗安岩和粗面岩可能

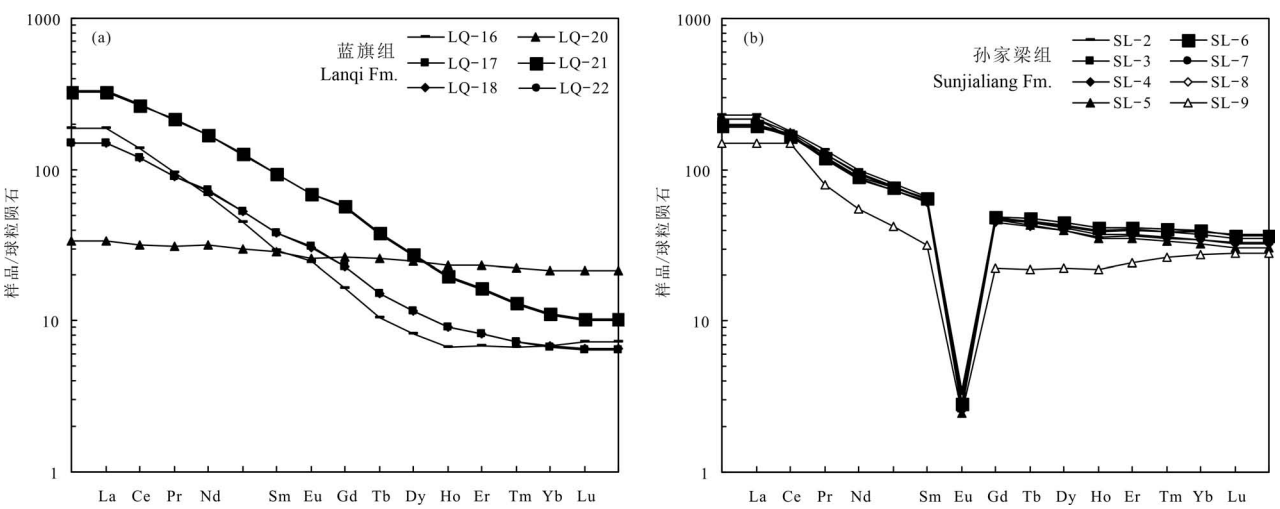


图 8 秦皇岛石门寨蓝旗组(a)和孙家梁组(b)火山岩稀土元素配分曲线模式

(球粒陨石标准值采用 Sun and McDonough,1989)

Fig. 8 Chondrite-normalized REE distribution patterns for volcanic rocks of the Lanqi Formation(a) and the Sunjialiang Formation(b) in Shimenzhai, Qinhuangdao

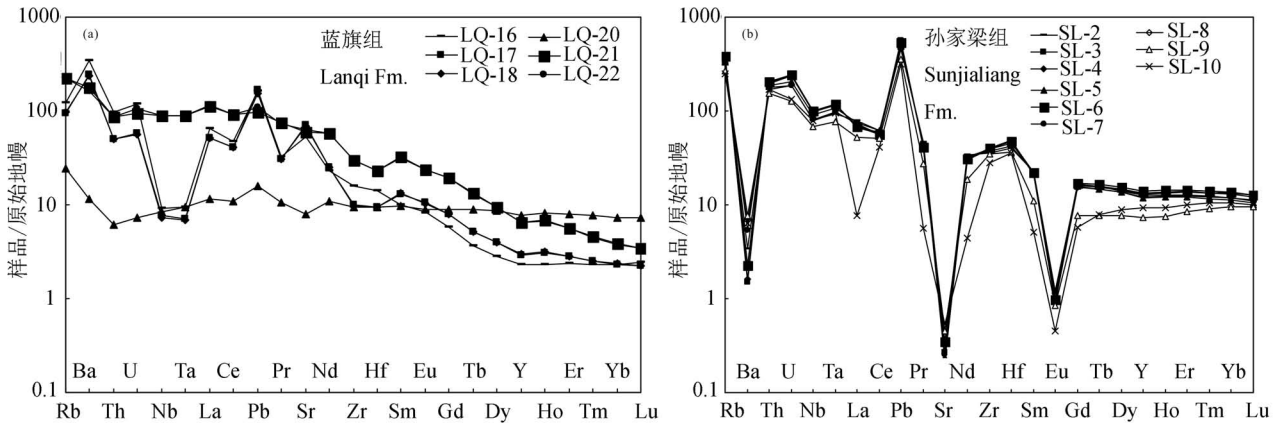


图 9 秦皇岛石门寨蓝旗组(a)和孙家梁组(b)火山岩微量元素蛛网图(原始地幔标准值采用 Sun and McDonough,1989)

