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扬子北缘大洪山地区早古生代基性岩脉的厘定及其地质意义

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摘要:扬子北缘大洪山地区广泛出露北西—南东向基性岩脉,脉体主要侵位于区内前南华系基底砂板岩、白云岩中,而南华系及上覆盖层中少见。长期以来,这套基性侵入岩的形成时代和背景都存在疑问,通过对七里冲、姚家咀、姚家冲、刘关4个地区的基性岩脉进行锆石LA-ICP-MS U-Pb测年,获得成岩年龄分别为433.7 Ma、435.6 Ma、433.4 Ma、436.4 Ma,这些年龄值在误差范围内一致,同属于早志留世,为大洪山地区这期基性岩脉提供了精确的同位素年代学依据。地球化学方面,大洪山地区基性岩脉表现为亚碱性系列的特点,较高ΣREE含量,轻、重稀土存在分异,富集LILEs而亏损HFSEs,Zr>100×10⁻⁶,TiO₂>2%,Zr/Y>3.5,指示其形成于大陆伸展环境。首次在扬子地块北缘识别出一套早古生代晚期代表大陆伸展环境的基性岩脉,为扬子地块北缘大洪山地区存在早古生代近北东向的区域伸展提供强有力的证据。研究表明,早古生代秦岭—大别南缘和扬子地块北缘虽然在沉积上地层存在差异,但可能同属于扬子北缘陆缘裂谷拉张环境。

关键词:扬子北缘;基性岩脉;早古生代;锆石U-Pb测年;地球化学。

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Documentation of Early Paleozoic Mafic Dykes in the Dahongshan Region, Northern Yangze Block and Its Geological Significance

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Abstract: NE-SW mafic dykes are widespread in the Dahongshan region, northern Yangtze block. They mainly emplaced the pre-Nanhua basement rock, e.g. dolomite, sandstone and slate, and scarcely found in Nanhuan system and its overlying strata. It has been controversial for their formation age and background of the mafic dykes for a long time. In this paper, LA-ICP-MS zircon dating for 4 mafic dykes from Qilichong, Yaojiaju, Yaojiachong and Liuguan yield U-Pb ages of 433.7 Ma, 435.6 Ma, 433.4 Ma and 436.4 Ma respectively. All the ages belong to the Early Silurian and are consistent within measuring errors, and offer precise isotope chronology to the mafic dykes in the Dahongshan region. The mafic dykes in the Dahongshan region are characterized by subalkalic series, high ΣREE content, medium differentiation between LREE and HREE, enriched LILEs and depleted HFSEs, Zr>100×10⁻⁶, TiO₂>2%, and Zr/Y>3.5. Accordingly, it is suggested that they may have formed in a continental extension environment. We have discerned Early Paleozoic mafic dykes swarm indicative of continental extension in the northern Yangtze block for the first time. It provides powerful evidence that the Dahongshan region in the northern Yangtze block shows NE regional extension. Additionally, we tentatively thought that the south Qinling-Dabie mountain and the north Yangtze block belong to same extensional epicontinental rift environment although different sedimentary strata appeared

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between them in Early Paleozoic.

Key words: northern Yangze block; mafic dykes; Early Paleozoic; zircon U-Pb dating; geochemistry.

0 引言

扬子地块是华南大陆的主体组成部分,南华纪—三叠纪以稳定盖层为主,岩浆活动、变质作用微弱,构造运动以整体升降为特征,习惯上被称为扬子克拉通。扬子地块北侧的秦岭一大别造山带和东侧的江南造山带风格迥异,南华纪以来发生了多期的构造—岩浆活动(张国伟等,1995,1997; Dong *et al.*, 2011a; 何卫红等,2014; 张思敏等,2014; 徐先兵等,2015)。其中,早古生代(加里东期)是秦岭一大别造山带和江南造山带演化的重要时期,二者都保存了该时期较广泛的构造—岩浆记录。在秦岭一大别造山带,大量事实证明商丹蛇绿带和二郎坪蛇绿岩—弧火山岩主体都形成于早古生代(张国伟等,1995,1997; 孙卫东等,1996; 陆松年等,2006; 闫全人等,2007; 陈隽璐等,2008; Dong *et al.*, 2011a, 2011b; 赵姣等,2012),说明该时期秦岭一大别造山带发生了较为广泛的俯冲—增生事件;而同时期的南秦岭大巴山—武当—随枣地区则发育大量双峰式火山岩—侵入岩组合(黄月华等,1992; 董云鹏等,1998a; 张成立等,2002; 马昌前等,2004; 万俊等,2016),指示南秦岭该时期表现为较一致的裂谷环境。在江南造山带,近年来随着带内早古生代与俯冲相关的蛇绿岩、岛弧火山岩以及高压变质岩的发现,逐渐确定了该时期俯冲—增生—碰撞造山事件的存在(覃小锋等,2013,2015; 彭松柏等,2016a,2016b)。因此,前人认为早古生代扬子地块与秦岭一大别造山带、江南造山带具有不同的构造演化背景。并且后二者发育强烈的构造运动、岩浆活动,而扬子地块基本呈克拉通式稳定状态。

本文在系统地野外地质调查和室内测试分析的基础上,主要分析扬子北缘大洪山地区早古生代晚期的基性岩脉,旨在说明扬子克拉通南华纪以来并非绝对稳定,并且扬子北缘在早古生代可能卷入了区域伸展过程。

1 区域地质背景

研究区位于湖北随州市南部,扬子地块与秦岭一大别造山带的接触部位,二者边界襄樊—广济

断裂呈北西—南东向贯穿研究区北部(图1)。研究区及邻区秦岭一大别造山带南缘、扬子地块的南华纪—早古生代地层、岩石建造组合存在明显的不同。

北部造山带内由老到新主要出露南华系武当岩群和耀岭河组(原随县群)、震旦系灯影组和陡山沱组、下古生界和少量上古生界,局部可见少量早古生代基性侵入岩。早古生代,大巴—武当—随枣一带地层和岩石组合都具有较好的可对比性,以浅水的碳酸盐岩、碎屑岩夹大量的碱性玄武岩和粗面质火山岩为主,广泛发育奥陶纪—志留纪的碱性辉绿—辉长岩和正长岩,代表一套早古生代陆缘裂谷建造(董云鹏等,1998a; 张成立等,2002; 马昌前等,2004; 薛怀民和马芳,2005; 邹先武等,2011; 万俊等,2016; 向忠金等,2016)。值得一提的是,北部造山带内早古生代地层兰家畈组(群)中,存在一套高Ti的基性火山岩组合,主体岩性为变辉斑玄武岩,局部可见变玄武质角砾熔岩、变杏仁状玄武岩、变基性凝灰岩等(董云鹏等,1998a),古生物研究表明其形成时代为O₃-S₁。

南部扬子地块内主要出露前南华系基底和南华纪—早古生代盖层,基底和盖层之间为角度不整合接触,局部被后期断层改造。早期区域地质调查表明,区内前南华系基底主要由中元古界打鼓石群和青白口系花山群组成(湖北省地质局区域地质测量队,1982)。近年的调查研究将原花山群和部分打鼓石群定义为一套新元古代早期的岩浆弧—增生杂岩组合,代表晋宁期缝合带(董云鹏等,1998b; Dong *et al.*, 1999; 胡正祥等,2015,2017; 廖明芳等,2016; Xu *et al.*, 2016; 陈超等,2017a,2017b)。剩余部分被重新定义打鼓石群,其形成时代可能为1.2 Ga(李怀坤等,2016; 孔令耀等,2017; 刘浩等,2017)。盖层由下至上为南华系莲沱组陆相沉积、南沱组冰碛岩,向上逐渐过渡为一套震旦纪—志留纪的滨浅海稳定大陆边缘沉积(何卫红等,2014)。与南秦岭一大别造山带不同,整个扬子地块早古生代岩浆岩少见。

2 基性岩脉特征

最新详细的地质调查表明大洪山地区有大量的镁铁质岩组合,大体可以分为两期:一期主要以岩块

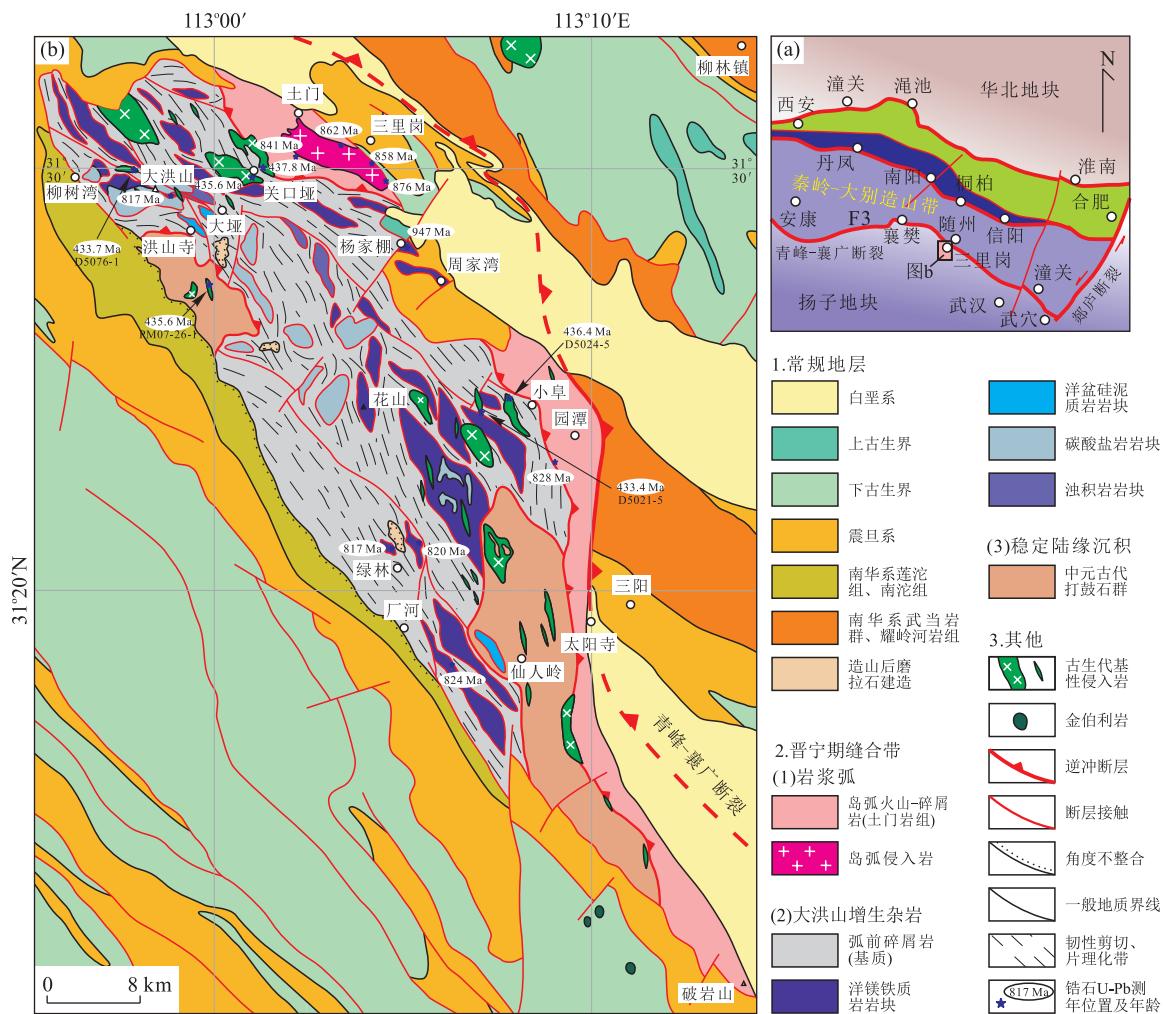


图 1 大洪山地区早古生代基性侵入岩地质背景简图

Fig.1 Simplified geological map about Early Paleozoic mafic intrusions in the Dahongshan region

