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甘肃合黎山古元古代正长岩的发现及其对阿拉善地块大地构造属性的启示

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提要：阿拉善地块的大地构造属性是近年来地质界激烈争论的科学问题：是华北克拉通的一部分，还是在前寒武纪尚未与华北克拉通拼合？研究阿拉善地块的基底并与华北克拉通主体进行对比，对探讨这一问题具有重要启示。阿拉善地块的基底仅在其东部和西南缘零星出露，且前人的研究主要集中在地块东部。在阿拉善地块西部的合黎山地区，有正长岩侵入龙首山群，并被震旦系不整合覆盖。该正长岩强烈富钾（K_2O = 13.77%），轻、重稀土明显分异（$(La/Yb)_N$ = 46.62），显示Nb−Ta负异常和Pb−Zr−Hf正异常，并具有高Sr低Nd的同位素特征（$\varepsilon_{Nd}(t)$ = −5.05），表明该岩体源于玄武质下地壳的部分熔融。LA−ICP−MS锆石U−Pb定年表明，该正长岩形成于(1872 ± 12) Ma，即古元古代，并记录了~2.7 Ga的地壳生长以及~2.5 Ga和~1.95 Ga的岩浆活动。合黎山古元古代正长岩的发现补充了阿拉善地块前寒武纪基底的组成，进一步完善了阿拉善地块新太古代—古元古代基底和构造热事件的时代格架，且与华北克拉通主体十分相似，指示二者具有明显的亲缘性。

关 键 词：前寒武纪基底；古元古代；阿拉善地块；大地构造属性；深地探测工程

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The discovery of the Paleoproterozoic syenite in Helishan, Gansu Province, and its implications for the tectonic attribution of the Alxa Block

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Abstract: The tectonic affinity of the Alxa block has long been in debate. It may be part of the North China Craton (NCC), or independent from the NCC during the Precambrian. The comparison of basements between the Alxa block and the NCC would be helpful to solving this dispute, but the Alxa basement is relatively poorly studied due to limited outcrops, with most of available data reported in eastern Alxa. Recently, a syenite that intruded into the Longshoushan Group has been sampled in Helishan area, western Alxa, and both of them are unconformably covered by Sinian strata. The Helishan syenite is characterized by extremely enriched

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K_2O (13.77 %) and LREE [$(La/Yb)_N$ = 46.62], and shows distinct negative and positive anomalies of Nb−Ta and Pb−Zr−Hf, respectively, with EM−I type Sr−Nd isotope features ($\varepsilon_{Nd}(t)$ = −5.05), implying partial melting of basaltic lower crust. Moreover, LA−ICP−MS zircon U−Pb data indicate that this syenite was formed during Paleoproterozoic (1872 ± 12) Ma and display records of ~2.7 Ga crustal growth and ~2.5, 2.1 and 1.95 Ga magmatic activities. According to data from this study and previously published data, the Neoarchean− Pelaoproterozoic basements and tectono− thermal events of the Alxa block and the NCC are geochronologically consistent, indicating very close affinity between them.

Key words: Precambrian basement; Paleoproterozoic; Alxa block; tectonic affinity; deep earth exploration engineering

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1 引　言

阿拉善地块东接华北克拉通主体，西南部通过河西走廊盆地邻接祁连造山带（陈宣华等, 2019），北侧以巴丹吉林断裂带为界与中亚造山带相接（Zhang et al., 2015a），其大地构造属性是近年来地质界激烈争论的科学问题。传统上，阿拉善地块被认为是华北克拉通的组成部分（图 1a；宫江华等, 2011; Gong et al., 2012; Hu et al., 2014），可能是阴山地块的西部（Zhao et al., 2005; Wan et al., 2006; Zhao et al., 2012），也可能是孔兹岩带的西延（耿元生等, 2010; Zhang et al., 2013a; 张建新和宫江华, 2018）。近年来，通过研究阿拉善地块中部的新元古代岩浆作用、东部的早古生代沉积源区和古地磁极以及东缘的古生代剪切和沉积构造特征，部分学者提出阿拉善地块在前寒武纪不属于华北克拉通（李锦轶等, 2012; 张进等, 2012; Dan et al., 2016），可能与塔里木或扬子克拉通更具亲缘性（董国安等, 2007; Zhang et al., 2011, 2015b, 2016b; Dan et al., 2014; Yuan and Yang, 2015；Song et al., 2017），也可能是一个独立演化的前寒武纪微陆块（耿元生等, 2010; Dan et al., 2012; Zhang et al., 2013b, 2016a）。

阿拉善地区是否存在华北克拉通特征性的新太古代—古元古代基底及构造热事件（~2.7 Ga、~2.5 Ga、~1.95 Ga 和 ~1.85 Ga；Zhao et al., 2005, 2010, 2012; Xia et al., 2006; Jiang et al., 2010; Han et al., 2012; Jian et al., 2012; Ma et al., 2012; Wang and Liu, 2012; Wan et al., 2014），是讨论上述争议问题的

