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萨吾尔山松树沟地层形成时代及火山岩地球化学研究

翁 凯[1,2] 张 雪[2] 马中平[1] 陈隽璐[1] 孙吉明[1] 张 涛[1,2]

(1.国土资源部岩浆作用成矿与找矿重点实验室,西安地质调查中心,陕西 西安710054;
2.长安大学地球科学与资源学院,陕西 西安710054)

提要：西准噶尔松树沟地区地层主要由碎屑沉积岩和火山岩组成,以玄武岩、安山岩和火山碎屑岩为主,其中玄武岩属于钙碱性系列,安山岩属于拉斑系列。对岩石中锆石开展LA-ICP-MS锆石U-Pb年代学研究,安山岩锆石年龄表明其形成于(317.1±6.4)Ma,粗砂岩56颗锆石中仅有1颗锆石年龄((389±9)Ma)属于中泥盆世,其余主要集中在319 ~359 Ma,最小年龄(319±6)Ma。因此,该套地层并非形成于中泥盆世,很可能形成于晚石炭世早期。地球化学研究表明,玄武岩和安山岩具有相似的稀土配分曲线,轻稀土富集的右倾REE分配模式,富集大离子亲石元素K、Rb、Ba、Sr等,亏损高场强元素Nb、Ta、Th、Zr、Hf等,呈现出Ta、Nb、Ti负异常,认为该火山岩形成于岛弧环境,岩浆来源于俯冲板片脱水产生的流体不均一交代的地幔楔。该套岛弧火山岩的形成时代限定了斋桑洋盆的关闭时限(晚于317.1 Ma)。

关 键 词:西准噶尔;岛弧火山岩;锆石U-Pb测年;地球化学

中图分类号：P584;P597[+].3 **文献标志码**：A **文章编号**:1000-3657(201)05-1438-14

西准噶尔地区地处于西伯利亚板块、哈萨克—准噶尔板块的交接部位,是中亚古生代俯冲-增生复合造山带的重要组成部分[1-3],是了解西伯利亚板块、哈萨克—准噶尔板块和古亚洲洋构造演化的关键地区,引起了国内外学者的广泛关注[4-7]。萨吾尔地区位于新疆维吾尔自治区伊犁哈萨克自治州阿勒泰地区吉木乃县及塔城地区和丰县,构造上归属于哈萨克斯坦—准噶尔板块北缘[8-11]。区内岩浆活动剧烈,广泛发育石炭纪、二叠纪花岗岩和晚古生代火山岩。前人对区内的花岗岩进行了大量的研究,取得了一定的认识[12-18],对二叠纪广泛分布的火山岩也有较为详细的研究报道[19-24],但对泥盆纪、石炭纪火山岩的研究相对欠缺。作者在萨吾尔山南坡松树沟地区进行了详细的地质调研,通过火山岩岩相学、地球化学、锆石U-Pb同位素及粗砂岩锆石U-Pb同位素的研究,对其形成环境和时代进行分析讨论,为探讨区域构造演化提供重要的依据。

1 区域地质概况

西准噶尔北部地区主要出露以志留系、泥盆系

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作者简介:翁凯,男,1985年生,博士生,从事矿物学、岩石学、矿床学方面的研究;E-mail:kaikaino1@qq.com。

通讯作者:马中平,男,1970年生,博士,研究员,矿物、岩石、矿床学专业; E-mail:xamzhongping@cgs.gov.cn。

和石炭系为主的古生代地层,以及呈东西向带状展布的蛇绿岩、火山岩和花岗岩侵入体。蛇绿岩包括查干陶勒盖、库吉拜、和布克赛尔和洪古勒楞等蛇绿岩,时代从早寒武世到晚奥陶世[25−27],火山岩为志留纪谢米斯台火山岩、泥盆—石炭纪塔尔巴哈台—萨吾尔山火山岩,花岗岩为晚志留世—早泥盆世谢米斯台—赛尔山花岗岩、石炭纪塔尔巴哈台—萨吾尔山花岗岩[28−30,16]。

研究区位于萨吾尔山南坡一带,区内出露的地层从老到新为泥盆系萨吾尔山组(D_2s),石炭系黑山头组(C_1h)、姜巴斯套组(C_1j),二叠系哈尔加乌组(P_1h)和卡拉岗组(P_1k)。自中泥盆世至早二叠世均有火山活动。萨吾尔山组为一套海相−海陆交互相的碎屑岩、火山碎屑岩和火山岩,黑山头组为一套海相基性火山岩夹中酸性火山碎屑岩,姜巴斯套组为一套浅海−海陆交互相碎屑沉积岩,哈尔加乌组为一套陆相中基性−中性火山岩及火山碎屑岩,卡拉岗组为一套陆相中基性−中酸性火山岩及火山碎屑岩(图1)。

2　剖面描述与岩石学特征

本次研究实测了松树沟地区地层剖面,如图2所示。该区地层主要由碎屑沉积岩和火山岩建造组成,碎屑沉积岩构造变形强烈,发育多个背斜和向斜构造,与火山岩地层呈断层接触(图2,图3−a~b)。对碎屑岩地层进行沉积学研究,发现其具有