形式混杂于一套碎屑岩中,与围岩呈断层接触,形成时代为青白口纪 (Shi *et al.*, 2007; 胡正祥等, 2015; 陈超等, 2017a);另一期主要以岩脉、小型岩株产出,与围岩呈侵入接触关系,形成时代为早古生代晚期(图 1).这些早古生代基性侵入岩主要在区内前南华系基底中大范围出露,而在南华系及其上盖层中发育较少.笔者统计了大洪山地区 21 条基性岩脉位置、产状、围岩、围岩蚀变及其被改造的特征(表 1).脉体出露宽度一般在 0.8~11.0 m 之间,多数集中在 1~2 m.产状多数向北东倾斜,倾向集中在 60°~80°之间,倾角一般近直立,少数呈平缓状态侵位.围岩主要包括砂板岩、泥晶白云岩、白云岩、白云质砾岩等(图 2),大部分围岩都产生了一定程度的蚀变,产生角岩化、白色大理岩化,并发育赤红色烘烤边(图 2a, 2e).多数基性岩脉存在被后期构造改造的痕迹,脉体与围岩之间发生一定错动(图 2b),且脉体本身片理化强烈(图 2a, 2d),但也有少数保持

了原有的产状和岩石结构(图 2c).在一般后期构造改造影响较小的情况下,大规模的基性岩脉、岩墙群指示伸展环境,其伸展方向与脉体走向近垂直(Williams *et al.*, 2001; 李宏博等, 2012).考虑到大洪山地区基性岩脉大部分侵入前南华系基底中,基底相对较为稳定,且大部分侵入接触界面被后期构造改造的特征不明显,因此这些岩脉的产状一定程度上可以反映原始区域伸展方向.大洪山地区以花山一线为界,北部脉体多呈北西西延伸,12 条脉体赤平投影反映北北东向的伸展作用(图 2f);南部脉体多呈北北西向延伸,9 条脉体赤平投影反映北东东向的伸展作用(图 2g).

室内显微镜下显示(图 3),大洪山地区的基性岩脉主要由基性斜长石和辉石组成.斜长石多呈自形一半自形板条状,大小 0.2~1.8 mm 不等,含量多达 55%~73%,大部分斜长石都发生较强的碳酸盐化蚀变,内部形成大量细粒的黏土矿物,但基本都保

表1 大洪山地区典型基性岩脉特征统计

Table 1 Statistical table of the features for typical mafic dykes in the Dahongshan region

编号	地点	GPS	产状	描述(脉体和围岩特征)
北部				
1	南风垭公路边	E112°59'25" N31°28'47"	60°∠85°	辉绿岩脉宽约2.5m,内部基本未发生变形,围岩为白云质、硅质砾岩,围岩发生一定蚀变,接触界面有错动,边部片理化强烈。
2	南坡公路边	E112°58'16" N31°29'09"	98°∠44°	辉绿岩脉宽约1.5m,内部基本未发生变形,围岩为白云岩,白云岩产状与接触界面近平行,围岩发生一定褐铁矿化,接触界面无错动。
3	南坡公路边	E112°58'12" N31°29'08"	62°∠64°	辉绿岩脉宽约4m,片理化强烈,片理产状90°∠48°,围岩为白云岩,白云岩层理产状345°∠70°,围岩发生一定蚀变,接触界面基本无错动,边部片理化强烈。
4	白龙池边	E112°57'40" N31°28'59"	72°∠76°	辉绿岩脉宽1~3m,基本未发生变形,围岩为泥质条带白云岩,产状5°∠66°,围岩发生一定蚀变,且岩脉中可见白云岩包体,脉体与围岩接触界面无错动。
5	白龙池边	E112°57'41" N31°28'58"	67°∠24°	辉绿岩脉宽约0.5m,围岩为白云岩,围岩发育宽约3cm的蚀变带,脉体与围岩接触界面基本无错动,但都发生强烈片理化,片理产状123°∠45°。
6	白龙池边	E112°57'41" N31°28'58"	76°∠42°	辉绿岩脉宽约2m,围岩为白云岩,蚀变带发育,脉体与围岩接触界面基本无错动,但都发生强烈片理化。
7	白龙池边	E112°57'44" N31°28'59"	61°∠44°	辉绿岩脉宽约3.5m,围岩为白云岩,蚀变带发育,层理产状25°∠70°,脉体与围岩接触界面基本无错动,但都发生强烈片理化。
8	灵官垭	E112°56'43" N31°29'08"	60°∠45°	辉绿岩脉宽约6m,围岩为白云岩,蚀变带发育,层理产状0°∠84°,脉体与围岩接触界面基本无错动。
9	灵官垭	E112°58'11" N31°29'12"	105°∠84°	辉绿岩脉宽约10m,围岩为紫红色白云岩,层理产状155°∠66°,脉体与围岩之间略有错动。
10	七里冲	E112°58'12" N31°29'13"	8°∠55°	辉绿岩脉宽约5m,脉体破碎,围岩为粉砂岩,层理产状355°∠10°,脉体与围岩之间略有错动。
11	七里冲	E112°57'30" N31°29'35"	25°∠74°	辉绿岩脉宽约2.5m,脉体破碎,围岩为砂岩、粉砂岩,鲍马序列发育,脉体与围岩之间略有错动。
12	七里冲	E112°57'08" N31°30'20"	73°∠86°	辉绿岩脉宽约6m,围岩为中一细粒杂砂岩、白云质砂岩,层理产状70°∠54°,脉体与围岩之间基本无错动,围岩发育烘烤边,片理化强烈,片理产状50°∠70°。
南部				
13	罗家咀	E113°05'15" N31°22'01"	265°∠82°	辉绿岩脉宽约0.8m,脉体片理化强烈,片理产状与脉体产状基本一致,围岩为白云岩,层理产状284°∠35°,脉体与围岩之间基本无错动。
14	罗家咀	E113°05'16" N31°22'11"	67°∠72°	辉绿岩脉宽约4m,脉体片理化强烈,片理产状25°∠70°,围岩为硅质条带白云岩,脉体与围岩之间基本无错动。
15	姚家冲	E113°06'28" N31°23'16"	75°∠75°	辉绿岩脉宽2~4m,脉体有一定片理化,围岩为刀砍纹白云岩,脉体与围岩之间基本无错动,蚀变带发育。
16	观音咀	E113°08'36" N31°20'55"	64°∠80°	辉绿岩脉宽2~3m,脉体发生劈理化,围岩为中一粗粒杂砂岩,脉体近直立,与围岩之间基本无错动。
17	罗汉岭	E113°07'03" N31°19'37"	72°∠64°	辉绿岩脉宽约2m,围岩为含硅质泥质板岩,板理产状:262°∠78°,脉体与围岩之间略有错动。
18	唐关	E113°07'02" N31°30'21"	64°∠82°	辉绿岩脉宽约11m,围岩为碎裂白云岩,刀砍纹发育,脉体与围岩呈切层关系,之间基本无错动。
19	仙人岭	E113°07'37" N31°18'20"	76°∠74°	辉绿岩脉宽2~7m不等,由下往上逐渐变窄,围岩为白云岩,切层明显,脉体与围岩接触部位发育红色褐铁矿化,白云岩围岩发育强烈大理岩化。
20	晏家咀	E113°09'43" N31°14'16"	50°∠73°	辉绿岩脉宽约1.5m,脉体破碎强烈,围岩为微晶白云岩,表明发育刀砍纹,二者之间有错动。
21	刘关	E113°09'29" N31°14'11"	45°∠80°	辉绿岩脉宽约5m,风化破碎严重,围岩为粉砂质板岩,片理产状32°∠50°,二者之间有错动。

留了斜长石的板条状外形。辉石多呈他形粒状充填于斜长石格架之间,大小0.2~0.3mm,含量20%~35%,辉石常发生绿泥石化蚀变,部分辉石变质为角闪石。另外,岩石中还含有少量的磁铁矿、钛磁铁矿,含量5%左右,局部可见少量的他形细粒(大小0.05~0.10mm)石英颗粒。镜下岩石整体保留了原始辉绿结构的特点,为典型的辉绿岩。

3 LA-ICP-MS 锆石 U-Pb 测年

3.1 分析方法

笔者分别选取了北部七里冲(D5076-1)、姚家咀(PM07-26-1)和南部姚家冲(D5021-5)、刘关(D5024-5)4件辉绿岩样品进行了LA-ICP-MS 锆石

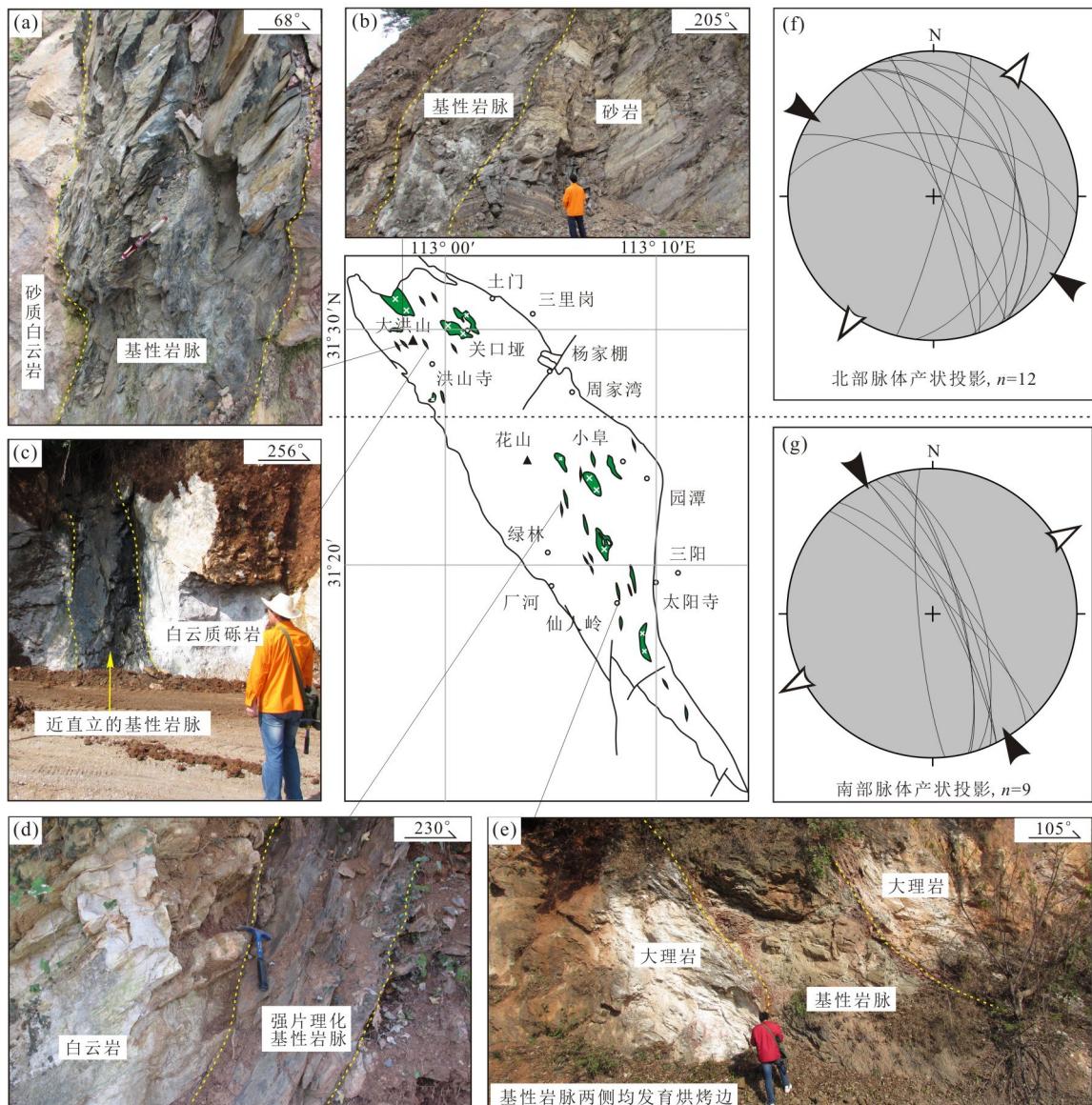


图 2 大洪山地区基性岩脉野外产出特征(a~e)和产状赤平投影(f,g)