Fig. 9 Primitive mantle-normalized spider diagrams for volcanic rocks of the Lanqi Formation(a) and the Sunjialiang Formation(b) in Shimenzhai, Qinhuangdao

与受上地壳俯冲脱水交代作用有关。

第二类:包括样品 LQ-21 和 LQ-22,均为碱玄岩。高场强元素 Nb、Ta、Zr、Hf 呈弱负异常,稀土元素含量较高($385.51\times10^{-6}\sim385.55\times10^{-6}$),轻重稀土分馏较为明显($(La/Yb)_N=29.58\sim30.16$),有较为明显的重稀土相对中稀土的亏损(Gd/Yb=6.18~6.21),其具有比 LQ-16、LQ-17、LQ-18 相对较高的 Y 含量($>29.4\times10^{-6}$),相对较高的 Yb 含量($>1.86\times10^{-6}$),相对较低的 Sr/Y(<44.87),U 含量($1.99\times10^{-6}\sim2.22\times10^{-6}$)和 Th 含量($2.29\times10^{-6}\sim2.39\times10^{-6}$)较高,U/Pb(0.29)较高。其地球化学特征类似 HIMU 型 OIB(图 9a),前人研究一般认为,洋岛型镁铁质岩浆岩的微量元素特征继承自俯冲洋壳(Hofmann and White, 1982; Hofmann et al., 1986; Sun Weidong et al., 2008; 黄士春和郑永飞,2017)。郑永飞等(2018)根据华北中生代洋岛型镁铁质岩浆岩显示出亏损至弱富集的 Sr—Nd 同位素组成得出其源区可能是软流圈地幔受俯冲洋壳衍生物质交代所形成的富集地幔,且其 Ba、Pb、Sr、LREE 含量较高,这可能与富集软流圈地幔部分熔融产生的基性岩浆有关,因为富集软流圈地幔部分熔融产生的基性岩浆一般富集 Ba、Sr 、LREE(Chen Bin et al., 2003),因此本文蓝旗组的碱玄岩的源区可能为受俯冲洋壳衍生物质交代所形成的富集软流圈地幔。

第三类仅一个玄武岩样品 LQ-20,具有较高的 Al_2O_3(13.01%)和 CaO 含量(10.11%),较低的 K_2O 含量(0.5%),中等的 TiO_2 含量(1.83%),较高的 Cr 含量(102×10^{-6})和 Ni 含量(60.9×10^{-6})。稀土曲线基本平坦,稀土总量相当于 30 倍球粒陨石,轻、重稀土分异不明显。微量元素蛛网图中无明显的高场强元素异常,Nb、Ta、Zr、Hf 均无明显亏损,只有轻微的 Th、Sr 负异常。其地球化学特征类似 N-MORB(图 9a),岩浆源区可能为弱亏损的软流圈地幔。