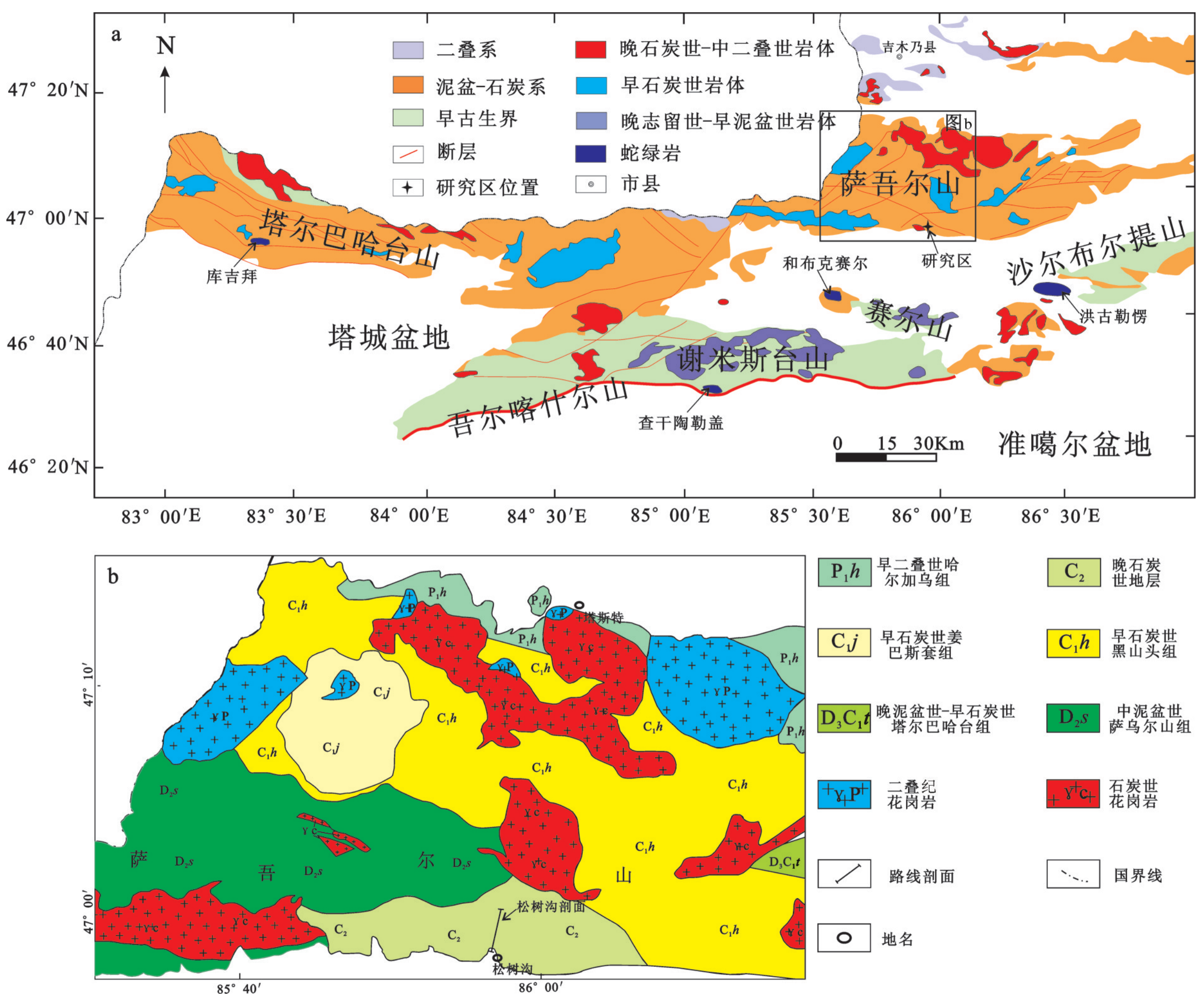

图1 西准噶尔北部地质简图(a)[31] 和萨乌尔山区域地质简图(b)

Fig.1 Simplified geological map (a) of northern West Junggar Basin; regional geological map of the Sawuer Mountain area (b)

典型的浊积岩特征，形成于海底扇环境。与其为断层接触的火山岩建造为火山熔岩和与其同质火山凝灰岩，火山熔岩主要为玄武岩、安山岩。玄武岩为玻晶交织结构，块状构造，含少量的杏仁体。主要由斜长石（60%~70%）、辉石（10%~15%）、玄武玻璃（10%~15%）和钛铁矿（＜1%）等组成，斜长石呈长条状，大小为0.1~0.2 mm，分布杂乱，晶体之间充填的暗色矿物多被绿泥石交代（图3-c）。安山岩为

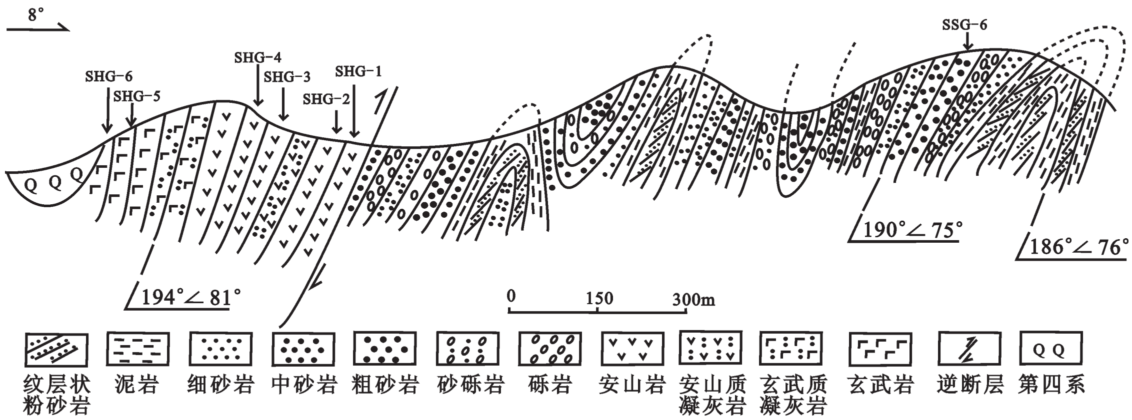

图2 松树沟地区地层路线剖面图
Fig.2 Regional stratigraphic route section in the Songshugou area

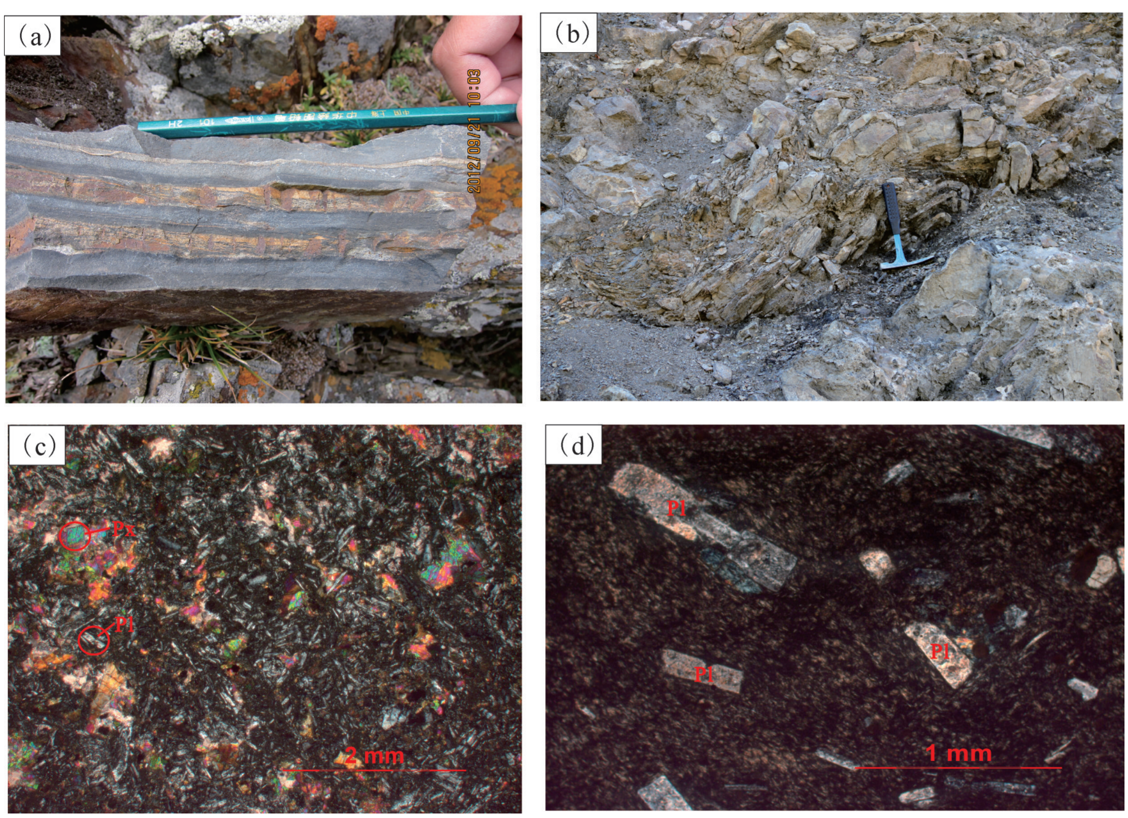

图3 松树沟地区地层产出特征(a,b)及火山岩显微镜下特征(c,d)
a—浊积岩鲍马序列CD段；b—沉积岩褶皱变形；c—玄武岩正交显微照片；d—安山岩正交显微照片
Fig. 3 Field stratigraphic characteristics of the Songshugou area (a, b) and microscopic characteristics of volcanic rocks (c, d)
a – Turbidite Bouma sequence; b – Fold deformation of sedimentary rocks; c – Microscopic photo of basalt (crossed nicols); d – Microscopic photo of andesite (crossed nicols)