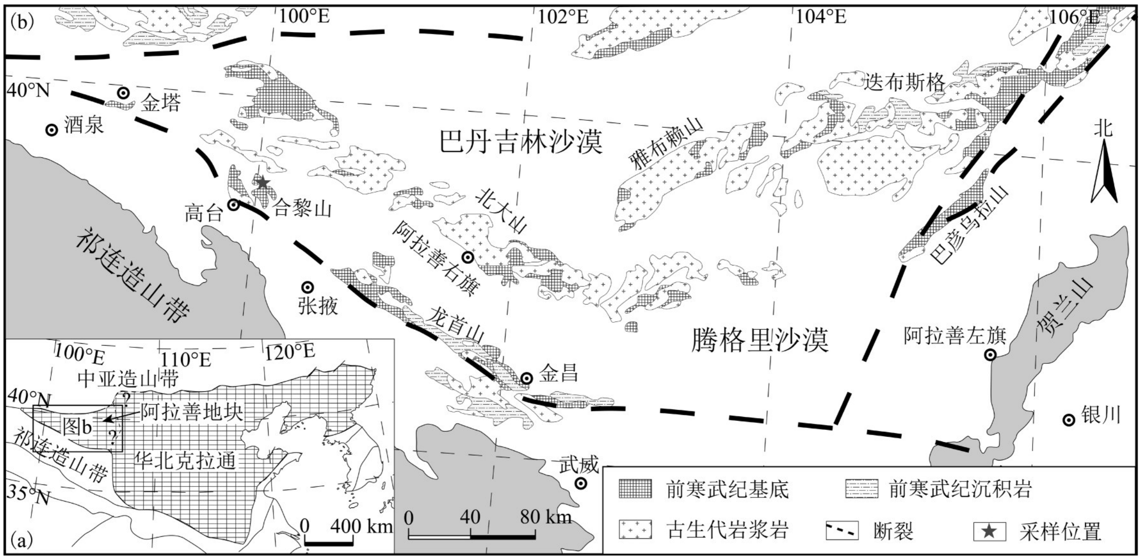

图 1 阿拉善地块大地构造位置（a 据 Zhao et al., 2005 修改）和地质简图（b 据 Gong et al., 2012 修改）
Fig.1 Tectonic map of the Alxa Block (a,modified from Zhao et al., 2005) and Geological sketch map of the Alxa Block (b,modified from Gong et al., 2012)

关键。阿拉善地块前寒武纪基底主要分布在东北部的迭布斯格、东部的巴彦乌拉山、西南部的龙首山和北大山等地区(图1b)。迭布斯格杂岩可能是新太古代基底(~2.7 Ga;内蒙古自治区地质矿产局, 1991;耿元生等, 2006),但其副片麻岩的沉积年龄为古元古代(2.45~2.0 Ga;Dan et al., 2012)。巴彦乌拉山杂岩也曾被认为是新太古代基底(内蒙古自治区地质矿产局, 1991),而其变质火山岩的原岩可能形成于古元古代(2.34~2.24 Ga;耿元生等, 2006; Dan et al., 2012; Wu et al., 2014)。汤中立和白云来(1999)曾在龙首山群基性火山岩中获得中太古代(3.18 Ga)的Sm−Nd等时线年龄,但近年的锆石U−Pb定年结果表明其变质沉积岩(2.2~1.7 Ga)和花岗质片麻岩(2.17~1.91 Ga)都可能形成于古元古代(修群业等, 2002; 董国安等, 2007; 宫江华等, 2011)。此外,最近有学者在合黎山的前震旦系中识别出中元古代花岗质片麻岩(~1.2 Ga)和含新元古代碎屑锆石((968 ± 70) Ma)的变质沉积岩(Song et al., 2017)。值得注意的是,北大山地区出露的花岗闪长质片麻岩的成岩年龄为~2.5 Ga,其Hf同位素模式年龄为3.0~2.7 Ga(Gong et al., 2012; Zhang et al., 2013a)。并且,阿拉善基底记录的变质年龄主要集中在3个时段:~2.5 Ga、1.95~1.9 Ga和1.85~1.8 Ga(宫江华等, 2011; Dan et al., 2012; Gong et al., 2012; Zhang et al., 2013a; Wu et al., 2014)。

本文在阿拉善南缘西部合黎山地区发现了侵入龙首山群的正长岩,并进行了锆石U−Pb定年以及元素和同位素地球化学分析。通过研究该岩体的成岩时代、岩浆成因和源区特征,结合前人研究成果,分析阿拉善基底及构造热事件的时代格架,这将有助于探讨阿拉善地块的大地构造属性。