5.1.2 孙家梁组

孙家梁组火山岩样品具有较集中的 SiO_2 含量(76.9%~78.2%),$Mg^{\#}$ 较低(5.72~9.25),孙家梁组火山岩的岩浆源区以壳源为主,底侵于下地壳的幔源玄武质岩浆是最可能的热源和岩浆源区(Guffanti et al., 1996)。孙家梁组火山岩的稀土总量变化范围很宽($113.04\times10^{-6}\sim271.94\times10^{-6}$),REE 分布特征为 LREE 相对富集,HREE 相对亏损的配分型式(图 8b)。轻重稀土分馏较明显($(La/Yb)_N=4.98\sim6.69$),只有 SL-10 的 $(La/Yb)_N$ 很低(0.73),轻重稀土分馏很弱。孙家梁组呈现强烈的 Eu 负异常($Eu/Eu^*=0.05\sim0.09$)(图 8b),说明其源区残留相中含有斜长石,或者岩浆上升和就位过程中经历过斜长石的分离结晶,二者都会导致在斜长石中相容的 Eu^{2+} 的消耗。其富 Si、K、Na,强烈亏损 Ba、Sr、Eu 等特征类似 A 型花岗岩,说明其为高温条件下的伸展背景所产生(Whalen et al., 1987; Patiño, 1997; Wu Fuyuan et al., 2002; Bonin, 2007),形成 A 型花岗岩的低压、高温等物理化学条件与地壳拉张之间存在着联系(魏春生等,1998;张旗等,2012)。晚侏罗世开始,燕山地区产生了幔源岩浆的底侵作用,其底侵于下地壳—壳幔过渡带产生麻粒岩相变质作用(邓晋福等,1996;陈绍海等,

1998),有可能引起岩石圈地幔与下地壳玄武质岩石的部分熔融。郑永飞等(2018)提出古太平洋板块从 144 Ma 开始俯冲后撤,并且由低角度俯冲至华北克拉通岩石圈地幔之下转变为高角度俯冲(Xu Zheng et al., 2012)。结合本文新得到的孙家梁组流纹岩的形成年代,孙家梁组流纹岩的形成可能与早白垩世华北克拉通强烈的陆内伸展背景下的幔源岩浆底侵有关。

5.2　构造环境

本文选择可能区分 N-MORB、E-MORB 和板内拉斑、板内碱性、岛弧玄武岩类的 Th—Hf/3—Ta 图解,可能区分洋岛、活动大陆边缘、洋脊、板内玄武岩类的 Th/Yb—Ta/Yb 图解,可能区分板内、火山弧和同碰撞、洋中脊花岗岩类的 Nb—Y 图解,以及可能区分同碰撞、板内、火山弧、洋中脊花岗岩类的 Rb—Yb+Ta 图解。

蓝旗组构造环境判别图解中(图 10),在 Hf/3—Th—Ta 图解中,LQ-20 主要落入 N-MORB 区域,LQ-16、17、18 主要落入岛弧区域,LQ-21、22 落入板内碱性玄武岩区域。在 Ta/Yb—Th/Yb 图解中,LQ-20 落入洋脊玄武岩区域,LQ-21、22 落入板内玄武岩区域,LQ-16、17、18 主要落入活动大陆边缘区域。

孙家梁组构造环境判别图解中(图 11),在 Y—Nb 图解和(Yb+Ta)—Rb 图解中,孙家梁组全部样品均落入板内花岗岩环境。此外,孙家梁组流纹岩强烈亏损 Ba、Sr、Eu、Ti、P,其地球化学特征类似 A 型花岗岩,说明其可能形成于低压条件下,产于地壳伸展减薄的构造背景下(张旗等,2012),这也与本文中得到的孙家梁组流纹岩锆石 U-Pb 年龄处于早白垩世这一华北克拉通减薄峰期相符合。

5.3　秦皇岛石门寨孙家梁组火山岩的时代

前人对秦皇岛石门寨地区孙家梁组的年代学研究比较缺乏,只是认为整合接触于蓝旗组之上的孙家梁组同蓝旗组一样属于侏罗纪(如滕志宏等,1999),本文对孙家梁组流纹岩进行了锆石 U-Pb 同位素年代学研究,该区孙家梁组流纹岩的 LA-ICP-MS 锆石 U-Pb 定年结果显示,$^{206}Pb/^{238}U$ 加权平均年龄为 118.0±1.1 Ma(图 7),处于早白垩世,这与前人所广泛认为的该区孙家梁组属于晚侏罗世的观点所不同。早白垩世是中国东部中生代岩浆作用的峰期(翟明国等,2003;Wu Fuyuan et al., 2005; Zhu Rixiang et al., 2012; Zhang Shuanhong et al., 2014),也是华北克拉通中生代减薄与破坏作用的峰期(吴福元等,1999,2003;翟明国等,2003;许文良等,2004;邓晋福等,2006; Menzies et al., 2007; Zhu Rixiang et al., 2012)。孙家梁组流纹岩的形成时代基本和中国东部中生代的强烈的岩浆作用时期符合,处于华北克拉通中生代减薄与破坏作用的峰期。