斑状结构,块状构造。斑晶主要为斜长石,大小多为0.2~0.8 mm,含量约15%。基质为玻晶交织结构,由斜长石和暗色矿物组成,基质长石具有一定的定向性(图3-d)。

3 测试方法

通过对所采集样品进行室内挑选和镜下观察,选取6件新鲜的火山熔岩样品进行地球化学分析,对安山岩样品(SHG-1)和粗砂岩样品(SSG-6)进行锆石U-Pb同位素测年。主量、稀土及微量元素含量分析在西安地调中心国土资源部岩浆作用成矿与找矿重点实验室完成,锆石阴极发光图像和LA-ICP-MS锆石U-Pb原位同位素分析均在西北大学大陆动力学国家重点实验室完成。

用于挑选锆石的样品为新鲜的岩石,重量大于20 kg,采回后粉碎至80目,经人工淘选,然后在双目镜下挑纯。用于主量和稀土、微量元素分析的火山熔岩样品先进行去风化面处理,选取新鲜的样品粗碎至1~2 mm,粗碎在刚玉鄂式破碎机中进行,粗碎样品经过超声波清洗后,用日本CMT公司生产的TI-100型碳化钨细碎机碎至200目以下。

主量元素采用XRF(Rigaku,2100)玻璃熔饼法完成,精度优于5%,稀土、微量元素采用ICP-MS (Perkin-Elmer公司具动态反应池的Elan600DRC)完成,精度优于10%,样品的溶解在Teflon高压溶样弹中利用1.5 mL HNO_3+1.5 mL HF+0.02 mL $HClO_4$混合酸进行。锆石U-Pb原位同位素分析之前,采用FEI公司的场发射环境扫描电子显微镜Quanta 400 EFG对样品靶进行阴极发光图像照像。锆石U-Pb原位同位素分析所采用的ICP-MS为Elan 6100DRC,测试所用的激光剥蚀系统为Geolas 200M深紫外(DUV)193 nmArF准分子(excimer)激光剥蚀系统,激光斑束半径为15μm。在数据处理时,以Si为内标、NIST610为外标进行U、Th、Pb含量计算,以91500标准锆石为外标进行年代校正。具体过程参见文献[32-35]。

4 岩石地球化学特征

4.1 主量元素

剖面顶部6件玄武岩和安山岩样品的地球化学分析结果(表1,对主量元素扣除烧失量做归一化处理)显示,岩石样品的SiO_2含量为51.14%~64.60%,Na_2O含量为3.65%~4.77%,K_2O为1.34%~2.49%,$Na_2O/K_2O>1$,介于1.63~3.18,在Nb/Y- Zr/TiO_2*0.0001图解(图4)上落入安山岩/玄武岩区域。样品Al_2O_3含量(14.40%~19.76%,均值16.18%)和P_2O_5含量(0.37%~0.47%,均值0.43%)与火山岛弧玄武岩(Al_2O_3 16.00%; P_2O_5 0.44%)接近;CaO(均值4.69%)和MgO(均值3.05%)含量与板内玄武岩(CaO 9.70%; MgO 5.90%)相比明显偏低;TiO_2含量(1.07%~1.26%)也低于板内玄武岩(2.23%)和标准洋中脊玄武岩(1.5%),接近于火山岛弧玄武岩(0.98%)[36-37]。样品主量元素的整体特征与火山岛弧玄武岩相似。

4.2 稀土微量元素

松树沟地区火山熔岩稀土含量较高,∑REE=123.03×10^{-6}~162.88×10^{-6},平均值为147.61×10^{-6},为球粒陨石的(∑REE=3.29×10^{-6})37~50倍。LREE/HREE=3.58~5.52,样品具有轻稀土富集,配分曲线右倾的特征(图5-a); Ce_N/Yb_N=2.38~4.54,δEu=0.74~0.99,铕呈弱的负异常,表明岩浆源区可能为斜长石分离结晶后的残余熔体。原始地幔标准化蛛网图(图5-b)显示,样品富集大离子亲石元素K、Rb、Ba、Sr,亏损高场强元素Nb、Ta、Th、Zr、Hf,呈现出Ta、Nb、Ti负异常特征。

5 锆石U-Pb年代学

对松树沟安山岩(SHG-1)(样品位置:北纬46° 59.317′,东经85°57.364′)和粗砂岩(SSG-6)(样品位置:北纬47°00.005′,东经85°57.545′)样品中的锆石进行阴极发光(CL)观察和LA-ICP-MS锆石U-Pb同位素测定。

安山岩锆石阴极发光图像显示,锆石颗粒多为粒状和不规则状,直径介于40~150μm,表现出无分带、弱分带和面状分带特征(图6)。从锆石U-Pb同位素测定结果(表2)可以看出,锆石测点的U含量为57.1×10^{-6}~705.1×10^{-6}、Th含量为23×10^{-6}~486.4×10^{-6},Th/U比值为0.13~0.9 ,普遍大于0.4,具有岩浆成因锆石特征[39-40]。对于小于10亿年的用$^{206}Pb/^{238}U$年龄作为锆石的结晶年龄,大于10亿年的用$^{207}Pb/^{206}Pb$年龄作为锆石的结晶年龄。样品的年龄介于为257~2089 Ma,明显分为3组,其中较老的年龄有5个,较小的有1个,其余8个年龄集中在308~322 Ma

表1 松树沟火山岩主量(%)、微量元素(10^{-6})分析结果

Table 1 Main volume (%) and trace elements (10^{-6}) analytical results of Songshugou volcanic rocks

样号	SHG-1	SHG-2	SHG-3	SHG-4	SHG-5	SHG-6
岩性	安山岩	安山岩	安山岩	安山岩	玄武岩	玄武岩
SiO_2	64.02	63.62	64.60	63.21	51.24	51.14
TiO_2	1.11	1.12	1.07	1.11	1.17	1.26
Al_2O_3	14.65	14.80	14.40	14.79	18.70	19.76
Fe_2O_3	1.73	1.63	2.05	1.56	4.66	2.55
FeO	6.36	6.33	5.23	6.27	5.50	7.59
MnO	0.16	0.16	0.14	0.19	0.18	0.19
MgO	1.85	1.87	1.52	1.74	5.21	6.14
CaO	3.76	3.77	3.82	4.10	7.98	4.68
Na_2O	4.17	4.02	4.68	4.06	3.65	4.77
K_2O	1.75	2.23	2.06	2.49	1.34	1.50
P_2O_5	0.45	0.45	0.44	0.47	0.37	0.42
Ga	17.4	17.5	16.6	18.1	18.6	20.8
Rb	35.5	43.4	39.5	48.6	14.2	28.2
Sr	760	813	683	831	880	355
Y	38.4	38	35.9	37.8	22	21.8
Zr	154	151	144	151	97.8	93
Nb	4.41	4.28	4.09	4.28	3.89	3.67
Cs	1.04	1.1	0.8	1.57	0.28	1.14
Ba	531	683	548	596	466	451
La	16.3	16.2	15	16	15.3	14.9
Ce	40.9	40.6	37.2	41	39.1	36.3
Pr	5.63	5.58	5.14	5.6	5.16	4.96
Nd	26.9	26.3	24.6	26.3	23.3	22.3
Sm	6.52	6.36	6.09	6.27	5.1	5.01
Eu	1.84	2.08	1.55	1.88	1.68	1.62
Gd	7.13	7.02	6.72	7.02	5.16	5.12
Tb	1.09	1.08	1.04	1.04	0.75	0.73
Dy	6.83	6.66	6.42	6.39	4.18	4.09
Ho	1.48	1.44	1.43	1.42	0.85	0.84
Er	4.18	4.21	4.1	4.15	2.38	2.36
Tm	0.65	0.65	0.63	0.63	0.35	0.36
Yb	4.39	4.32	4.05	4.14	2.23	2.29
Lu	0.64	0.64	0.6	0.62	0.34	0.35
Hf	4.7	4.58	4.47	4.61	2.78	2.65
Ta	0.35	0.33	0.31	0.34	0.3	0.26
U	0.71	0.72	0.67	0.73	0.28	0.28
Th	1.88	1.84	1.74	1.83	0.75	0.72
Cr	4.43	5.18	5.38	4.55	95.6	80.7
Ni	3.56	3.26	2.68	2.27	41.4	30.2
Ti	6656.39	6702.19	6419.40	6683.02	7017.54	7536.73