2 地质背景及样品描述

合黎山位于阿拉善南缘的最西端(图1b),是龙首山的西延部分(宫江华等, 2011; Song et al., 2017),主要出露龙首山群、震旦系和古生代岩浆岩。龙首山群分布在河西走廊北侧,呈NWW−SEE走向,西起金塔县境内,经高台合黎山到金昌龙首山一带,以角闪岩相—绿片岩相的变质中基性火山岩和变沉积岩为主,岩性包括混合岩、大理岩、斜长角闪岩、黑云斜长片麻岩、云母片岩、石英片岩等。震旦系绿片岩相变质沉积岩不整合覆盖在龙首山群之上,岩性包括变石英砂岩、变硅质岩、大理岩、云母石英片岩以及黑云斜长片麻岩等。阿拉善地块西南缘的古生代岩浆岩可分为志留纪—早泥盆世和晚石炭世—二叠纪两期,岩性以中酸性花岗岩为主,基性和超基性岩浆岩零星出露。

采样点位于合黎山的东部(图1b;39°32′06.00″N,100°01′29.94″E),花岗岩侵入龙首山群黑云斜长片麻岩,二者共同被震旦系变石英砂岩不整合覆盖(图2a)。该花岗岩(CQL2016−74)野外呈肉红色,中粗粒,主要由碱性长石(包括正长石、微斜长石、歪长石,~75%)、斜长石(~10%)、黑云母(~15%)和少量白云母构成,定名为正长岩(图2b)。微斜长石和斜长石分别发育格子双晶和聚片双晶,偶见石英,副矿物可见锆石和磷灰石。

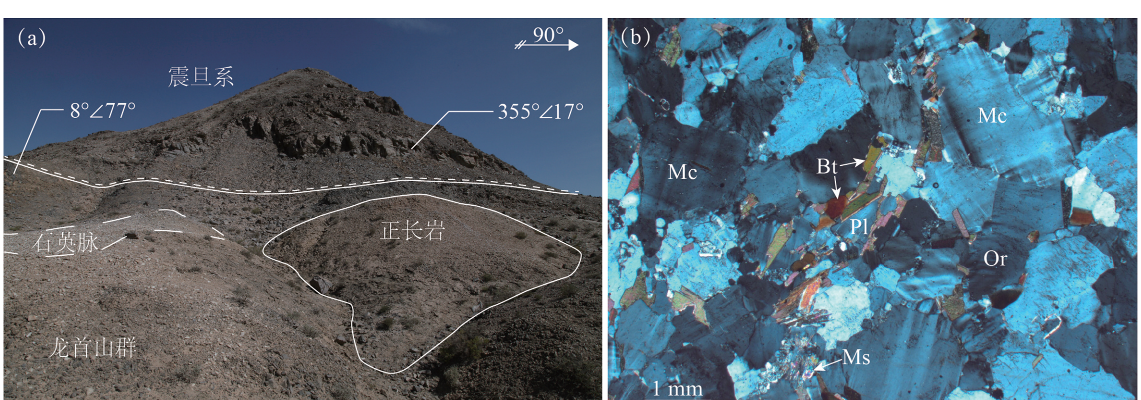

图2 合黎山正长岩的野外特征(a)和镜下特征(b,正交偏光)
Bt—黑云母;Mc—微斜长石;Ms—白云母;Or—正长石;Pl—斜长石
Fig.2 Field characteristics (a) and mineral assemblages (b, crossed nicols) of the Helishan syenite
Bt−Biotite; Mc−Microcline; Ms−Muscovite; Or−Orthoclase; Pl−Plagioclase

3 分析方法

锆石的分离采用常规的重液和磁选方法，然后在双目镜下手工挑选。样品靶的制备过程参考宋彪等(2002)文献。在光学显微镜的透、反射光下分别观察锆石包体和裂隙分布，并用JSMIT−500型钨灯丝扫描电镜观察锆石生长结构。锆石U−Pb测年在中国地质科学院矿产资源研究所完成，测试仪器由Finnigan Neptune型多接收等离子质谱仪(MC−ICP−MS)和Newwave UP 213型激光剥蚀系统组成，详细操作流程参考侯可军等(2007, 2009)。普通铅校正采用Andersen(2002)，谐和图和年龄计算应用ISOPLOT 4.15(Ludwig, 2009)。单个点位的同位素比值和表观年龄误差为1σ，加权平均年龄采用2σ误差，置信度为95%。测年数据见表1。

全岩主量及微量元素测试在中国地质科学院国家地质实验测试中心完成。主量元素含量的测试仪器为PW4400型X射线荧光光谱仪。其中，FeO的检测方法依据GB/T 14506.14−2010，其他主要氧化物含量的检测方法依据GB/T 14506.28−2010。稀土及微量元素含量的测试仪器为PE300D型等离子质谱仪，检测方法依据GB/T 14506.30−2010。分析结果见表2。