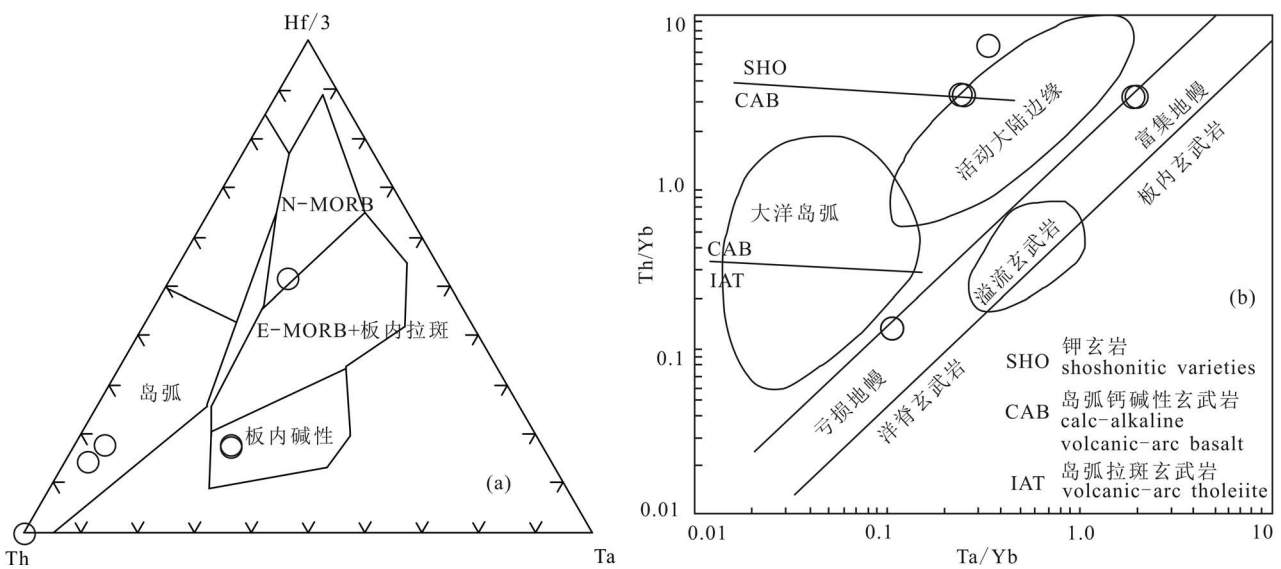


图 10 秦皇岛石门寨蓝旗组火山岩 Th—Hf/3—Ta(a)(据 Wood et al., 1979)和 Ta/Yb—Th/Yb(b)(据 Pearce, 1983)构造环境判别图解

Fig. 10 Th—Hf/3—Ta(a)(After Wood et al., 1979) and Ta/Yb—Th/Yb(b)(After Pearce, 1983) diagrams for volcanic rocks of the Lanqi Formation in Shimenzhai, Qinhuangdao