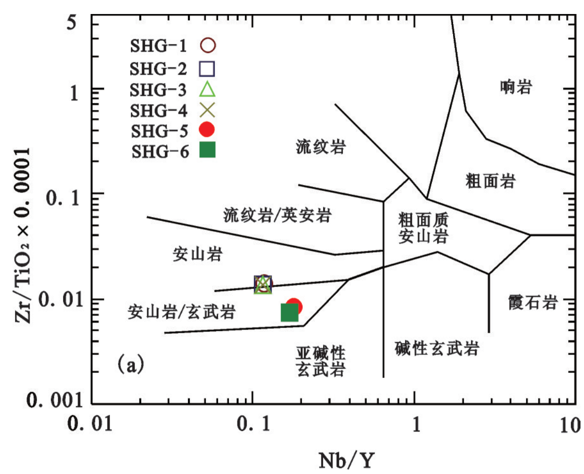

图4 松树沟火山岩Nb/Y−Zr/TiO_2×0.0001图解

Fig.4 Nb/Y −Zr/TiO_2 ×0.0001 diagram of Songshugou volcanic rocks

(图7−a)。

粗砂岩锆石的阴极发光图像显示(图8),锆石直径为50~120 μm,以次棱角状和圆形为主,还有少量为柱状。锆石U−Pb谐和图上,样品的锆石年龄点均沿谐和曲线分布(图9−a),表明锆石形成后基本上没有U、Pb的丢失和加入,锆石的年龄反映成岩或结晶年龄,能够很好地指示源区。从锆石U−Pb同位素测定结果(表3)及年龄分布图(图9−b)可以看出,粗砂岩中锆石颗粒的Th/U比值几乎都大于0.4,显示岩浆成因特征。锆石U−Pb谐和年龄($^{206}Pb/^{238}U$的年龄)主要集中在319~359 Ma,最小年龄为(319±6)Ma,最老为(389±9) Ma。

6 讨 论

6.1 岩石系列划分

Nb、Y为非活动性元素,受蚀变、变质作用影响较小,Nb/Y比值可以有效对碱性和亚碱性系列火山岩进行区分。本次所采样品在SiO_2−Nb/Y图解中都落入亚碱性区域(图10−a)。由于亚碱性系列有着两种不同的岩浆演化趋势,又可以进一步分为钙碱性系列和拉斑系列。在AFM图解(图10−b)中,安山岩样品都落入拉斑系列,玄武岩落入钙碱性系列。

6.2 形成年代

通过锆石成因矿物学研究认为,安山岩中较老的锆石为岩浆捕获锆石,其中出现大量的元古宙信

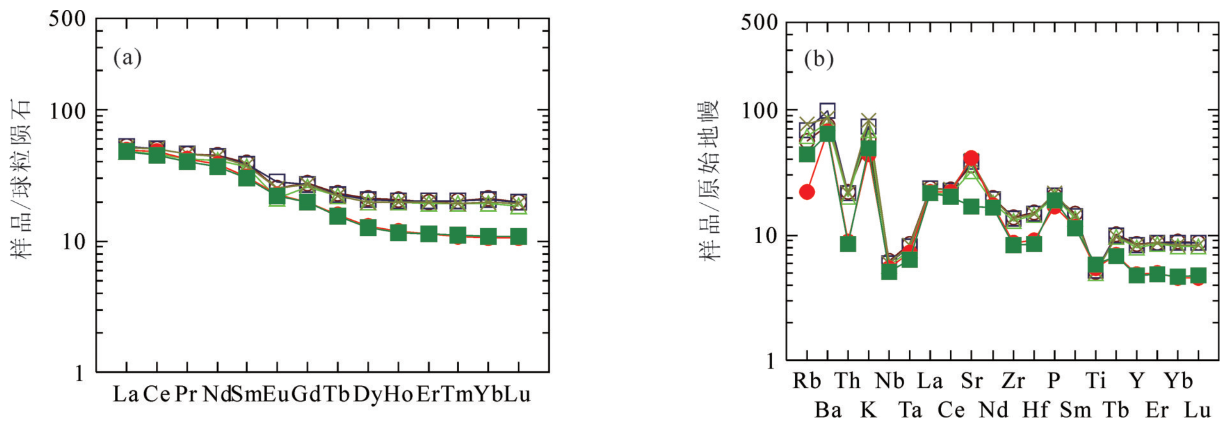

图5 松树沟火山岩稀土微量元素配分曲线(a)和微量元素蛛网图(b)(图例同图4,标准化值据Sun et al.,1989[38])
Fig.5 REE distribution curve (a) and trace elements spider diagram (b) (legends as for Fig. 4, standardized values after Sun et al., 1989[38])

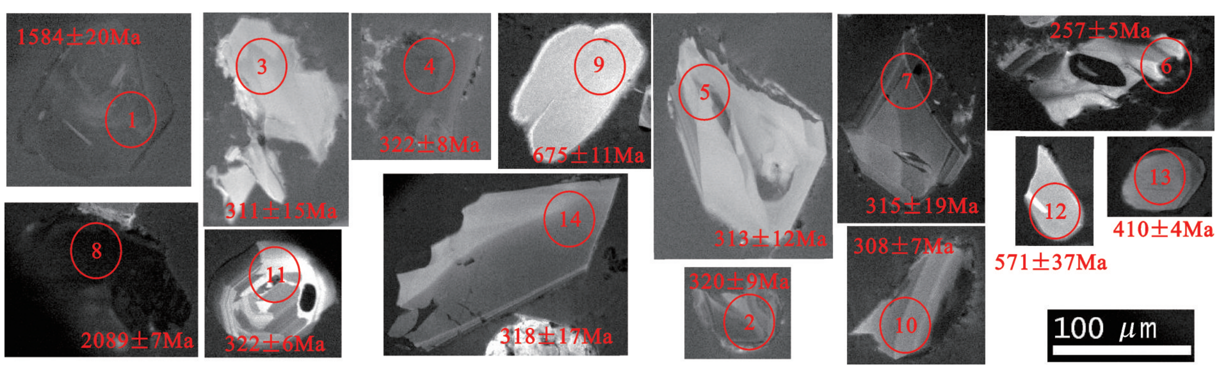

图6 安山岩(SHG−1)锆石CL图像
Fig.6 Zircon CL images of andesite (SHG−1) sample

表2 安山岩(SHG−1)样品锆石U−Pb同位素分析结果
Table 2 Zircon U−Pb isotope analytical results of andesite (SHG−1) sample