全岩Sr−Nd同位素测试在中国地质科学院地质研究所完成。其中，Sr同位素比值采用MAT262型固体同位素质谱计测定，SRM 987标准测定结果

表1 合黎山古元古代正长岩LA−ICP−MS锆石U−Pb定年数据

Table 1 LA−ICP−MS zircon U–Pb data for the Paleoproterozoic syenite in Helishan

点号	同位素比值						年龄/Ma						谐和度/%	Th/10^{-6}	U/10^{-6}	Th/U
	$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ				
1	0.114440	0.001664	5.017675	0.088737	0.318370	0.003646	1872	21	1822	15	1782	18	95	186.22	304.93	0.61
2	0.114797	0.001610	5.147837	0.091605	0.325118	0.003481	1877	25	1844	15	1815	17	97	103.87	217.40	0.48
3	0.123427	0.003758	5.464166	0.170195	0.322998	0.004982	2006	55	1895	27	1804	24	90	70.36	32.18	2.19
4	0.117310	0.001706	5.269447	0.102104	0.326070	0.004573	1917	21	1864	17	1819	22	95	102.57	150.09	0.68
5	0.114102	0.001604	5.283526	0.085895	0.336256	0.003539	1866	25	1866	14	1869	17	100	94.26	147.57	0.64
6	0.114183	0.004050	4.680410	0.159668	0.301451	0.006960	1933	60	1764	29	1699	34	88	130.49	238.73	0.55
7	0.163831	0.001860	10.379742	0.150588	0.459717	0.004758	2495	19	2469	13	2438	21	98	95.76	189.87	0.5
8	0.115299	0.001284	5.308434	0.081375	0.333713	0.003615	1884	20	1870	13	1856	17	99	271.22	443.52	0.61
9	0.112773	0.001957	5.202999	0.101683	0.334722	0.003708	1856	32	1853	17	1861	18	100	55.03	85.68	0.64
10	0.116439	0.001656	5.032394	0.105341	0.313218	0.005477	1902	26	1825	18	1757	27	92	169.25	346.50	0.49
11	0.113461	0.001693	5.268591	0.098090	0.336705	0.004161	1857	28	1864	16	1871	20	101	75.09	130.39	0.58
12	0.116421	0.001623	5.157780	0.090048	0.321313	0.003929	1902	25	1846	15	1796	19	94	74.85	234.90	0.32
13	0.129929	0.002378	6.802791	0.165656	0.378379	0.005399	2098	32	2086	22	2069	25	99	40.45	57.31	0.71
14	0.112517	0.001519	5.066841	0.071340	0.327001	0.003010	1840	24	1831	12	1824	15	99	199.74	178.11	1.12
15	0.113417	0.001396	4.869909	0.073721	0.311269	0.003243	1855	22	1797	13	1747	16	94	81.71	196.56	0.42
16	0.112875	0.001178	4.974941	0.060728	0.319421	0.002579	1846	19	1815	10	1787	13	97	260.86	621.51	0.42
17	0.163533	0.001542	10.393848	0.141033	0.460642	0.005004	2492	16	2471	13	2442	22	98	247.14	383.73	0.64
18	0.160779	0.001626	9.676856	0.121038	0.436229	0.003947	2465	17	2405	12	2334	18	95	181.14	230.13	0.79
19	0.113096	0.001495	5.181197	0.082486	0.332312	0.003790	1850	24	1850	14	1850	18	100	114.96	195.33	0.59
20	0.113586	0.001452	4.982631	0.079069	0.317538	0.003059	1858	23	1816	13	1778	15	96	44.64	179.47	0.25
21	0.117271	0.001922	5.265973	0.109857	0.324793	0.003894	1917	29	1863	18	1813	19	95	81.80	159.06	0.51
22	0.112576	0.001565	5.104952	0.088827	0.329051	0.004257	1843	25	1837	15	1834	21	100	84.16	231.18	0.36
23	0.118823	0.003814	5.185845	0.164244	0.319062	0.004984	1939	57	1850	27	1785	24	92	37.25	19.14	1.95
24	0.121214	0.002036	5.862185	0.157088	0.347949	0.005843	1976	31	1956	23	1925	28	97	40.09	110.91	0.36
25	0.114652	0.001386	5.073111	0.072786	0.320769	0.003072	1876	21	1832	12	1793	15	96	101.37	227.11	0.45
26	0.113320	0.002452	5.088000	0.121102	0.325604	0.004182	1854	39	1834	20	1817	20	98	43.45	122.18	0.36
27	0.113241	0.002114	5.258621	0.116763	0.336719	0.004502	1854	34	1862	19	1871	22	101	158.68	84.37	1.88
28	0.114611	0.001429	5.306895	0.079504	0.335550	0.003290	1874	23	1870	13	1865	16	100	299.69	348.49	0.86

注：本文谐和度=($^{206}Pb/^{238}U$年龄/$^{207}Pb/^{206}Pb$年龄)×100%。

表2 合黎山正长岩主量(%)及微量元素(10^{-6})含量

Table 2 Major (%) and trace element (10^{-6}) concentrations of the Paleoproterozoic syenite in Helishan