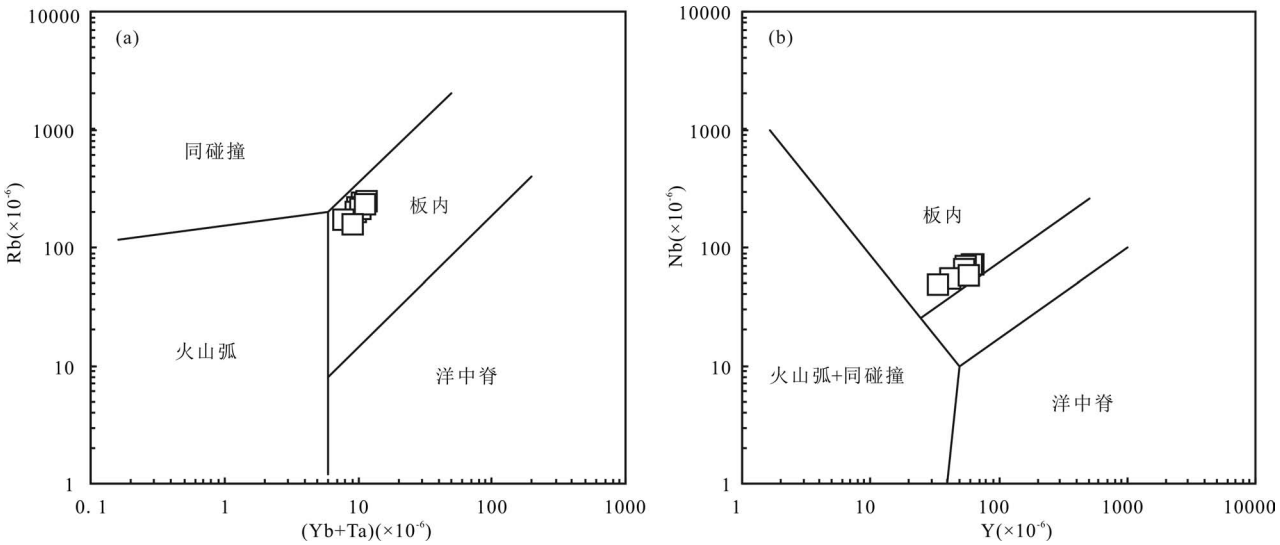


图 11 秦皇岛石门寨孙家梁组火山岩(Yb+Ta)—Rb(a)和 Y—Nb(b)构造环境判别图解(据 Pearce et al., 1984)

Fig. 11 (Yb+Ta)—Rb(a) and Y—Nb(b) diagrams for volcanic rocks of the Sunjialiang Formation in Shimenzhai, Qinhuangdao(After Pearce et al., 1984)

该区孙家梁组流纹岩与许保良等(1998)报道的邻区的山海关碱性花岗岩的 Rb-Sr 等时线年龄(113±12 Ma)在误差范围内一致,而且它们的地球化学特征都与 A 型花岗岩相似,因此,它们可能为同一时期的岩浆事件所形成的侵入—喷出岩系列。其形成年龄也与中国东部广泛出现的锆石 U-Pb 年龄为 130~120 Ma 的花岗岩基本一致(Wu Fuyuan et al., 2005; Zhang Shuanhong et al., 2014)。并且,该区孙家梁组与辽西广泛分布的义县组在层位和岩性上均可以相互对比,前人对辽西地区义县组进行了大量的年代学研究,取得了很多义县组的年龄数据,彭艳东(2003)报道了义县火山旋回发生的时间大致介于 120~135 Ma 之间,张宏等(2005)报道了辽西义县组顶部角砾岩层的锆石 LA-ICP-MS U-Pb 年龄为 118.9±1.4 Ma,杨蔚(2007)报道了辽西义县组火山岩的锆石 U-Pb SHRIMP 年龄为 122~125 Ma,郭胜哲等(2001)报道了辽西义县组凝灰岩的同位素年龄为 121.3~124.6 Ma,邢德和等(2005)报道了北票上园新开岭义县组橄榄玄武玢岩的 K-Ar 年龄为 133.20±0.11 Ma,张宏等(2006)报道了辽西凌源义县组下部大王杖子层的锆石 LA-ICP-MS U-Pb 年龄为 122~125 Ma,孟凡雪等(2008)报道了辽西凌源义县组流纹岩的锆石 U-Pb 年龄为 124.4±1.4 Ma。综上所述,本文秦皇岛石门寨地区的孙家梁组年代应该与辽西地区的义县组顶部年代相对应,并且辽西义县组与冀北孙家梁组均处于早白垩世华北克拉通东部发生的岩石圈减薄与破坏,深部岩浆活动,关键构造转换的时期(Zhu Rixiang et al., 2011,2012;朱日祥等,2009,2012;嵇少丞等,2008)。