点号	Th/μg·g^{-1}	U/μg·g^{-1}	Th/U	同位素比值								谐和年龄	
				$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{208}Pb/^{232}Th$	1σ	年龄/Ma	1σ
NO1	78	212	0.37	0.0979	0.0019	3.3128	0.0583	0.2464	0.0022	0.0670	0.0013	1584	20
NO2	285	334	0.85	0.0533	0.0058	0.3720	0.0398	0.0509	0.0014	0.0158	0.0008	320	9
NO3	28	74	0.37	0.0528	0.0110	0.3592	0.0732	0.0495	0.0024	0.0176	0.0025	311	15
NO4	45	136	0.33	0.0541	0.0057	0.3812	0.0391	0.0512	0.0014	0.0161	0.0013	322	8
NO5	83	168	0.49	0.0526	0.0083	0.3603	0.0558	0.0498	0.0020	0.0167	0.0011	313	12
NO6	54	415	0.13	0.0522	0.0038	0.2929	0.0207	0.0408	0.0008	0.0046	0.0003	257	5
NO7	23	86	0.27	0.0521	0.0129	0.3595	0.0873	0.0501	0.0030	0.0118	0.0028	315	19
NO8	151	237	0.64	0.1293	0.0015	6.8264	0.0553	0.3833	0.0022	0.1071	0.0008	2089	7
NO9	61	77	0.80	0.0618	0.0035	0.9409	0.0514	0.1104	0.0019	0.0408	0.0011	675	11
NO10	81	170	0.48	0.0522	0.0049	0.3515	0.0321	0.0489	0.0012	0.0219	0.0010	308	7
NO11	62	96	0.65	0.0528	0.0042	0.3723	0.0292	0.0512	0.0011	0.0188	0.0009	322	6
NO12	52	57	0.90	0.0588	0.0140	0.7522	0.1756	0.0926	0.0064	0.0348	0.0030	571	37
NO13	486	705	0.69	0.0549	0.0017	0.4978	0.0146	0.0657	0.0006	0.0208	0.0003	410	4
NO14	148	209	0.71	0.0532	0.0115	0.3720	0.0789	0.0506	0.0028	0.0221	0.0033	318	17

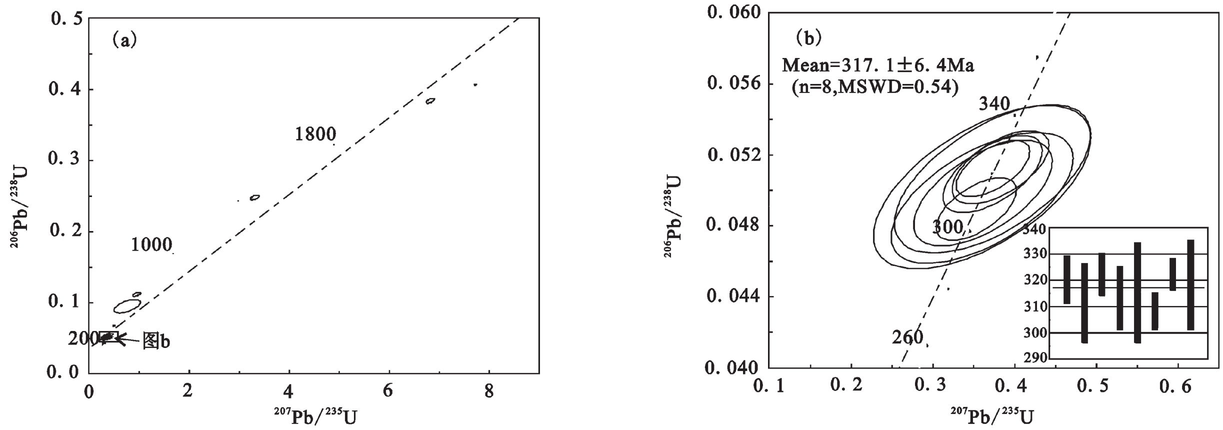

图7 安山岩样品(SHG-1)锆石U-Pb谐和曲线
Fig.7 Zircon U－Pb concordia curve of andesite (SHG-1)

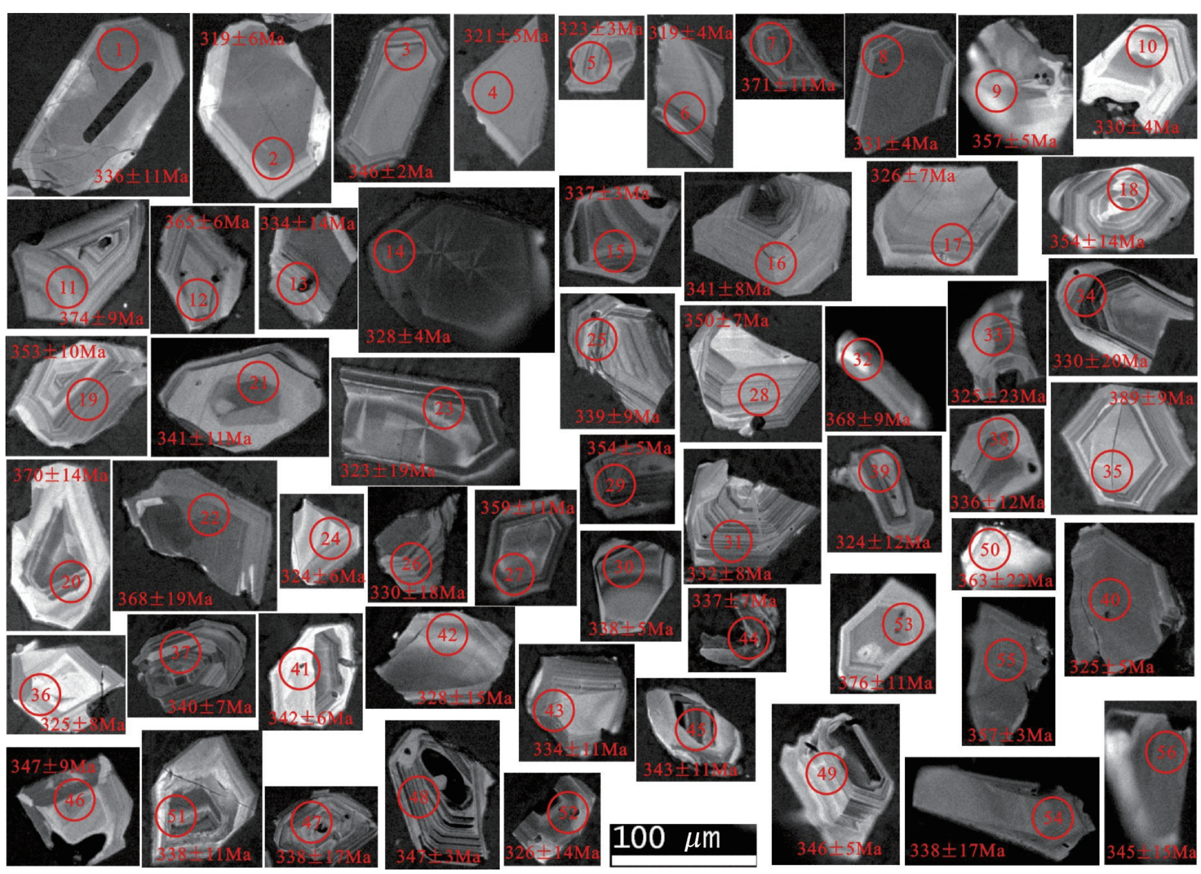

图8 粗砂岩样品(SSG-6)锆石CL图像
Fig.8 Zircon CL images of coarse sandstone (SSG－6) sample

息，表明该区可能存在前寒武纪基底；较小的年龄为257 Ma，其锆石破碎严重，表面为海绵状分带，具有变质锆石特征，Th/U比值较小(0.13)，可能表明后期发生过构造热事件；相对集中的8个$^{206}Pb/^{238}U$年龄加权平均值为(317.1±6.4)Ma(MSWD=0.45)，集中分布在U-Pb谐和线上(图7－b)，代表了岩浆