SiO_2	62.40	Tl	0.71
Al_2O_3	18.39	Pb	36.6
CaO	0.27	Bi	0.11
Fe_2O_3	0.73	Th	8.85
FeO	0.94	U	1.24
K_2O	13.77	Nb	7.18
MgO	0.76	Ta	0.47
MnO	0.03	Zr	144
Na_2O	1.09	Hf	3.99
P_2O_5	0.04	Ti	1388
TiO_2	0.24	W	0.62
CO_2	0.11	As	0.10
H_2O^+	0.84	V	17.3
LOI	0.58	Sc	3.04
Total	100.19	Y	4.6
A/CNK	1.07	Cr	2.50
$Mg^{\#}$	51.80	Sn	0.43
ALK	14.86	Sb	<0.05
K_2O/Na_2O	12.63	La	35.1
σ	11.38	Ce	65.5
Li	12.3	Pr	6.84
Be	0.55	Nd	23.2
Mn	225	Sm	3.06
Co	3.13	Eu	0.79
Ni	1.88	Gd	1.96
Cu	5.96	Tb	0.27
Zn	20.5	Dy	1.17
Ga	15.1	Ho	0.21
Rb	225.0	Er	0.55
Sr	527	Tm	0.08
Mo	0.18	Yb	0.54
Cd	<0.05	Lu	0.10
In	<0.05	∑REE	139.37
Cs	1.68	$(La/Yb)_N$	46.62
Ba	2211	δ Eu	0.92

为 $^{87}Sr/^{86}Sr = 0.710243 \pm 12\ (2\sigma)$，质量分馏以 $^{88}Sr/^{86}Sr = 8.37521$ 校正。Nd同位素的测试仪器为Nu Plasam HR型多接收电感耦合等离子体质谱仪(MC−ICP−MS)，分析方法参考唐索寒等(2017)。JMC标准测定结果为 $^{143}Nd/^{144}Nd = 0.511123 \pm 10\ (2\sigma)$，GSB标准测定结果为 $^{143}Nd/^{144}Nd = 0.512440 \pm 10\ (2\sigma)$，同位素质量分馏采用 $^{146}Nd/^{144}Nd = 0.7219$ 校正。测试结果见表3。

表3 合黎山正长岩Sr−Nd同位素数据

Table 3 Sr−Nd isotopic compositions of the Helishan syenite

$Rb/10^{-6}$	$Sr/10^{-6}$	$(^{87}Rb/^{86}Sr)s$	$(^{87}Sr/^{86}Sr)s$	error(2σ)	$(^{87}Sr/^{86}Sr)t$
225	527	1.235415	0.738443	0.000015	0.705162
$Sm/10^{-6}$	$Nd/10^{-6}$	$(^{147}Sm/^{144}Nd)s$	$(^{143}Nd/^{144}Nd)s$	error(2σ)	$(^{143}Nd/^{144}Nd)t$
3.06	23.2	0.080276	0.510946	0.000009	0.509957
年龄/Ma		$\varepsilon_{Nd}(t)$	T_{DM}/Ma	T_{DM2}/Ma	f_S
1872		−5.05	2505	2758	−0.59

注：1) s表示样品测定值，t表示t时刻的初始值；2) $(^{87}Rb/^{86}Sr)s$ 和 $(^{147}Sm/^{144}Nd)s$ 是根据Rb、Sr、Sm、Nd的全岩ICP−MS测定值估算的；3) $(^{87}Sr/^{86}Sr)t=(^{87}Sr/^{86}Sr)s-(^{87}Rb/^{86}Sr)s\times(e^{\lambda t}-1)$，$\lambda=1.42\times10^{-11}a^{-1}$；$(^{143}Nd/^{144}Nd)t=(^{143}Nd/^{144}Nd)s-(^{147}Sm/^{144}Nd)s\times(e^{\lambda t}-1)$，$\lambda=6.54\times10^{-12}/a^{-1}$；$\varepsilon_{Nd}(t)=[(^{143}Nd/^{144}Nd)t/(^{143}Nd/^{144}Nd)_{CHUR,,t}-1]\times10000$。