Fig.2 Characteristics in field (a—e) and attitude stereograms (f,g) of the mafic dykes in the Dahongshan region

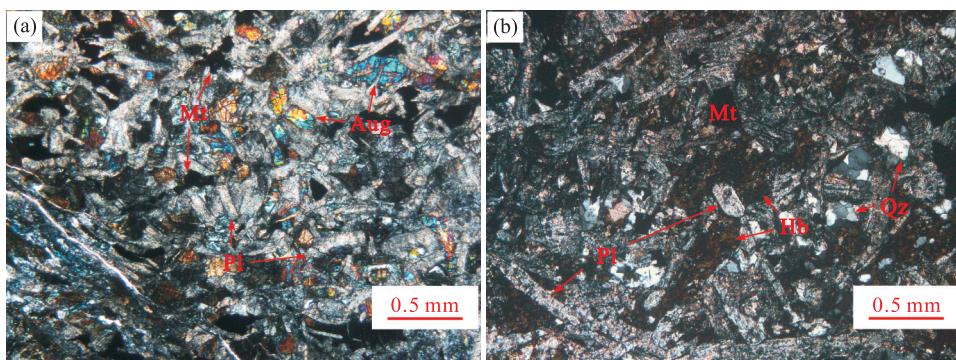


图 3 基性岩脉镜下特征

Fig.3 The characteristics of the mafic dykes under-microscope

a. 七里冲辉绿岩(正交光); b. 晏家咀辉绿岩(正交光). Aug.普通辉石; Hb.角闪石; Mt.磁铁矿; Pl.斜长石; Qz.石英

表2 基性岩脉锆石U-Pb测年结果

Table 2 U-Pb zircon data for the mafic dykes

分析点号	含量(10^{-6})			Th/U			$^{207}\text{Pb}/^{206}\text{Pb}$			比值			$^{206}\text{Pb}/^{238}\text{U}$			年龄(Ma)		
	Pb	Th	U	$^{207}\text{Pb}/^{206}\text{Pb}$	1σ	$^{207}\text{Pb}/^{235}\text{U}$	1σ	$^{206}\text{Pb}/^{238}\text{U}$	1σ	$^{207}\text{Pb}/^{206}\text{Pb}$	1σ	$^{206}\text{Pb}/^{232}\text{Th}$	1σ	$^{206}\text{Pb}/^{238}\text{U}$	1σ	$^{206}\text{Pb}/^{238}\text{U}$	1σ	
D0076-1																		
01	37.46	160.0	482	0.33	0.06445	0.0020	0.5887	0.0177	0.0659	0.0006	767	60	470	11	412	4		
02	28.56	123.0	359	0.34	0.06119	0.0018	0.5861	0.0165	0.0684	0.0006	672	61	468	11	427	4		
03	33.29	239.0	430	0.56	0.06779	0.0036	0.5691	0.0214	0.0618	0.0010	865	109	457	14	386	6		
04	39.50	229.0	508	0.45	0.0599	0.0019	0.5414	0.0162	0.0657	0.0008	600	101	439	11	410	5		
05	29.54	203.0	355	0.57	0.0556	0.0018	0.5355	0.0173	0.0697	0.0008	435	72	435	11	435	5		
06	31.28	141.0	394	0.36	0.0555	0.0017	0.5387	0.0172	0.0700	0.0009	435	69	438	11	436	5		
07	35.86	165.0	458	0.36	0.0555	0.0017	0.5348	0.0166	0.0697	0.0008	432	69	435	11	434	5		
08	53.40	258.0	654	0.39	0.0576	0.0015	0.5588	0.0140	0.0702	0.0007	522	56	451	9	437	4		
09	31.60	225.0	372	0.60	0.0573	0.0017	0.5480	0.0162	0.0695	0.0007	502	67	444	11	433	4		
10	33.42	242.0	393	0.62	0.0594	0.0017	0.5699	0.0161	0.0696	0.0007	583	68	458	10	434	4		
11	35.94	121.0	397	0.30	0.0574	0.0015	0.6825	0.0213	0.0863	0.0015	506	53	528	13	534	9		
12	34.89	146.0	429	0.34	0.0566	0.0017	0.5766	0.0181	0.0735	0.0011	476	65	458	12	457	7		
13	99.70	289.0	1288	0.22	0.0575	0.0013	0.5534	0.0132	0.0696	0.0006	522	50	447	9	434	4		
14	15.87	87.5	190	0.46	0.0609	0.0022	0.5849	0.0213	0.0704	0.0010	635	78	468	14	438	6		
15	50.75	203.0	645	0.31	0.0543	0.0012	0.5265	0.0126	0.0701	0.0007	52	430	8		437	4		
16	42.82	924.2	552	0.17	0.0589	0.0014	0.5705	0.0143	0.0700	0.0008	565	54	458	9	436	5		
17	42.05	155.0	534	0.29	0.0540	0.0015	0.5211	0.0141	0.0698	0.0008	372	63	426	9	435	5		
18	33.49	151.0	409	0.37	0.0616	0.0019	0.5945	0.0180	0.0698	0.0008	661	66	474	11	435	5		
19	35.77	137.0	453	0.30	0.0563	0.0017	0.5385	0.0166	0.0687	0.0008	465	67	437	10	428	5		
20	45.08	203.0	563	0.36	0.0574	0.0016	0.5445	0.0151	0.0687	0.0007	506	63	441	10	428	4		
21	32.41	134.0	421	0.32	0.0683	0.0021	0.6174	0.0198	0.0650	0.0007	880	64	488	12	406	4		
22	36.90	166.0	450	0.37	0.0562	0.0015	0.5433	0.0139	0.0701	0.0007	461	27	441	9	437	4		
23	46.14	215.0	639	0.34	0.0631	0.0034	0.5124	0.0151	0.0611	0.0009	722	121	420	10	382	5		
24	35.65	113.0	343	0.33	0.0691	0.0022	0.8203	0.0288	0.0851	0.0012	902	65	608	16	526	7		
P007-26-1																		
01	32.98	144.0	400	0.36	0.0570	0.0017	0.5504	0.0166	0.0702	0.0009	494	67	445	11	437	6		
02	37.23	152.0	454	0.34	0.0564	0.0015	0.5499	0.0159	0.0701	0.0008	478	59	445	10	437	5		
03	76.00	245.0	929	0.26	0.0545	0.0011	0.5314	0.0116	0.0706	0.0010	394	44	433	8	440	6		
04	45.29	168.0	557	0.30	0.0547	0.0014	0.5282	0.0140	0.0700	0.0009	467	57	431	9	436	5		
05	27.64	118.0	323	0.36	0.0547	0.0017	0.5252	0.0165	0.0696	0.0007	467	75	429	11	434	4		
06	35.82	105.0	416	0.25	0.0541	0.0017	0.5401	0.0170	0.0726	0.0011	376	69	438	11	452	7		
07	30.50	203.0	336	0.60	0.0547	0.0021	0.5159	0.0196	0.0689	0.0009	398	87	422	13	429	5		
08	41.65	221.0	459	0.48	0.0577	0.0021	0.5614	0.0244	0.0696	0.0009	517	81	452	16	434	6		
09	45.60	324.0	463	0.70	0.0582	0.0018	0.5669	0.0177	0.0703	0.0008	539	64	456	11	438	5		
10	49.92	197.0	569	0.35	0.0555	0.0013	0.5418	0.0143	0.0700	0.0008	432	54	440	9	436	5		
11	24.86	76.8	254	0.30	0.0617	0.0022	0.6920	0.0273	0.0801	0.0011	665	78	534	16	497	6		
12	100.70	253.0	1243	0.20	0.0562	0.0015	0.5352	0.0146	0.0684	0.0007	461	61	435	10	426	4		
13	33.80	115.0	299	0.38	0.0658	0.0020	0.8331	0.0279	0.0904	0.0014	1200	60	615	15	558	8		
14	18.98	93.9	215	0.44	0.0621	0.0024	0.5953	0.0203	0.0702	0.0011	676	81	474	13	437	7		
15	42.25	73.3	228	0.32	0.0876	0.0023	1.8184	0.0457	0.1499	0.0017	1374	55	1052	16	900	10		
16	129.00	178.0	332	0.54	0.1072	0.0019	4.4546	0.0803	0.2983	0.0027	1754	32	1723	15	1683	13		
17	36.70	221.0	417	0.53	0.0596	0.0016	0.5828	0.0158	0.0702	0.0007	587	56	466	10	438	4		
18	36.94	140.0	447	0.31	0.0590	0.0016	0.5749	0.0159	0.0704	0.0009	565	61	461	10	438	5		
19	47.20	168.0	551	0.30	0.0578	0.0016	0.5853	0.0155	0.0731	0.0009	520	64	468	10	455	5		
20	24.08	143.0	265	0.54	0.0572	0.0019	0.5951	0.0209	0.0751	0.0012	498	69	474	13	467	7		
21	32.85	152.0	384	0.39	0.0590	0.0018	0.5750	0.0172	0.0705	0.0010	565	67	461	11	439	6		
22	45.42	180.0	548	0.33	0.0581	0.0014	0.5643	0.0140	0.0693	0.0007	532	54	454	9	435	4		
23	55.60	340.0	641	0.53	0.0581	0.0014	0.5687	0.0138	0.0704	0.0007	600	52	457	9	438	4		
24	36.64	146.0	442	0.33	0.0571	0.0014	0.5557	0.0139	0.0702	0.0008	494	54	450	9	438	5		