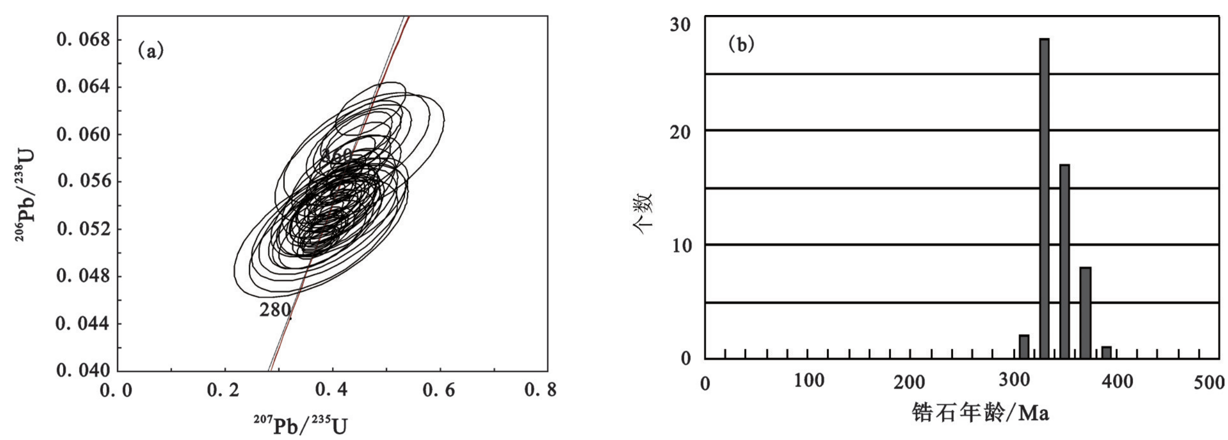

图9 粗砂岩(SSG-6)锆石U-Pb谐和曲线(a)和年龄分布频率图(b)
Fig.9 Zircon U－Pb concordia curve (a) and age distribution frequency diagram (b) of grit (SSG－6)

结晶年龄。

粗砂岩56颗锆石中仅有最老的1颗((389±9) Ma)时代属于中泥盆世,其余均为石炭纪,与前人所划地层时代相差较大。查阅前人的研究❶,发现其在松树沟地区并未找到生物化石,仅在松树沟以西地层中发现保存不好的具有中泥盆世特征的生物化石,这表明当时对松树沟地区地层时代的划分缺少依据。本次对该套地层中安山岩和粗砂岩的锆石U-Pb同位素测年研究表明,松树沟地区的地层时代不可能是中泥盆世,很可能为晚石炭世早期。

6.3 形成环境

火山岩样品SiO_2含量为51.14%~64.60%,Al_2O_3为14.40%~19.76%,P_2O_5为0.37%~0.47%,TiO_2为1.07%~1.26%,CaO均值4.69%,MgO均值3.05%,主量元素含量与火山岛弧玄武岩相近。微量元素研究表明,样品富集大离子亲石元素(K、Rb、Ba、Sr),亏损高场强元素(Nb、Ta、Th、Zr、Hf),明显不同于大离子亲石元素亏损的洋中脊玄武岩,具有Ta、Nb亏损的特征,有别于洋岛玄武岩[41]。微量元素Ta含量为0.26×10^{-6}~0.35×10^{-6},Nb为3.67×10^{-6}~4.41×10^{-6},Yb为2.23×10^{-6}~4.39×10^{-6},Ta/Yb(0.08~0.13)、Th/Nb(0.19~0.43)、Nb/La(0.25~0.27)、Hf/Th(2.49~3.71)均满足与俯冲相关的岛弧火山岩特征[42−43]。在玄武岩地球化学环境判别图解(图略)上,样品都落入与岛弧相关的区域。以上研究都表明,松树沟火山岩形成于与俯冲相关的岛弧环境。

6.4 岩浆来源

研究表明,地幔中的橄榄岩、俯冲带释放的流体和大洋壳转变为榴辉岩之后部分熔融形成的熔体是岛弧地区岩浆的物质来源[44−48]。松树沟火山岩稀土元素球粒陨石标准化分配模式图显示,其具有轻稀土富集的右倾曲线特征,在微量元素原始地幔标准化蛛网图上呈现出富集大离子亲石元素,亏损高场强元素,表明火山岩应该来源于相对富集的地幔。在微量元素Zr/Nb－La/Y、La/Nd－Sm/Yb图解(图11)上,松树沟火山岩位于N－MORB和OIB区域之间,与典型的N－MORB和OIB明显不同,说明其源区不是N－MORB源区和与洋岛类似的软流圈地幔源,最可能来源于富集的岩石圈地幔。样品Y(21.8×10^{-6}~38.4×10^{-6})、Yb(2.23×10^{-6}~4.39×10^{-6})含量较高,明显不同于埃达克质岩浆,暗示着岩浆源区不可能有俯冲板片熔体的加入。样品具有相对富集大离子亲石元素、轻稀土元素和亏损Nb、Ta的地化特征(图5－b),表明其岩浆源区是俯冲流体交代的地幔楔。样品中Ba/La比值(30.27~42.16)较高,说明俯冲带流体对岩浆源区影响显著[49]。

6.5 大地构造意义

笔者在松树沟地区研究发现,该区受俯冲作用的影响,岛弧火山岩被逆冲到海相浊积岩之上,沉积物伴随着强烈的褶皱变形。通过对安山岩和粗

❶新疆维吾尔自治区地质矿产局.中华人民共和国区域地质调查报告(1:200000塔克台、和布克赛尔幅L-45-Ⅶ、Ⅷ),1986.