4 分析结果

合黎山正长岩中的锆石自形程度较高，多为菱形或柱状，长与宽的分布范围分别是100~300 μm和80~200 μm，部分锆石具有核−幔−边结构，所有锆石都保存了良好的岩浆震荡环带(图3a)。在28颗锆石上进行了28点分析，谐和度均大于85%(图3b，表1)，其Th、U含量分别为 37×10^{-6}~300×10^{-6} 和 19×10^{-6}~622×10^{-6}，Th/U比值为0.25~2.19，指示锆石岩浆成因。$^{207}Pb/^{206}Pb$ 表观年龄的分布范围是2495~1840 Ma，且明显具有~2.5 Ga和~1.85 Ga两个峰值(图3d)。其中，测试点07、17和18均位于锆石核上(图3a)，其 $^{207}Pb/^{206}Pb$ 年龄的加权平均值为(2484 ± 20) Ma(MSWD = 0.95)；测试点13位于锆石幔上(图3a)，其 $^{207}Pb/^{206}Pb$ 表观年龄为(2098 ± 32) Ma；测试点6和24也位于锆石幔上，其 $^{207}Pb/^{206}Pb$ 表观年龄分别为(1933 ± 60) Ma和(1976 ± 31) Ma；剩余的22个测试点聚集成簇(图3c)，位于锆石边或不发育核−幔−边结构的锆石上，其 $^{207}Pb/^{206}Pb$ 年龄的加权平均值为(1872 ± 12) Ma(MSWD = 1.2；图3e)。

合黎山正长岩具有中硅(SiO_2 = 62.40%)、富铝(Al_2O_3 = 18.39%)、富碱(ALK = 14.86%)的特征(图4a)，特别是强烈富钾(K_2O = 13.77%，K_2O/Na_2O = 12.63)，弱过铝质(A/CNK = 1.07；图4b)。其稀土总量为 139.37×10^{-6}，轻、重稀土分异明显(图4c)，$(La/Yb)_N$ 比值为46.62，Eu异常不明显或弱负异常(δEu = 0.92)。大离子亲石元素富集(Cs、Rb、Ba等)，高场强元素亏损(Y、Yb、Lu等)，具有明显的Nb−Ta负异常

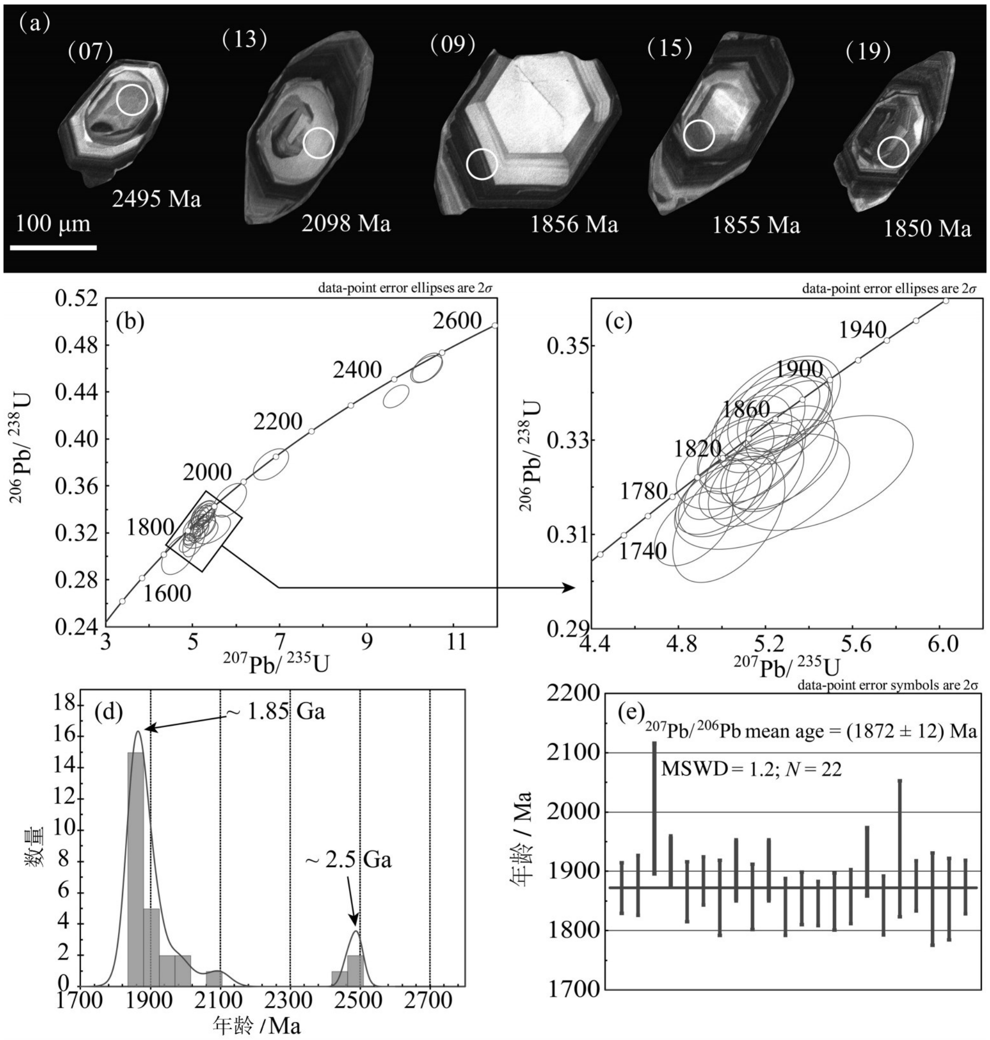

图3 合黎山正长岩锆石阴极发光照片(CL)与谐和图

Fig.3 Cathodoluminescence (CL) images and zircon U−Pb concordia diagrams of the Helishan syenite