续表 2

分析 点号	含量(10^{-6})			Th/ U			比值			年龄(Ma)					
	Pb	Th	U	$^{207}\text{Pb}/^{206}\text{Pb}$	1σ	$^{207}\text{Pb}/^{235}\text{U}$	1σ	$^{206}\text{Pb}/^{238}\text{U}$	1σ	$^{207}\text{Pb}/^{206}\text{Pb}$	1σ	$^{208}\text{Pb}/^{232}\text{Th}$	1σ	$^{206}\text{Pb}/^{238}\text{U}$	1σ
D021-5															
01	99.0	583	475	1.23	0.0583	0.0021	0.4411	0.0128	0.0549	0.0006	543	75.9	371	9.0	345
02	41.0	179	115	1.55	0.0865	0.0036	0.8411	0.0358	0.0704	0.0010	1350	75.0	620	19.8	439
03	21.4	49	245	0.20	0.0554	0.0021	0.5188	0.0183	0.0682	0.0009	428	91.7	424	12.3	425
04	278.0	135	316	0.43	0.1436	0.0022	10.1172	0.1813	0.5079	0.0062	2272	21.3	2446	16.6	26.5
05	38.0	111	361	0.31	0.0582	0.0019	0.5709	0.0176	0.0689	0.0010	600	74.1	459	11.4	439
06	40.0	105	435	0.24	0.0556	0.0014	0.5303	0.0142	0.0682	0.0007	435	52.8	432	9.4	430
07	22.0	320	597	0.54	0.0518	0.0018	0.1276	0.0046	0.0179	0.0003	276	79.6	122	4.1	114
08	25.6	228	232	0.98	0.0555	0.0022	0.2766	0.0105	0.0364	0.0005	432	87.0	248	8.3	230
09	15.7	286	361	0.79	0.0510	0.0024	0.1137	0.0053	0.0163	0.0002	243	111.1	109	4.8	105
10	168.0	610	809	0.75	0.0701	0.0013	0.8254	0.0152	0.0854	0.0009	931	34.3	611	8.4	528
11	310.0	300	414	0.73	0.1179	0.0022	4.9316	0.1028	0.3014	0.0036	1924	33.3	1808	17.6	1698
12	51.0	215	310	0.69	0.0592	0.0026	0.5541	0.0203	0.0689	0.0013	576	93.4	448	13.3	430
13	14.8	122	353	0.34	0.0514	0.0022	0.1845	0.0079	0.0259	0.0003	257	100.0	172	6.7	165
14	20.1	67	163	0.41	0.0638	0.0023	0.6271	0.0243	0.0706	0.0008	744	77.8	494	15.2	440
15	22.2	124	206	0.60	0.0595	0.0022	0.3837	0.0139	0.0469	0.0006	583	79.6	330	10.2	295
16	53.0	43	39	1.10	0.1586	0.0035	8.8505	0.2249	0.4028	0.0063	2440	38.7	2323	23.2	2182
17	227.0	2042	1844	1.11	0.0560	0.0012	0.2857	0.0063	0.0367	0.0004	454	46.3	255	5.0	233
18	35.5	53	338	0.16	0.0730	0.0024	0.7092	0.0256	0.0696	0.0009	1013	66.7	544	15.2	434
19	30.1	60	97	0.62	0.0688	0.0022	1.3228	0.0432	0.1398	0.0021	892	66.7	85.6	18.9	844
20	26.7	62	338	0.18	0.0551	0.0014	0.5233	0.0139	0.0699	0.0007	72	54.6	427	9.2	436
21	113.0	1191	2069	0.58	0.0551	0.0016	0.2037	0.0046	0.0271	0.0005	413	64.8	188	3.9	172
22	29.0	404	350	1.15	0.0516	0.0023	0.1537	0.0070	0.0221	0.0005	333	102	145	6.2	141
23	236.0	663	1759	0.38	0.0570	0.0009	0.6594	0.0120	0.0834	0.0010	494	35.2	514	7.3	517
24	122.0	86	90	0.95	0.1550	0.0029	9.4198	0.2171	0.4369	0.0068	2402	32.9	2380	21.2	2337
D024-5															
01	78.0	191	554	0.35	0.0636	0.0014	0.7213	0.0218	0.0817	0.0018	728	46.3	551	12.9	506
02	42.0	156	242	0.65	0.0520	0.0021	0.5206	0.0195	0.0706	0.0010	287	92.6	426	13.0	440
03	65.0	319	258	1.24	0.0550	0.0015	0.5310	0.0151	0.0698	0.0007	413	61.1	432	10.0	435
04	109.0	381	684	0.56	0.0560	0.0012	0.5880	0.0144	0.0764	0.0009	454	47.0	470	9.2	473
05	119.0	538	570	0.94	0.0537	0.0013	0.5240	0.0150	0.0705	0.0006	361	55.6	428	10.0	439
06	75.0	336	349	0.96	0.0577	0.0016	0.5565	0.0178	0.0703	0.0008	520	67.6	449	11.6	438
07	214.0	647	1937	0.33	0.0609	0.0013	0.5461	0.0150	0.0649	0.0006	635	48.1	442	9.9	406
08	163.0	736	999	0.74	0.0617	0.0017	0.5715	0.0173	0.0667	0.0008	665	57.4	459	11.2	422
09	309.0	101	439	0.23	0.1633	0.0025	10.5861	0.2103	0.4683	0.0045	2490	25.8	2487	18.6	2476
10	109.0	372	643	0.58	0.0617	0.0012	0.5992	0.0133	0.0703	0.0008	665	43.4	477	8.4	438
11	289.0	158	235	0.67	0.1622	0.0023	10.9027	0.1783	0.4842	0.0049	2480	24.1	2515	15.3	2546
12	213.0	140	221	0.63	0.1567	0.0027	8.5925	0.1869	0.3938	0.0058	420	29.8	2296	19.8	2141
13	53.0	192	267	0.72	0.0871	0.0022	1.0802	0.0397	0.0885	0.0022	1365	48.5	744	19.4	547
14	213.0	402	502	0.80	0.0746	0.0016	1.7431	0.0305	0.1694	0.0017	1057	42.6	1025	11.3	1009
15	112.0	215	448	0.48	0.0708	0.0015	1.2555	0.0256	0.1278	0.0010	954	42.6	826	11.6	776
16	142.0	337	635	0.53	0.0627	0.0012	0.7633	0.0180	0.0875	0.0012	698	43.5	576	10.4	541
17	35.0	45	101	0.44	0.0842	0.0020	2.4603	0.0606	0.2114	0.0025	1298	45.8	1260	17.8	1236
18	71.0	277	399	0.69	0.0584	0.0019	0.5849	0.0304	0.0704	0.0011	543	70.4	468	19.4	439
19	70.0	170	158	1.08	0.0635	0.0017	1.1778	0.0308	0.1350	0.0017	724	61.3	790	14.4	816
20	23.7	98	144	0.68	0.0515	0.0019	0.4943	0.0186	0.0696	0.0008	265	85.2	408	12.6	434
21	44.0	157	231	0.68	0.0527	0.0024	0.5489	0.0178	0.0697	0.0013	322	105.5	444	11.7	434
22	63.0	192	345	0.56	0.0602	0.0014	0.6765	0.0160	0.0820	0.0013	613	50.0	525	9.7	508
23	50.0	385	704	0.55	0.0519	0.0014	0.2386	0.0065	0.0333	0.0004	280	61.1	217	5.4	211
24	70.0	290	473	0.61	0.0541	0.0015	0.5190	0.0129	0.0693	0.0007	376	56.5	425	8.6	432

U-Pb测年分析.锆石挑选、制靶、反射光、透射光和阴极发光照相都在南京宏创地质勘查技术服务有限公司完成,将基性岩脉样品粉碎到 $0.180\sim0.154\text{ mm}$ (80~100目),然后利用常规的浮选和电磁法分离出锆石,在双目镜下挑选出晶型较好的锆石制靶,阴极发光(CL)采用TESCAN MIRA3场发射扫描电镜和TESCAN公司阴极发光探头进行锆石内部结构分析研究.LA-ICP-MS锆石U-Th-Pb同位素和微量元素微区分析在湖北省地质试验测试中心完成,测试仪器采用美国Coherent Inc公司生产的GeoLasPro全自动版193 nm ArF准分子激光剥蚀系统(LA)和美国Agilent公司生产的7700X型电感耦合等离子质谱仪(ICP-MS)联用构成的激光剥蚀电感耦合等离子体质谱分析系统(LA-ICP-MS),激光束斑直径为 $32\mu\text{m}$,用He作为剥蚀物质的载气,哈佛大学标准锆石91500作为外标,GJ-1或者Plešovic为监控标样,具体操作详见(周亮亮等,2017).采用ICPMsDataCal(V10.1)软件对测试结果进行处理(Liu *et al.*, 2009),处理后的数据见表2,所得的数据用Isoplot 3.0程序进行谐和图绘制和加权平均年龄计算(Ludwig, 2003).

3.2 分析结果

3.2.1 D5076-1 样品中的锆石以短柱状为主,大小 $50\sim110\mu\text{m}$ 不等,主要集中在 $80\mu\text{m}$ 左右,锆石晶形大部分较好,裂纹少见,具有较好的振荡环带结构(图4).24个分析点中01、03、21、23、24号分析点因谐和度太低舍弃,其余19个点Th含量 $87\times10^{-6}\sim289\times10^{-6}$,U含量 $190\times10^{-6}\sim1288\times10^{-6}$,Th/U值在 $0.17\sim0.62$ 之间,这说明大部分锆石为岩浆锆石.除3个分析点(04、11、12)较分散外,剩余16个分析点在 $^{207}\text{Pb}/^{235}\text{U}$ - $^{206}\text{Pb}/^{238}\text{U}$ 谐和图上表现最为集中(图5),且锆石晶形完整,振荡环带清

图上比较集中(图5), $^{206}\text{Pb}/^{238}\text{U}$ 加权平均年龄为 $433.7\pm2.2\text{ Ma}$ (MSWD=0.60),代表成岩年龄.

3.2.2 PM07-26-1 样品中的锆石以短柱状为主,少量呈长柱状,大小集中在 $50\sim90\mu\text{m}$,少量达 $110\mu\text{m}$,锆石晶形基本较好,裂纹少见,具有较好的振荡环带结构(图4).24个分析点中13、15号因谐和度太低舍弃,其余22个点Th含量 $77\times10^{-6}\sim340\times10^{-6}$,U含量 $215\times10^{-6}\sim1243\times10^{-6}$,Th/U值在 $0.20\sim0.70$ 之间,基本表现为岩浆锆石的特点.其中16号分析点 $^{206}\text{Pb}/^{207}\text{Pb}$ 年龄为1754 Ma,代表扬子古老基底的捕获锆石.其他除4个(06、11、19、20)较分散分析点外,剩余17个比较集中的分析点 $^{206}\text{Pb}/^{238}\text{U}$ 加权平均年龄为 $435.6\pm2.3\text{ Ma}$ (MSWD=0.59),代表成岩年龄(图5).