表3 粗砂岩(SSG−6)样品锆石U−Pb同位素分析结果

Table 3 Zircon U−Pb isotope analytical results of grit (SSG −6) sample

点号	Th/μg·g^{-1}	U/μg·g^{-1}	Th/U	同位素比值								谐和年龄	
				$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{208}Pb/^{232}Th$	1σ	年龄/Ma	1σ
NO1	34	69	0.49	0.0543	0.0076	0.4003	0.0552	0.0535	0.0019	0.0168	0.0013	336	11
NO2	199	147	1.36	0.0529	0.0038	0.3707	0.0261	0.0508	0.0009	0.0146	0.0004	319	6
NO3	148	297	0.50	0.0535	0.0013	0.4069	0.0086	0.0552	0.0004	0.0173	0.0002	346	2
NO4	77	129	0.60	0.0526	0.0031	0.3703	0.0209	0.0511	0.0007	0.0134	0.0004	321	5
NO5	196	351	0.56	0.0532	0.0022	0.3771	0.0148	0.0514	0.0006	0.0162	0.0003	323	3
NO6	243	415	0.59	0.0530	0.0029	0.3700	0.0194	0.0507	0.0007	0.0156	0.0005	319	4
NO7	78	193	0.41	0.0540	0.0067	0.4416	0.0537	0.0593	0.0019	0.0175	0.0014	371	11
NO8	176	212	0.83	0.0530	0.0028	0.3858	0.0197	0.0527	0.0007	0.0160	0.0004	331	4
NO9	39	93	0.42	0.0536	0.0031	0.4214	0.0239	0.0570	0.0008	0.0186	0.0006	357	5
NO10	64	97	0.65	0.0531	0.0026	0.3854	0.0183	0.0526	0.0007	0.0157	0.0004	330	4
NO11	65	172	0.38	0.0541	0.0050	0.4452	0.0405	0.0597	0.0014	0.0189	0.0011	374	9
NO12	81	125	0.65	0.0539	0.0035	0.4335	0.0272	0.0583	0.0010	0.0217	0.0007	365	6
NO13	90	173	0.52	0.0535	0.0092	0.3922	0.0660	0.0532	0.0023	0.0192	0.0017	334	14
NO14	107	195	0.55	0.0529	0.0027	0.3810	0.0185	0.0522	0.0007	0.0157	0.0004	328	4
NO15	66	167	0.39	0.0532	0.0021	0.3935	0.0146	0.0536	0.0006	0.0156	0.0004	337	3
NO16	51	113	0.45	0.0534	0.0050	0.3996	0.0369	0.0542	0.0013	0.0166	0.0009	341	8
NO17	122	203	0.60	0.0529	0.0044	0.3786	0.0310	0.0518	0.0011	0.0211	0.0011	326	7
NO18	54	98	0.55	0.0541	0.0088	0.4214	0.0668	0.0564	0.0023	0.0186	0.0015	354	14
NO19	49	73	0.67	0.0535	0.0060	0.4151	0.0454	0.0562	0.0016	0.0189	0.0010	353	10
NO20	64	120	0.53	0.0544	0.0080	0.4441	0.0640	0.0591	0.0022	0.0173	0.0015	370	14
NO21	80	129	0.62	0.0541	0.0070	0.4057	0.0511	0.0544	0.0018	0.0185	0.0011	341	11
NO22	71	154	0.46	0.0543	0.0112	0.4401	0.0891	0.0587	0.0031	0.0209	0.0024	368	19
NO23	589	463	1.27	0.0535	0.0131	0.3792	0.0911	0.0514	0.0031	0.0192	0.0022	323	19
NO24	76	113	0.67	0.0532	0.0041	0.3786	0.0284	0.0515	0.0010	0.0147	0.0006	324	6
NO25	32	71	0.44	0.0531	0.0060	0.3963	0.0441	0.0541	0.0015	0.0200	0.0013	339	9
NO26	69	105	0.66	0.0533	0.0119	0.3870	0.0843	0.0526	0.0030	0.0172	0.0017	330	18
NO27	84	163	0.52	0.0542	0.0064	0.4284	0.0493	0.0573	0.0017	0.0180	0.0012	359	11
NO28	33	77	0.43	0.0536	0.0043	0.4134	0.0327	0.0559	0.0011	0.0168	0.0008	350	7
NO29	146	169	0.87	0.0536	0.0030	0.4177	0.0226	0.0564	0.0008	0.0163	0.0004	354	5
NO30	55	141	0.39	0.0533	0.0029	0.3960	0.0210	0.0539	0.0008	0.0161	0.0006	338	5
NO31	48	116	0.41	0.0535	0.0053	0.3903	0.0378	0.0528	0.0013	0.0203	0.0011	332	8
NO32	39	84	0.46	0.0541	0.0055	0.4381	0.0437	0.0587	0.0015	0.0175	0.0010	368	9
NO33	71	108	0.65	0.0525	0.0152	0.3750	0.1062	0.0518	0.0037	0.0207	0.0028	325	23
NO34	120	143	0.84	0.0536	0.0132	0.3887	0.0940	0.0525	0.0033	0.0163	0.0021	330	20
NO35	45	81	0.56	0.0544	0.0051	0.4664	0.0431	0.0621	0.0015	0.0184	0.0010	389	9
NO36	35	67	0.53	0.0531	0.0054	0.3788	0.0378	0.0517	0.0013	0.0151	0.0008	325	8
NO37	92	187	0.49	0.0536	0.0045	0.4004	0.0327	0.0541	0.0012	0.0171	0.0008	340	7
NO38	59	120	0.49	0.0536	0.0074	0.3961	0.0537	0.0536	0.0019	0.0174	0.0014	336	12
NO39	89	149	0.60	0.0531	0.0077	0.3771	0.0538	0.0515	0.0019	0.0142	0.0009	324	12
NO40	100	143	0.70	0.0530	0.0034	0.3779	0.0233	0.0517	0.0009	0.0151	0.0004	325	5
NO41	111	146	0.76	0.0533	0.0035	0.4003	0.0259	0.0544	0.0009	0.0145	0.0005	342	6
NO42	110	241	0.46	0.0530	0.0098	0.3821	0.0692	0.0523	0.0024	0.0211	0.0025	328	15
NO43	38	65	0.58	0.0534	0.0075	0.3919	0.0538	0.0533	0.0019	0.0183	0.0013	334	11
NO44	256	286	0.90	0.0535	0.0042	0.3962	0.0305	0.0537	0.0011	0.0167	0.0006	337	7
NO45	64	152	0.42	0.0537	0.0067	0.4048	0.0494	0.0547	0.0018	0.0169	0.0013	343	11
NO46	27	65	0.42	0.0539	0.0055	0.4111	0.0411	0.0553	0.0015	0.0183	0.0012	347	9
NO47	115	176	0.65	0.0562	0.0109	0.4173	0.0790	0.0538	0.0027	0.0215	0.0019	338	17
NO48	256	385	0.67	0.0540	0.0019	0.4117	0.0140	0.0553	0.0006	0.0170	0.0003	347	3
NO49	120	161	0.75	0.0535	0.0030	0.4068	0.0220	0.0552	0.0008	0.0182	0.0005	346	5
NO50	65	101	0.64	0.0559	0.0132	0.4456	0.1032	0.0579	0.0036	0.0178	0.0025	363	22
NO51	421	422	1.00	0.0536	0.0071	0.3982	0.0514	0.0539	0.0018	0.0163	0.0013	338	11
NO52	73	163	0.45	0.0529	0.0088	0.3789	0.0618	0.0519	0.0022	0.0169	0.0017	326	14
NO53	118	127	0.93	0.0542	0.0062	0.4494	0.0498	0.0601	0.0018	0.0215	0.0012	376	11
NO54	184	211	0.87	0.0538	0.0107	0.3989	0.0777	0.0538	0.0028	0.0162	0.0014	338	17
NO55	66	113	0.58	0.0538	0.0020	0.4229	0.0148	0.0570	0.0006	0.0184	0.0004	357	3
NO56	148	239	0.62	0.0537	0.0094	0.4067	0.0694	0.0550	0.0025	0.0224	0.0021	345	15