和Pb−Zr−Hf正异常(图4d)。此外,该正长岩具有EM−I型同位素特征(图5a),其初始 $^{87}Sr/^{86}Sr$ 和初始 $^{143}Nd/^{144}Nd$ 分别为0.705162和0.509957,$\varepsilon_{Nd}(t)$为负值(−5.05)。样品的分异程度(f_s=−0.59)高于大陆地壳平均水平(f_{cc}=−0.4;Depaolo et al., 1991; Wu et al., 2005),计算得到其单阶段和二阶段Nd模式年龄分别为2505 Ma和2758 Ma(图5b)。

5 讨　论

5.1 合黎山正长岩的岩石成因与成岩时代

合黎山正长岩属于中性岩浆岩(SiO_2 = 62.40 %),其源区应为玄武质,而强烈富钾与低Nb/U比值(5.79)进一步指向陆壳源区(赵振华, 2005)。与下地壳平均组分相比,该正长岩的稀土分异程度更高(图4c),表明源区残留相中可能存在石榴子石;Rb、Ba和Pb的富集(图4d)可能与碱性长石作为主要熔体相有关(图2b),但没有同时出现明显的Sr和Eu正异常,表明在残留相中可能存在大量斜长石;Zr−Hf正异常的出现与大陆地壳特征相似(Rudnick and Gao, 2003),而与典型岛弧岩浆岩特征不符(Wang et al., 2016a)。此外,合黎山正长岩的Sr−Nd同位素特征也指示大陆下地壳源区,综合判断该正长岩可能源于大陆玄武质下地壳的部分熔融。

LA−ICP−MS锆石U−Pb定年结果表明,合黎山正长岩形成于中元古代((1872 ± 12) Ma),且记录了~2.5 Ga和~1.95 Ga的岩浆活动信息。该正长岩的分异因子小于大陆地壳平均值(f_s=−0.59 <f_{cc}=

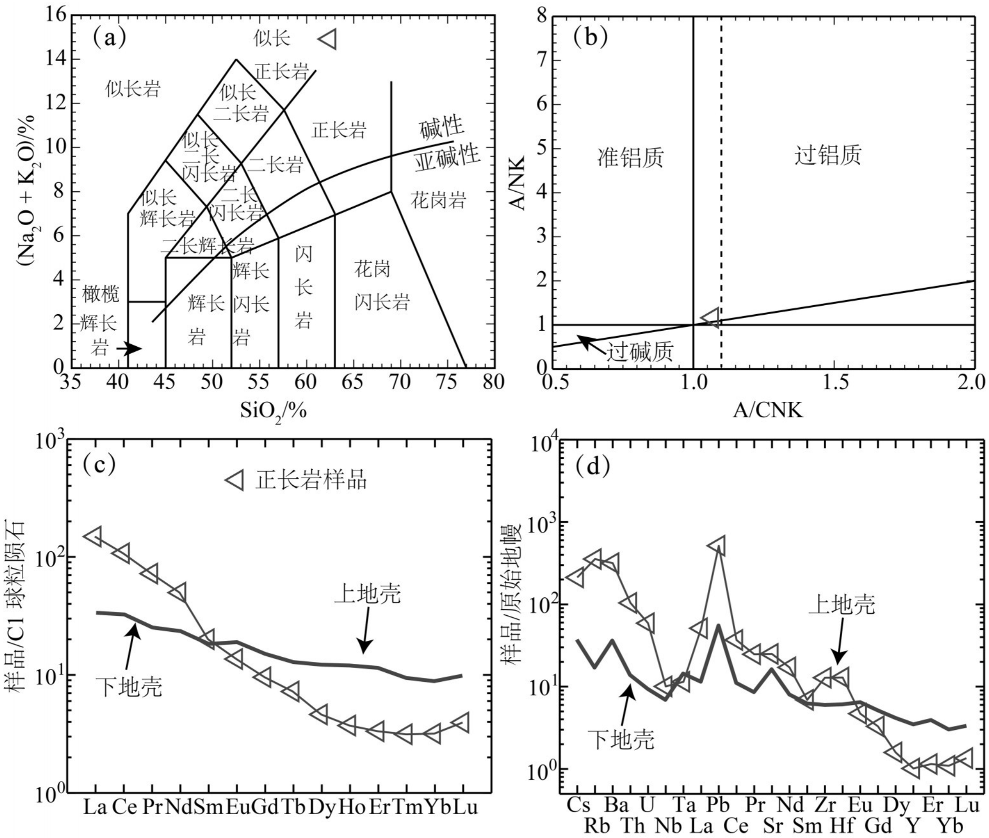

图4 合黎山正长岩主量及微量元素特征
（下地壳平均组分参考Rudnick and Gao, 2003）
Fig.4 Diagrams showing major and trace element features of the Helishan syenite
(the composition of lower crust after Rudnick and Gao, 2003)