3.2.3 D5021-5 24个分析点中02、10、15号分析点因谐和度太低舍弃,其余21个点Th含量 $43\times10^{-6}\sim2042\times10^{-6}$,U含量 $39\times10^{-6}\sim2069\times10^{-6}$,Th/U值在 $0.16\sim1.55$ 之间,大部分锆石表现为岩浆锆石的特点.分析点04、11、16、24锆石颗粒较小,大小 $50\sim80\mu\text{m}$,且晶形不完整,环带较为模糊(图4), $^{206}\text{Pb}/^{207}\text{Pb}$ 年龄分别为2272 Ma、1924 Ma、2440 Ma、2402 Ma,代表捕获的古元古代基底锆石残片.19号分析点锆石较亮,环带可见, $^{206}\text{Pb}/^{238}\text{U}$ 年龄为844 Ma,而23号分析点锆石较暗,但环带清晰, $^{206}\text{Pb}/^{238}\text{U}$ 年龄为517 Ma,此二者也应为捕获锆石.另外,有8个分析点(01、07、08、09、13、17、21、22)锆石形态完整,环带清晰, $^{206}\text{Pb}/^{238}\text{U}$ 年龄值分散于105~345 Ma,它们可能为锆石挑选过程中混入年轻锆石.其余7个分析点在 $^{207}\text{Pb}/^{235}\text{U}$ - $^{206}\text{Pb}/^{238}\text{U}$ 年龄谐和图和频率图上表现最为集中(图5),且锆石晶形完整,振荡环带清

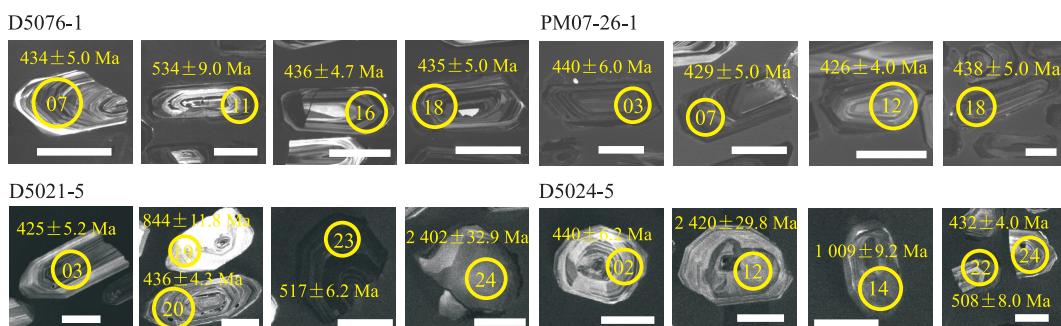


图4 基性岩脉代表性锆石阴极发光图、LA-ICP-MS测点位置、编号及年龄值

Fig.4 Cathodoluminescence (CL) images, LA-ICP-MS analytical locations, serial numbers and their ages for representative zircon grains from the mafic dykes in the Dahongshan region

白色标尺代表 $50\mu\text{m}$

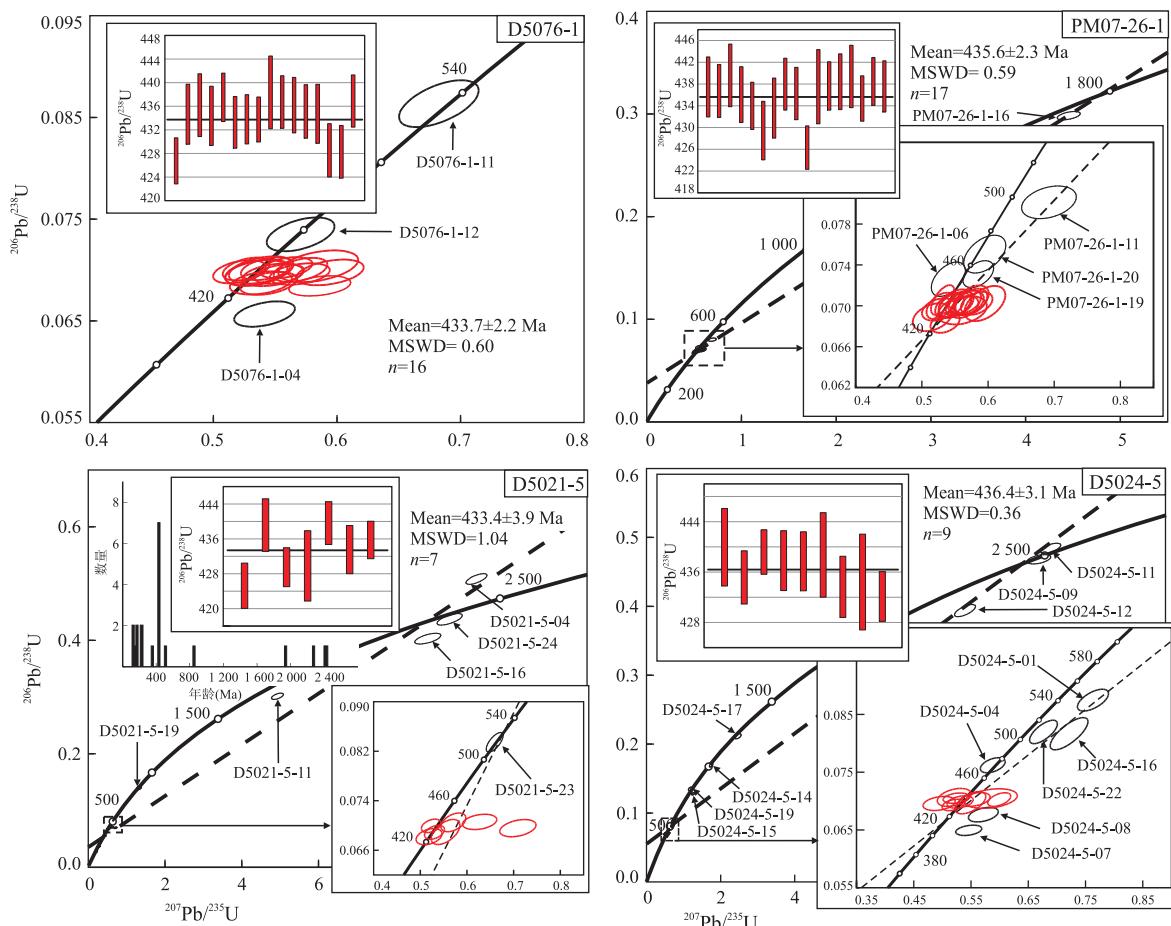


图 5 基性岩脉 LA-ICP-MS 锆石 U-Pb 测年谐和年龄图和加权平均年龄

Fig.5 Concordia plots of LA-ICP-MS zircon U-Pb dating and the mean ages for the mafic dykes

晰,大小 $70 \sim 100 \mu\text{m}$, $^{206}\text{Pb}/^{238}\text{U}$ 加权平均年龄为 433.4 ± 3.9 Ma(MSWD=1.04),代表成岩年龄。

3.2.4 D5024-5 样品中的锆石以短柱状、粒状为主,锆石整体偏小,大小集中在 $40 \sim 90 \mu\text{m}$ 之间,大部分锆石具有较好的晶形和振荡环带结构,少量呈碎裂状,部分环带存在被改造的痕迹(图 4).24 个分析点中除 13 号因谐和度太低而舍弃,其余 23 个点 Th 含量 $45 \times 10^{-6} \sim 736 \times 10^{-6}$, U 含量 $101 \times 10^{-6} \sim 1937 \times 10^{-6}$, Th/U 值在 $0.23 \sim 1.24$ 之间,大部分锆石表现为岩浆锆石的特点.与样品 D5021-5 类似,本样品中同样存在许多捕获锆石,它们或呈碎裂,或具有核-增生边结构,年龄值分散在元古宙-古生代早期.样品中也有一颗年轻锆石(分析点 23)混入, $^{206}\text{Pb}/^{238}\text{U}$ 年龄值 211 Ma.取 9 个锆石晶形完整、振荡环带清晰、且 $^{207}\text{Pb}/^{235}\text{U}$ - $^{206}\text{Pb}/^{238}\text{U}$ 年龄谐和图上表现集中的分析点(图 5),获得 $^{206}\text{Pb}/^{238}\text{U}$ 加权平均年龄为 436.4 ± 3.1 Ma (MSWD = 0.36),代表成岩年龄.

4 地球化学

4.1 分析方法

对在大洪山地区采集的 11 件基性岩脉样品进行全岩地球化学分析,全岩主量元素、微量元素和稀土元素分析均在湖北省地质试验测试中心化学分析研究室完成.主量元素 SiO_2 、 TiO_2 、 Al_2O_3 、 $\text{Fe}_2\text{O}_3^\text{T}$ 、 MnO 、 MgO 、 CaO 、 Na_2O 、 K_2O 、 P_2O_5 采用 X 荧光光谱法(XRF)在 X 荧光光谱仪(XRF-1800)上测定,而 FeO^T 则是通过湿化学分析方法获得,微量元素和稀土元素分析采用电感耦合等离子质谱法(ICP-MS)在电感耦合等离子体质谱仪(X2)上测定(马天芳等, 2011).获得的数据见表 3,并对实验数据采用 Geokit 软件进行分析处理(路远发, 2004).

4.2 主量元素

主量元素方面,大洪山地区 11 件样品扣除烧失量换算为 100% 之后, SiO_2 含量为 $45.05\% \sim 56.84\%$, 表现为中-基性的特点.全碱($\text{Na}_2\text{O} + \text{K}_2\text{O}$)含量跨

表3 大洪山地区基性岩脉主量、微量元素数据

Table 3 Data of major and trace elements of the mafic dykes in the Dahongshan region