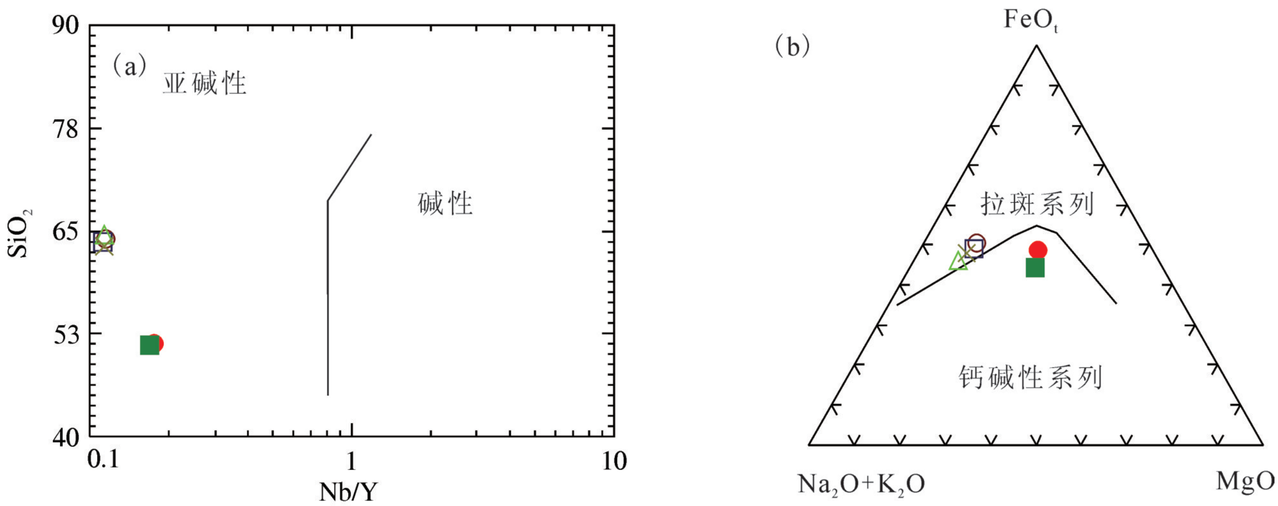

图10 松树沟火山岩SiO₂-Nb/Y图解(a)和AFM图解(b)(图例同图4)

Fig.10 SiO_2 – Nb/Y diagram (a) and age distribution diagram (b) of the Songshugou volcanic rocks (legends as for Fig. 4)

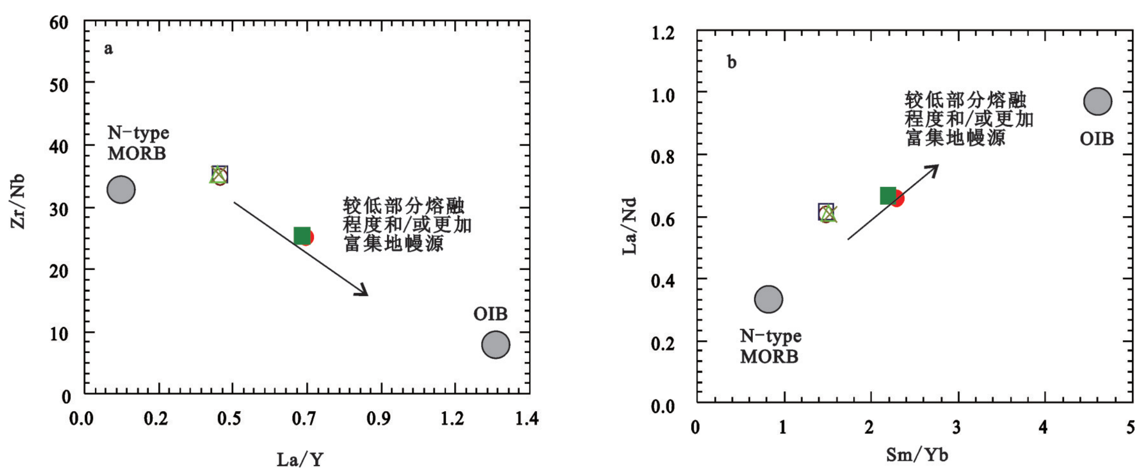

图11 火山岩La/Y-Zr/Nb(a)和Sm/Yb-La/Nd(b)图解(图例同图4)

Fig. 11 La/Y–Zr/Nb (a) and Sm/Yb–La/Nd (b) diagram of the volcanic rocks (legends as for Fig. 4)

砂岩的锆石U-Pb同位素测年，认为该套地层可能形成于晚石炭世早期，同时岩浆岩捕获锆石((1584±20) Ma、(2089±7) Ma、(675±11) Ma、(571±37) Ma)也给出了前寒武纪古老地块存在的信息。最北部察尔斯克蛇绿岩研究发现有晚泥盆世到早石炭世牙形石和放射虫化石[50-51]，表明斋桑洋盆在晚泥盆世到早石炭世依然存在，结合本次研究认为北部斋桑洋盆的关闭时限晚于317 Ma。

7 结　论

(1)松树沟地区火山岩组合中安山岩的LA－ICP－MS锆石U－Pb年代学研究表明其形成年龄为(317.1±6.4)Ma，沉积岩粗砂岩中锆石U-Pb年龄主要集中在319~359 Ma，最小年龄(319±6) Ma，最老年龄为(389±9) Ma，这些都表明该套地层并非形成于中泥盆世，很可能形成于晚石炭世早期。岩浆锆石中还获得大量的捕获锆石信息((1584±20) Ma、(2089±7) Ma、(675±11) Ma、(571±37) Ma)，进一步佐证了该区存在前寒武纪古老地块。

(2)火山岩具有轻稀土富集的右倾型REE分布模式，δEu弱的负异常(0.74~0.99)，富集大离子亲石元素K、Rb、Ba、Sr等，亏损高场强元素Nb、Ta、Th、Zr、Hf等，呈现出Ta、Nb、Ti负异常，具有典型岛弧火山岩地化特征，岩浆源区为俯冲流体不均一交

代的地幔楔。

(3)本区岛弧火山岩的形成时代限定了斋桑洋盆的关闭时限晚于317.1 Ma。

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The formation age and volcanic rock geochemical study of Songshugou strata in the Sawuer Mountain

WENG Kai[1,2], ZHANG Xue[2], MA Zhong−ping[1], CHEN Jun−lu[1], SUN Ji−ming[1], ZHANG Tao[1,2]

(1. *Key Laboratory for the Study of Focused Magmatism and Giant Ore Deposits, MLR, Xi' an Center of Geological Survey, Xi' an* 710054*, Shaanxi, China;* 2. *School of Earth Science & Resources, Chang' an University, Xi' an* 710054, *Shaanxi, China*)

Abstract: Songshugou strata in the west of the Junggar Basin are made up of clastic sedimentary rocks and volcanic rocks. The volcanic rocks are mainly basalt, andesite and volcanic clastic rock, in which basalt belongs to calc−alkaline series and andesite belongs to porphyry series. Zircon U − Pb dating of these rocks shows that the age of zircon in andesite is (317.1±6.4) Ma. In 56 zircon samples, only one age is (389±9) Ma, suggesting the middle Devonian, whereas all other ages are concentrated in 319 ~359 Ma, with the youngest one being (319±6) Ma. It is thus held that the strata were probably formed at the early stage of the late Carboniferous rather than in the middle Devonian. Geochemical studies show that the basalt and andesite have similar REE partition curves as well as right−oblique REE patterns of rich light rare earth elements, and are enriched in high ionic elements such as K, Rb, Ba, Sr and depleted in high field strength elements such as Nb, Ta, Th, Zr and Hf, with Ta, Nb, Ti negative anomalies. It is concluded that the volcanic rocks were formed in an island− arc environment and the magma was derived from mantle wedge formed by metasomatism of subducting plate dehydration that produced fluid. The formation of island arc volcanic rock restricted the closing time of the zhaisang basin(later than 317.1 Ma).

Key words: western Junggar; island arc volcanic rocks; zircon U−Pb dating; geochemistry

About the first author: WENG Kai, male, born in 1985, doctor candidate, majors in petrology and mineral deposits; E−mail: kaikaino1@qq.com.

About the corresponding author: MA Zhong−ping, male, born in 1970, doctor, professor, majors in mineralogy, petrology and mineral deposits; E−mail: xamzhongping@cgs.gov.cn.