−0.4)，表明玄武质下地壳在部分熔融过程中发生了Sm/Nd分馏(Jahn et al., 2000)，而f_{cc}与fs可分别描述部分熔融发生前与发生后的Nd同位素演化(图5b；Jacobsen, 1988)，因此采用二阶段Nd模式年龄(T_{DM2})，即该正长岩源区玄武质岩浆从亏损地幔的分离发生在新太古代(~2.7 Ga)。

5.2 对阿拉善地块大地构造属性的启示

合黎山正长岩的发现，表明在远离华北克拉通主体的阿拉善地块西端(图1)存在~2.7 Ga的地壳生长、~1.85 Ga的构造热事件，以及~2.5 Ga和~1.95 Ga的岩浆活动记录。在阿拉善地块南部的北大山地区，存在~2.5 Ga具有TTG特征的基底片麻岩，并记录了~2.8 Ga的地壳生长以及~2.5 Ga和~1.85 Ga两期变质事件(Gong et al., 2012; Zhang et al., 2013a)。在阿拉善地块东部的巴彦乌拉山地区，古元古代变质火山岩记录了~1.95 Ga和~1.85 Ga两期变质事件(Dan et al., 2012; Wu et al., 2014)。在阿拉善地块东北部的狼山地区，新太古代—古元古代基底的形成时代可分为~2.7 Ga、~2.6 Ga、~2.5 Ga、~1.95 Ga和~1.7 Ga 5个期次(Wang et al., 2016b)。此外，龙首山和迭布斯格地区的古元古代变质基底也记录了~1.95 Ga和1.85 Ga两期变质事件(宫江华等, 2011; Dan et al., 2012; Gong et al., 2016)。总结起来，阿拉善地块经历了2.8~2.7 Ga的地壳生长，存在~2.5 Ga变质基底和古元古代岩浆活动，并记录了~2.5 Ga、~1.95 Ga和~1.85 Ga三期变质事件。

华北克拉通主体的前寒武纪变质基底主要形成于新太古代—古元古代，以2.8~2.7 Ga的地壳生长时代(Wu et al., 2005; Jiang et al., 2010; Han et al., 2012)和~2.5 Ga的基底成岩时代为特征(Zhao et al., 2005; Zhai and Santosh, 2011; Wang and Liu, 2012; Wan et al., 2014),并记录了~1.95 Ga和~1.85 Ga两期大规模构造事件(Wu et al., 2005; Wan et al., 2006, 2014; Yin et al., 2009, 2011, 2014; Zhao et al., 2010, 2012; Dong et al., 2013; Cai et al., 2014)。可见,阿拉善地块与华北克拉通主体的新太古代—古元古代基底和构造热事件的时代特征非常一致,表明二者具有明显的亲缘关系。

如果阿拉善地块在前寒武纪不属于华北克拉通,那么二者之间应该存在古缝合带。值得注意的是,Liu et al.(2017)发表的近东西向横穿贺兰山及银川盆地的深地震反射剖面恰好位于阿拉善地块与鄂尔多斯地块的边界位置(图1,图4),但地壳中并不存在俯冲缝合结构,这意味着这条尚未发现的缝合带如果存在的话,应位于贺兰山以西。因此,贺兰山及其南部的牛首山、香山、大罗山和小罗山等地区早古生界的沉积源区和古地磁极等地质特征不适合作为阿拉善地块与华北克拉通在早古生代尚未拼合的证据。并且,已有学者提出这一区域的早古生界可能是祁连造山带的组成部分(张建新和宫江华, 2018)。然而,阿拉善地块中部巴音诺尔公地区出露的新元古代S型花岗岩(ca. 930~904 Ma;耿元生和周喜文, 2010; Dan et al., 2014)与华北克拉通广泛发育的新元古代基性岩墙群(ca. 925~890 Ma;Peng et al., 2011; 翟明国等, 2014; Peng, 2015)确实存在明显差异。如果阿拉善地块属于华北克拉通的一部分,则必须对此差异进行合理解释,这需进一步深入研究。

6 结　论

合黎山正长岩形成于(1872 ± 12) Ma,属于中元古代,其记录了~2.7 Ga的地壳生长以及~2.5 Ga、~2.1 Ga和~1.95 Ga的岩浆活动,可能源于玄武质下地壳的部分熔融。该正长岩的发现进一步完善了阿拉善地块基底的区域分布和年代学格架,显示阿拉善地块与华北克拉通主体新太古代—古元古代基底和构造热事件的时代特征一致,这是二者具有亲缘性的重要佐证。

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