编号	D4013-2	D4021-4	D4024-1	D5017-4	D5017-9	D5019-2	D5020-2	D5072-1	D5073-1	D5074-1	D5076-1
主要元素(%)											
SiO ₂	48.76	53.29	47.57	56.84	49.94	50.61	49.27	45.05	48.04	52.31	47.94
TiO ₂	2.35	2.03	2.90	3.70	2.28	2.71	2.80	2.59	2.84	2.15	1.44
Al ₂ O ₃	12.32	12.26	12.06	13.97	18.34	14.04	19.85	12.74	18.64	12.24	15.79
Fe ₂ O ₃	2.76	3.79	10.02	10.19	2.27	6.99	3.69	5.62	2.24	3.15	3.25
FeO	10.6	7.25	6.9	2.92	9.13	7.95	10.88	7.65	7.55	9.05	7.70
MnO	0.24	0.12	0.25	0.01	0.11	0.17	0.10	0.09	0.01	0.15	0.22
MgO	5.71	4.01	5.46	5.02	7.81	4.11	4.76	6.46	4.63	5.26	6.91
CaO	9.83	4.83	4.42	1.37	4.41	7.87	2.80	6.10	1.79	4.39	7.53
Na ₂ O	2.50	0.65	3.50	0.80	4.00	3.33	3.49	0.12	0.12	3.15	2.21
K ₂ O	0.36	3.79	0.23	4.33	1.32	1.71	1.86	3.73	7.80	0.28	2.94
P ₂ O ₅	0.22	0.45	0.48	0.85	0.38	0.50	0.49	0.50	1.19	0.92	0.14
LOI	2.97	6.57	5.26	3.73	6.83	7.18	5.41	8.34	4.02	5.81	2.78
FeOT ^T	13.09	10.66	15.91	12.09	11.17	14.24	14.21	12.71	9.56	11.88	10.63
Na ₂ O+K ₂ O	0.57	4.24	0.70	5.18	1.70	2.22	2.35	4.23	8.99	1.20	3.08
Mg [#]	43.75	40.14	37.94	42.52	55.49	33.94	37.42	47.52	46.31	44.10	53.69
微量元素(10⁻⁶)											
Sc	42.80	24.34	38.08	39.33	40.54	33.88	44.54	33.72	28.88	25.86	40.06
Cr	59.81	9.85	31.56	26.24	219.6	27.80	215.9	41.77	15.17	4.35	215.6
Co	42.93	20.26	38.79	58.40	65.35	41.77	71.79	28.94	44.08	11.01	43.83
Ni	34.67	9.92	15.83	45.98	77.39	15.90	61.79	18.88	42.27	1.43	49.90
Rb	11.29	65.89	7.13	69.15	17.90	22.14	19.04	84.35	61.40	2.44	71.09
Sr	159.8	58.69	120.8	25.42	107.3	194.3	56.95	81.59	20.29	86.52	266.0
Y	47.55	63.27	49.23	45.50	31.10	38.42	41.16	42.28	77.29	70.43	32.19
Nb	4.77	8.69	4.58	6.48	5.20	5.96	5.54	6.65	8.21	9.68	2.84
Zr	169.9	378.0	196.2	227.3	140.8	186.9	169.7	205.5	401.5	432.5	93.40
Ba	347.8	136.0	481.5	176.2	563.2	272.2	150.5	134.9	1463	221.2	1084
Th	1.31	3.36	0.75	1.12	0.59	2.43	0.83	1.38	2.87	2.24	0.51
U	0.27	0.76	0.20	0.52	0.73	0.60	0.48	0.32	1.17	0.51	0.16
La	12.20	34.88	24.53	17.42	15.24	22.36	15.49	20.72	35.45	46.54	5.18
Ce	27.91	76.26	51.01	39.13	33.09	49.52	36.59	46.80	96.03	107.2	13.39
Nd	20.47	45.58	34.57	32.10	23.47	29.82	24.43	30.31	66.15	69.85	12.09
Sm	6.04	11.06	8.76	8.71	5.88	7.21	6.54	7.68	15.78	16.69	3.83
Tb	1.41	2.01	1.65	1.51	1.02	1.20	1.27	1.33	2.42	2.41	0.85
Hf	5.8	8.6	6.0	4.45	3.56	4.36	3.74	4.01	7.12	10.24	2.14
Ta	0.54	0.63	0.41	0.50	0.47	0.49	0.52	0.59	0.42	0.56	0.31
Pb	1.64	6.34	7.15	4.10	3.83	7.00	6.67	6.33	5.56	2.17	2.09
V	444.2	290.0	513.8	438.2	352.8	397.1	404.2	402.8	221.6	88.91	275.6
La	12.20	34.88	24.53	17.42	15.24	22.36	15.49	20.72	35.45	46.54	5.18
Ce	27.91	76.26	51.01	39.13	33.09	49.52	36.59	46.80	96.03	107.2	13.39
Pr	4.28	10.68	7.79	6.65	5.12	6.86	5.43	6.87	14.79	15.60	2.39
Nd	20.47	45.58	34.57	32.10	23.47	29.82	24.43	30.31	66.15	69.85	12.09
Sm	6.04	11.06	8.76	8.71	5.88	7.21	6.54	7.68	15.78	16.69	3.83
Eu	2.00	2.78	2.56	2.42	1.75	1.99	1.95	2.07	3.96	5.01	1.42
Gd	7.00	10.90	8.95	9.79	6.36	7.56	7.72	8.35	15.94	16.14	4.93
Tb	1.41	2.01	1.65	1.51	1.02	1.20	1.27	1.33	2.42	2.41	0.85
Dy	8.71	11.94	9.68	8.81	6.27	7.52	7.84	8.52	14.53	14.11	5.73
Ho	1.77	2.37	1.89	1.67	1.19	1.43	1.52	1.65	2.88	2.64	1.16
Er	5.05	6.58	5.10	4.35	3.10	4.10	4.31	4.41	7.94	7.50	3.44
Tm	0.78	1.03	0.80	0.55	0.40	0.58	0.59	0.60	1.12	1.05	0.48
Yb	4.92	6.82	4.76	3.28	2.28	3.38	3.59	3.59	6.45	6.30	2.83
Lu	0.68	0.89	0.62	0.44	0.34	0.51	0.54	0.51	0.98	0.97	0.42
Zr/Y	3.57	5.97	3.99	5.00	4.53	4.86	4.12	4.86	5.19	6.14	2.90
ΣREE	103.21	223.78	162.67	136.83	105.51	144.02	117.80	143.40	284.41	312.00	58.14
LREE/HREE	2.40	4.26	3.86	3.50	4.04	4.48	3.30	3.95	4.44	5.10	1.93
(La/Yb) _N	1.78	3.67	3.69	3.81	4.79	4.75	3.09	4.14	3.94	5.30	1.31
δEu	0.87	0.71	0.81	0.75	0.81	0.76	0.78	0.73	0.70	0.85	0.93
δCe	0.94	0.96	0.90	0.89	0.91	0.97	0.98	0.96	1.03	0.97	0.93

注:主要元素数据已经换算成干体系, $\text{FeOT}^T = \text{FeO} + 0.899 \times \text{Fe}_2\text{O}_3$, $\text{Mg}^{\#} = (\text{MgO}/40.31) \times 100 / (\text{MgO}/40.31 + \text{FeOT}^T/71.85)$.

度较大,0.57%~8.99%不等,这种不均一性可能与不同程度的变形与变质作用有关.样品有着较高的 TiO_2 含量(1.44%~3.70%)、 Al_2O_3 含量(12.06%

~19.85%)和 FeOT^T 含量(9.56%~15.91%), MgO 含量4.01%~7.81%, $\text{Mg}^{\#}$ 在33.94~55.49之间.这些高 Ti 、高 Al 而相对低 $\text{Mg}^{\#}$ 的特征与兰家畈玄武

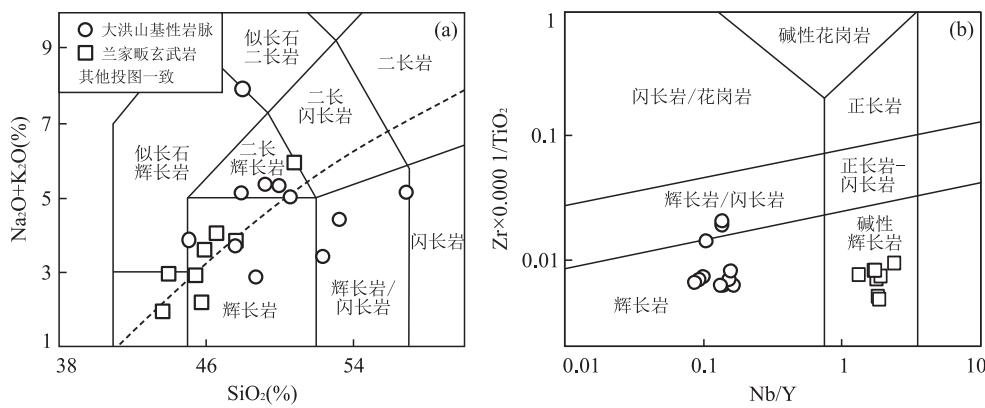


图 6 大洪山地区基性岩脉分类图解

Fig.6 Classification diagrams of the mafic dykes from the Dahongshan region

a.TAS 图解,据 Irvine and Baragar(1971)、Le Bas *et al.*(1986);b.Nb/Y-Zr × 10⁻⁴ / TiO₂,据 Winchester and Floyd(1977)、Pearce(2014);兰家畈玄武岩数据摘自董云鹏等(1998a),下文一致

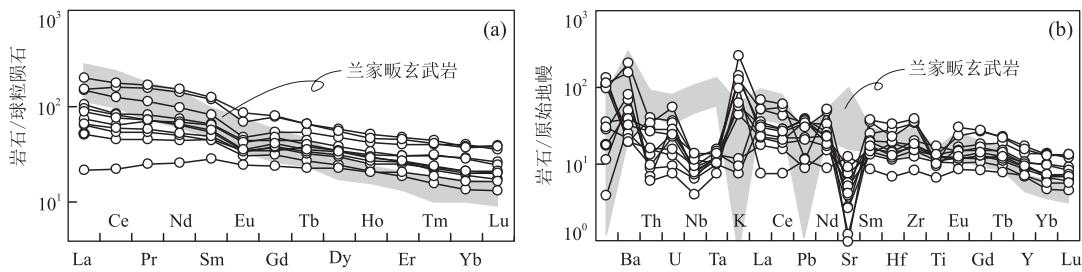


图 7 基性岩脉球粒陨石标准化稀土元素配分图(a)和原始地幔标准化蛛网图(b)

Fig.7 Chondrite-normalized REE distribution patterns (a) and primitive mantle-normalized spidergrams (b) for the mafic dykes
据 Sun and McDonough(1989)

岩有一定相似之处(董云鹏等, 1998a).在 TAS 图中(图 6a),11 件基性岩脉样品与兰家畈玄武岩投点都较为分散,大体于基性岩碱性、亚碱性系列范围内都有分布,这可能与样品存在较强的蚀变有关.大量事实证明,在运用主量元素进行岩浆岩岩性和岩石系列判别时,有必要用受到蚀变作用影响较小高场强元素、稀土元素进行佐证(Hastie *et al.*, 2007; Pearce, 2014; 陈超等, 2016).通过 Nb/Y-Zr × 10⁻⁴ / TiO₂ 投图,大洪山基性岩脉除 2 件样品落入辉长岩/闪长岩范围内,整体都落在亚碱性系列辉长岩区域内,而兰家畈玄武岩都落在碱性辉长岩范围内(图 6b).因此,大洪山基性岩脉与兰家畈玄武岩主量元素方面特点较为相似,但大洪山基性岩脉整体表现为亚碱性系列的特点,而兰家畈玄武岩表现为碱性系列的特点.

4.3 微量元素

稀土元素方面,大洪山地区基性岩脉总稀土元素含量 $\Sigma \text{REE} = 58 \times 10^{-6} \sim 312 \times 10^{-6}$, 总体含量相对较高.LREE/HREE=1.93~5.10,(La/Yb)_N=1.31~5.30,具有较强的轻、重稀土元素分异度.在球粒陨石

标准化稀土元素配分图上(图 7a),除 1 件样品外,其他均表现为“右倾”配分模式特点. $\delta \text{Eu}=0.70 \sim 0.93$,具有一定程度的负 Eu 异常,说明存在斜长石的结晶分离.和近同时代的兰家畈玄武岩相比,后者的 LREE 更富、HREE 更为亏损,轻、重稀土元素分异度更高.在原始地幔标准化蛛网图上(图 7b),基性岩脉样品不同程度的富集大离子亲石元素(LILE)Rb、Ba、K、Pb,而亏损高场强元素(HFSE)Nb、Ta、Ti 等,Sr 元素表现为强烈亏损状态,这同样与斜长石分离结晶有关.相比大洪山基性岩脉,兰家畈玄武岩强烈富集 Nb、Ta,强烈亏损 K、Pb,一定程度上富集 Sr 元素.

5 讨论

5.1 形成时代

对于大洪山地区出露的这套基性侵入岩,长期以来缺乏精确的同位素年代学证据.早期的地质调查根据其侵入前南华系基底的特点,将它们的形成归为新元古代晚期(湖北省地质局区域地质测量队,

1982).本文选取了6件典型基性侵入岩样品进行锆石U-Pb测年,其中七里冲、姚家咀、姚家冲、刘关4件基性岩脉锆石都有着较好的振荡环带,Th/U值都大于0.1,表明大部分为岩浆锆石.4件样品年龄结果都集中在435 Ma附近,加权平均年龄分别为433.7 Ma、435.6 Ma、433.4 Ma、436.4 Ma.另外,笔者还对关口垭2件基性岩株样进行了锆石U-Pb测年,加权平均年龄分别为437.8 Ma、435.6 Ma(采样位置见图1,数据另文发表).此6个年龄值误差范围内一致,同属于早志留世.