6 结论

(1)河北秦皇岛石门寨地区蓝旗组火山岩主要为钾玄岩系列,孙家梁组火山岩为高钾钙碱性系列。蓝旗组粗面岩和玄武粗安岩地球化学特征类似岛弧,可能与受上地壳俯冲脱水交代作用有关,碱玄岩地球化学特征类似 HIMU 型 OIB,源区可能为受俯冲洋壳衍生物质交代所形成的富集软流圈地幔,玄武岩地球化学特征类似 N-MORB,源区可能为亏损的软流圈地幔。孙家梁组流纹岩可能由早白垩世华北克拉通强烈的伸展作用导致幔源岩浆底侵下地壳使其部分熔融或古太平洋板块从 144 Ma 开始俯冲后撤所导致俯冲地壳岩石发生部分熔融产生。

(2)河北秦皇岛石门寨地区孙家梁组流纹岩的锆石 LA-ICP-MS U-Pb 定年结果显示,其时代为 118.0±1.1 Ma,为早白垩世,与辽西地区义县组相对应,处于华北克拉通中生代减薄与破坏作用的峰期。

致谢:感谢西北大学大陆动力学国家重点实验室弓化栋老师对主量、微量元素测试,锆石 U-Pb 原位定年分析的指导,以及西北大学地质学系研究生孟祥舒、务磊、徐可心在实验测试过程中的帮助。感谢审稿专家和责任编辑对本文提出的宝贵意见。

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Geochemical features and zircon LA-ICP-MS U-Pb ages of Mesozoic volcanic rocks in Shimenzhai, Qinhuangdao, Hebei Province

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Objectives: Mesozoic volcanic rocks are widespread in eastern China. In Shimenzhai, Qinhuangdao, northern Hebei province, there occur a suite of Mesozoic volcanic rocks of the Lanqi Formation and the Sunjialiang Formation, unconformitly overlying on the Jurassic conglomerate of the Beipiao Formation. The Lanqi Formation consists of tephrites, trachyandesites and tephrites, and the Sunjialiang Formation mainly consists of dacites and rhyolites. The petrogenesis and age of volcanic rocks of the Lanqi Formation and the Sunjialiang Formation in Shimenzhai, Qinhuangdao, Hebei province is important for discussing mechanism and timing of thinning of North China Craton in Mesozoic.

Methods: Whole rock geochemistry analysis and zircon U-Pb age dating are carried out on selective volcanic rocks samples of the Lanqi Formation and the Sunjialiang Formation.

Results: The volcanic rocks of the Lanqi Formation are mafic alkaline, with high K, Na and Al contents, some of samples also have high Mg and Fe contents. Trachytes and trachyandesites are enriched in LILE and LREE, depleted in HFSE and HREE. Tephrites are slightly depleted in HFSE, with significant fractionation between LREE and HREE. Basalts have no HFSE anomaly, LREE enrichment and HREE depletion. The volcanic rocks of the Sunjialiang Formation have high K, Na, Al, and low Mg and Fe contents. They have LREE enriched patterns, with significant negative Eu anomalies. The Lanqi Formation is mainly shoshonite series, and the Sunjialiang Formation is high K calc alkaline series.

Conclusions: The geochemical characteristics of trachyte and basaltic trachy-andesite of the Lanqi Formation are similar to those of island arc, which may be related to the subduction and dehydration metasomatism of the upper crust. The geochemical characteristics of tephrite are similar to those of HIMU type OIB, and the source region may be enriched asthenospheric mantle by metasomatism of the subducted oceanic crust. The geochemical characteristics of basalt are similar to those of N-MORB, and the source area may be depleted asthenospheric mantle. The rhyolites of the Sunjialiang Formation may be partial melting of lower crust by underplating of mantle source magma by the Early Cretaceous extension of North China Craton or the partial melting of subducted oceanic crustal rocks by subduction of the palaeo-Pacific plate. LA-ICP-MS U-Pb dating on zircons from a rhyolite of the Sunjialiang Formation, yield a concordant age of 118.0±1.1Ma. This age indicate that the Sunjialiang Formation is chronologically comparable with Yixian Formation in western Liaoning province.

Keywords: Lanqi Formation; Sunjialiang Formation; Mesozoic volcanic rocks; Eastern China; zircon U-Pb age

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