基性—超基性岩锆石测年的可靠性一直存在争议,有的学者在对基性岩测年过程中,利用斜锆石测年对结果进行验证(李怀坤等,2013).然而,笔者认为大洪山地区基性侵入岩锆石测年结果相对可信,原因如下:(1)大洪山地区6件基性侵入岩锆石测年结果相对一致,并且年龄结果可信度较高,共同指示区内存在早志留世岩浆事件.(2)大洪山地区基性岩脉中的锆石颗粒相对较小,粒径集中在40~90 μm ,而一般情况下,酸性岩锆石粒径都大于100 μm ,大洪山基性岩脉中的锆石与酸性岩中锆石粒径上存在一定区别.(3)据调查研究,大洪山及邻区基本未见早古生代中酸性侵入岩出露,虽北部造山带内黄羊山一带曾报道过志留纪中酸性侵入岩(马昌前等,2004),但造山带与扬子地块自古生代早期以来有着明显不同的地质演化背景,基性岩脉中435 Ma左右的岩浆锆石从相邻造山带内捕获的可能性较小,从而基本可以排除大洪山地区这些基性侵入岩中大量的435 Ma左右的岩浆锆石为捕获锆石的可能性.(4)结合区域资料,随南地区以西的整个扬子北缘(包括造山带)都基本不发育晚古生代以来的基性侵入岩,故大洪山地区基性岩脉形成于晚古生代以后

的可能性较小,这从另一角度证明435 Ma左右的年龄数据可以代表岩脉的形成年龄.

综上所述,本文获得的年龄值能代表大洪山地区早古生代岩浆事件的具体形成时间,成岩时代为早志留世,此年龄数据的获得,为大洪山地区这期基性岩脉提供了精确的同位素年代学依据.

5.2 构造背景

通常情况下,基性岩脉是岩石圈地幔部分熔融的产物,基性岩脉的大量出现,是区域伸展作用的重要标志(Williams *et al.*, 2001).部分基性岩脉形成于洋盆或者与俯冲相关的弧盆体系伸展环境,其成岩岩浆来源于亏损地幔(Deng *et al.*, 2013)或者流体交代地幔(张贵山等,2004; Xu *et al.*, 2016).而现存的大量基性岩脉,多形成于大陆裂谷环境,其成岩岩浆多来源于富集型地幔,并有一定程度的地壳混染(张成立等,2002; 晏云翔,2005; 邹先武等,2011; 李宏博等,2012; 曹亮等,2015).地球化学方面,大洪山地区基性岩脉具有较高 ΣREE 含量,一定程度的轻、重稀土分异度,富集LILE而亏损HFSE.这种地球化学特点可明显区别于洋盆拉张环境下形成的基性岩脉(Sun and McDonough, 1989; Pearce, 2008; Dilek and Furnes, 2009),却兼具有陆内玄武岩和岛弧玄武岩地球化学的共同特点(张鸿翔等,2001).研究证实,陆内玄武岩比岛弧玄武岩具有更高的 Zr 、 TiO_2 含量和 Zr/Y 比值(夏林圻等,2007; 王金荣等,2016).大洪山地区基性岩脉 Zr 含量多大于 100×10^{-6} , TiO_2 含量多大于2%, Zr/Y 比值多大于3.5(表3),在 $\text{Zr}-\text{Zr}/\text{Y}$ 和 $\text{Zr}-\text{TiO}_2$ 图解中,基性岩脉和兰家畈玄武岩都投在大陆板内玄武岩范围内(图8).这说明大洪山地区的基性岩脉和兰家畈玄武岩一致,都形成于早古生代晚期大陆伸展环境.

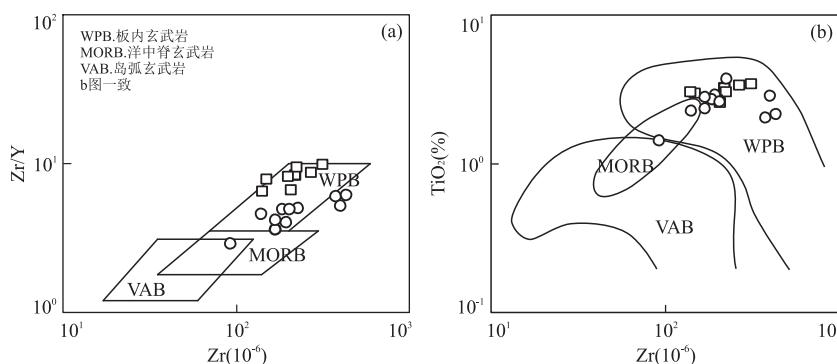


图8 大洪山地区基性岩脉构造环境判别图解

Fig.8 Discrimination diagrams for the mafic dykes from Dahongshan region

a.Zr-Zr/Y图解,据 Pearce(1982); b.Zr-TiO₂图解,据 Pearce(1982)

5.3 地质意义

同位素地球化学研究证明,南秦岭一大别造山带 Pb 同位素组成具有亲扬子地块的特点,可能属于扬子地块的组成部分(张本仁等,2002)。扬子地块北缘和秦岭一大别南缘都发育陡山沱期和灯影期的相似沉积(陈公信和金经炜,1996),说明两者至少在该时期应连在一起,进入古生代以后,扬子北缘和秦岭一大别南缘沉积地层、岩浆活动发生了较大的分异。早古生代南秦岭一大别构造—岩浆—成矿事件活跃(Xu et al., 2008; Zhu et al., 2016),尤其在奥陶纪—志留纪,广泛发育一套大陆裂谷环境的碱性火山岩和侵入岩(雒昆利和端木和顺,2001; 张成立等,2002; 马昌前等,2004; 李夫杰,2009; 邹先武等,2011; 曹亮等,2015; 曹强等,2015; 龙井山等,2016; 万俊等,2016),说明这段时间南秦岭一大别形成近北西—南东向的修长裂谷带。而同时期的扬子地块都以稳定的滨浅海沉积为主,火山—岩浆事件鲜见,表现为稳定大陆边缘的特点(何卫红等,2014)。表面上从沉积建造对比,扬子地块和南秦岭一大别在古生代早期可能不属于同一地块。

然而,本研究在扬子北缘大洪山地区厘定出一套早志留世基性岩脉,结合地球化学特点证明其形成于大陆伸展环境。因此,扬子地块北缘整个早古生代并非绝对稳定,至少在局部发生了一定规模的基性岩浆侵位,而这些基性岩的侵位说明扬子地块北缘一定范围内卷入了地壳伸展过程。并且,这些基性岩脉整体呈近北西—南东走向成群出现,指示近北东—南西向的区域伸展作用,其伸展方向与同时期南秦岭一大别南缘构造背景吻合。说明早古生代晚期扬子地块北缘大洪山地区与秦岭一大别南缘构造环境一致,二者当时可能仍连在一起,同属于扬子北缘的陆缘裂谷环境。扬子地块北缘与秦岭一大别南缘早古生代发育不同的沉积建造(倪世钊等,1994; 陈公信和金经炜,1996; 何卫红等,2014),虽然二者都发育早古生代晚期的裂谷岩浆岩,但岩性组合、岩石系列、地球化学都存在较大的差异。因此,笔者推测早古生代晚期扬子地块北缘与秦岭一大别南缘可能属于扬子北缘裂谷体系不同相带的组成部分,南秦岭一大别南缘处在裂谷中心带,发育完整的碳酸岩、碱性系列玄武岩、辉绿—辉长岩、正长岩组合(董云鹏等,1998a; 马昌前等,2004; 薛怀民和马芳,2005; 万俊等,2016; Ying et al., 2017),而大洪山地区处在裂谷边缘带,地表以稳定沉积岩为主,

地下局部发育拉斑玄武岩系列基性侵入岩。扬子地块北缘与秦岭一大别南缘早古生代晚期属于同一裂谷体系不同相带的观点,本文仅根据岩性组合和常规地球化学作出推测,仍然缺乏岩浆演化等方面的相关细节。

从现有的资料可知,大洪山地区早古生代基性岩脉的厘定应为扬子地块北缘早古生代区域伸展提供强有力的证据,说明扬子地块北缘和秦岭一大别南缘早古生代可能同属于扬子北缘陆缘裂谷拉张环境。

6 结论

(1) 扬子北缘大洪山地区前南华系基底中广泛发育一套基性岩脉,通过 LA-ICP-MS 锆石 U-Pb 测年,获得七里冲、姚家咀、姚家冲、刘关 4 件基性岩脉成岩年龄分别为 433.7 Ma、435.6 Ma、433.4 Ma、436.4 Ma,这些年龄值误差范围内一致,同属于早志留世,为大洪山地区这期基性岩脉提供了精确的同位素年代学依据。

(2) 地球化学特征显示,大洪山地区基性岩脉为大陆伸展环境下的产物,结合基性岩脉野外呈北西—南东走向成群出现的特点,说明大洪山地区早古生代晚期发生了近北东向的区域伸展作用,而这种区域伸展与南秦岭一大别同时期地质背景吻合。

(3) 对比扬子地块北缘和秦岭一大别南缘早古生代晚期的岩石建造属性特点,二者虽然存在一定的差异,但这两大构造单元该时期仍可能同属于扬子北缘的陆缘裂谷环境。

References

- Bureau of Regional Geology Surveying, 1982. 1 : 200 000 Regional Geology Survey of Yicheng (H-49-V) and Suixian (H-49-M). Hubei Geological Survey, Wuhan (in Chinese).
- Cao, L., Zhang, Q., Hu, S.J., et al., 2015. LA-ICP-MS Zircon U-Pb Age of Diabase Porphyry from the Donghe Area, Fangxian in South Daba Mountain and Its Tectonic Significance. *Acta Geologica Sinica*, 89 (12): 2314—2322 (in Chinese with English abstract). <https://doi.org/10.3969/j.issn.0001-5717.2015.12.009>
- Cao, Q., Liu, J.J., Li, L.Y., et al., 2015. Zircon U-Pb Age of Ore-Bearing Rock in the Qiaomaichong Gold Deposits on the Southern Margin of the Qinling Orogenic Belt and Its Geological Significance. *Geology in China*, 42 (5): 1303—1323

- (in Chinese with English abstract).<https://doi.org/10.3969/j.issn.1000-3657.2015.05.010>
- Chen,C., Mao,X.W., Hu,Z.X., et al., 2017a. Discovery of ~817 Ma Oceanic Island Basalts in the Dahongshan Region, Northern Hubei Province and Its Significance. *Geological Science and Technology Information*, 36(6): 22—31 (in Chinese with English abstract).<https://doi.org/10.19509/j.cnki.dzkq.2017.0603>
- Chen,C., Xiong,B.C., Hu,Z.X., et al., 2017b. A Rustic Opinion of Neoproterozoic Ocean-Continent Covergence Events on the Northern Margin of Yangtze Block. *Resources Environment & Engineering*, 31(6): 659—668 (in Chinese with English abstract).<https://doi.org/10.16536/j.cnki.issn.1671-1211.2017.06.001>
- Chen,J.L., Xu,X.Y., Wang,Z.Q., et al., 2008. Geological Features and SHRIMP U-Pb Zircon Age of the Yanwan-Yinggezui Ophiolitic Mélange in the Taibai Area, West Qinling, China. *Geological Bulletin of China*, 27(4): 500—509 (in Chinese).<https://doi.org/10.3969/j.issn.1671-2552.2008.04.007>
- Chen,G.X., Jin,J.W., 1996. Multiple Classification and Correlation of the Stratigraphy of China—Stratigraphy (Lithostatic) of Hubei Province. China University of Geosciences Press, Wuhan (in Chinese).
- Chen,C., Zhou,T., Hu,W.Y., et al., 2016. LA-ICP-MS Zircon U-Pb Dating, Geochemical Characteristics of Volcanic Rocks in Jianshui, Southeast Yunnan and Their Geological Implications. *Geotectonica et Metallogenesis*, 40(1): 161—173 (in Chinese with English abstract).<https://doi.org/10.16539/j.ddgzyckx.2016.01.014>
- Deng,H., Kusky,T.M., Polat,A., et al., 2013. Geochemistry of Neoarchean Mafic Volcanic Rocks and Late Mafic Dikes in the Zanhuang Complex, Central Orogenic Belt, North China Craton: Implications for Geodynamic Setting. *Lithos*, 175—176: 193—212.<https://doi.org/10.13039/501100001809>
- Dilek,Y., Furnes,H., 2009. Structure and Geochemistry of Tethyan Ophiolites and Their Petrogenesis in Subduction Rollback Systems. *Lithos*, 113(1/2): 1—20.<https://doi.org/10.1016/j.lithos.2009.04.022>
- Dong,Y.P., Zhou,D.W., Zhang,G.W., et al., 1998a. Geochemistry of the Caledonian Basic Volcanic Rocks in the South Margin of Qinling Orogenic Belt and Their Tectonic Implications. *Geochimica*, 27(5): 432—441 (in Chinese with English abstract).
- Dong,Y.P., Zhang,G.W., Liu,X.M., et al., 1998b. Disintegration of the Huashan Group in the Dahongshan Mountain Area, Northern Hubei. *Regional Geology of China*, 17(4): 371—376 (in Chinese with English abstract).
- Dong,Y.P., Zhang,G.W., Hauzenberger,C., et al., 2011b. Palaeozoic Tectonics and Evolutionary History of the Qinling Orogen: Evidence from Geochemistry and Geochronology of Ophiolite and Related Volcanic Rocks. *Lithos*, 122(1/2): 39—56.<https://doi.org/10.13039/501100001809>
- Dong,Y.P., Zhang,G.W., Neubauer,F., et al., 2011a. Tectonic Evolution of the Qinling Orogen, China: Review and Synthesis. *Journal of Asian Earth Sciences*, 41(3): 213—237.<https://doi.org/10.1016/j.jseaes.2011.03.002>
- Dong,Y.P., Zhou,D.W., Zhang,G.W., et al., 1999. Geochemistry of the Caledonian Basic Volcanic Rocks at the South Margin of the Qinling Orogenic Belt, and Its Tectonic Implications. *Chinese Journal of Geochemistry*, 18(3): 193—200.<https://doi.org/10.1007/bf02831064>
- Hastie,A.R., Kerr,A.C., Pearce,J.A., et al., 2007. Classification of Altered Volcanic Island Arc Rocks Using Immobile Trace Elements: Development of the Th-Co Discrimination Diagram. *Journal of Petrology*, 48(12): 2341—2357.<https://doi.org/10.1093/petrology/egm062>
- He,W.H., Tang,T.T., Yue,M.L., et al., 2014. Sedimentary and Tectonic Evolution of Nanhuan-Permian in South China. *Earth Science*, 39(8): 929—953 (in Chinese with English abstract).<https://doi.org/10.3799/dqkx.2014.087>
- Hu,Z.X., Chen,C., Mao,X.W., et al., 2015. Documentation of Jingningian Island-Arc Volcanic Rocks and Accretionary Complexes in the Dahongshan Region, Northern Hubei and Its Tectonic Significance. *Resources Environment & Engineering*, 29(6): 757—766 (in Chinese with English abstract).<https://doi.org/10.16536/j.cnki.issn.1671-1211.201506001>
- Hu,Z.X., Chen,C., Mao,X.W., et al., 2017. The Qingbaikouan Tumen Formation-Complex Island Arc Volcanic-Clastic Rocks on the Northern Margin of Yangtze Block and Its Significance. *Journal of Stratigraphy*, 41(3): 304—317 (in Chinese with English abstract).
- Huang,Y.H., Ren,Y.X., Xia,L.Q., et al., 1992. Early Palaeozoic Bimodal Igneous Suite on Northern Daba Mountains Gaotan Diabase and Haoping Trachyte as Examples. *Acta Petrologica Sinica*, 8(3): 243—256 (in Chinese with English abstract).
- Irvine,T.N., Baragar,W.R.A., 1971. A Guide to the Chemical Classification of the Common Volcanic Rocks. *Canadian Journal of Earth Sciences*, 8(5): 523—548.<https://doi.org/10.1139/e71-055>
- Kong,L.Y., Mao,X.W., Chen,C., et al., 2017. Chronological Study on Detrital Zircons and Its Geological Significance

- from Mesoproterozoic Dagushi Group in the Dahongshan Area, North Margin of the Yangtze Block. *Earth Science*, 42(4): 485—501 (in Chinese with English abstract). <https://doi.org/10.3799/dqkx.2017.039>
- Le Bas, M. J., Maitre, R. W. L., Streckeisen, A., et al., 1986. A Chemical Classification of Volcanic Rocks Based on the Total Alkali-Silica Diagram. *Journal of Petrology*, 27(3): 745—750. <https://doi.org/10.1093/petrology/27.3.745>
- Li, F. J., 2009. The Rock Geochemistry Characteristics and Tectonic Implications of Mafic Dyke Swarms and Syenite Porphyry Veins in Zhenba Eastern Area, the South of Shaanxi Province (Dissertation). Chang'an University, Xi'an (in Chinese with English abstract).
- Li, H.B., Zhang, Z.C., Lü, L.S., et al., 2012. Petrological, Geochemical and Geometric Characteristics of Dyke Swarms and Their Tectonic Significance. *Acta Petrologica et Mineralogica*, 31(1): 91—103 (in Chinese with English abstract).
- Li, H.K., Tian, H., Zhou, H. Y., et al., 2016. Correlation between the Dagushi Group in the Dahongshan Area and the Shennongjia Group in the Shennongjia Area on the Northern Margin of the Yangtze Craton: Constraints from Zircon U-Pb Ages and Lu-Hf Isotopic Systematics. *Earth Science Frontiers*, 23(6): 186—201 (in Chinese with English abstract). <https://doi.org/10.13745/j.esf.2016.06.013>
- Li, H. K., Zhang, C. L., Xiang, Z. Q., et al., 2013. Zircon and Baddeleyite U-Pb Geochronology of the Shennongjia Group in the Yangtze Craton and Its Tectonic Significance. *Acta Petrologica Sinica*, 29(2): 673—697 (in Chinese with English abstract).
- Liao, M. F., Xie, Y. B., Li, L. J., et al., 2016. Discussion about Genesis and Formation Age of Sanligang Pluton in the Dahongshan Region, Hubei. *Resources Environment & Engineering*, 30(2): 143—150, 158 (in Chinese with English abstract). <https://doi.org/10.16536/j.cnki.issn.1671-1211.2016.02.004>
- Liu, H., Xu, D. L., Wei, Y. X., et al., 2017. Depositional Age of the Dagushi Group in the Dahong Mountain, Hubei Province: Evidence from U-Pb Ages of Detrital Zircons. *Geological Bulletin of China*, 36(5): 715—725 (in Chinese with English abstract).
- Liu, Y. S., Gao, S., Hu, Z. C., et al., 2009. Continental and Oceanic Crust Recycling-Induced Melt-Peridotite Interactions in the Trans-North China Orogen: U-Pb Dating, Hf Isotopes and Trace Elements in Zircons from Mantle Xenoliths. *Journal of Petrology*, 51(1/2): 537—571. <https://doi.org/10.1093/petrology/egp082>
- Long, J. S., Zhang, G. S., Han, W. H., et al., 2016. Geochemical Characteristics and Zircon U-Pb Dating of the Syenite Porphyry Dike Swarms in the Ziyang Area in the Northern Daba Mountains. *Bulletin of Mineralogy, Petrology and Geochemistry*, 35(4): 681—691 (in Chinese). <https://doi.org/10.3969/j.issn.1007-2802.2016.04.009>
- Lu, S.N., Yu, H.F., Li, H.K., et al., 2006. Early Paleozoic Suture Zones and Tectonic Divisions in the “Central China Orogen”. *Geological Bulletin of China*, 25(12): 1368—1380 (in Chinese with English abstract). <https://doi.org/10.3969/j.issn.1671-2552.2006.12.004>
- Lu, Y. F., 2004. GeoKit—A Geochemical Toolkit for Microsoft Excel. *Geochimica*, 33(5): 459—464 (in Chinese with English abstract).
- Ludwig, K. R., 2003. User’s Manual for Isoplot 3.00: A Geochronological Toolkit for Microsoft Excel. Berkeley Geochronology Center, Berkeley.
- Luo, K. L., Duanmu, H. S., 2001. Timing of Early Paleozoic Basic Igneous Rocks in the Daba Mountains. *Regional Geology of China*, 20(3): 262—266 (in Chinese with English abstract).
- Ma, C. Q., She, Z. B., Xu, P., et al., 2004. Silurian A-type Granitoids in the Southern Margin of the Tongbai-Dabieshan: Evidence from SHRIMP Zircon Geochronology and Geochemistry. *Science in China (Series D)*, 34(12): 1100—1110 (in Chinese with English abstract).
- Ma, T. F., Li, X. L., Chen, Y. J., et al., 2011. Interchangeable Analysis of Method on the X-Ray Fluorescence Spectrometry. *Rock and Mineral Analysis*, 30(4): 486—490 (in Chinese with English abstract).
- Ni, S.Z., Yang, D.L., Yang, Z.Q., et al., 1994. Paleozoic Strata and Sedimentary Facies of the Southern Belt in the Eastern Section of East Qinling Mountains. China University of Geosciences Press, Wuhan, 1—80 (in Chinese).
- Pearce, J. A., 1982. Trace Element Characteristics of Lavas from Destructive Plate Boundaries. In: Thorpe, R. S. ed., *Andesites: Orogenic Andesites and Related Rocks*. John Wiley and Sons, New York, 525—548.
- Pearce, J. A., 2008. Geochemical Fingerprinting of Oceanic Basalts with Applications to Ophiolite Classification and the Search for Archean Oceanic Crust. *Lithos*, 100(1—4): 14—48. <https://doi.org/10.1016/j.lithos.2007.06.016>
- Pearce, J. A., 2014. Immobile Element Fingerprinting of Ophiolites. *Elements*, 10(2): 101—108. <https://doi.org/10.2113/gselements.10.2.101>
- Peng, S. B., Liu, S. F., Lin, M. S., et al., 2016a. Early Paleozoic Subduction in Cathaysia (I): New Evidence from Nudong Ophiolite. *Earth Science*, 41(5): 765—778 (in Chinese with English abstract).

- Chinese with English abstract). <https://doi.org/10.3799/dqkx.2016.065>
- Peng, S.B., Liu, S.F., Lin, M.S., et al., 2016b. Early Paleozoic Subduction in Cathaysia (II): New Evidence from the Dashuang High Magnesian-Magnesian Andesite. *Earth Science*, 41(6): 931—947 (in Chinese with English abstract). <https://doi.org/10.3799/dqkx.2016.079>
- Qin, X.F., Wang, Z.Q., Hu, G.A., et al., 2013. Geochronology and Geochemistry of Hudong Gneissic Composite Pluton in the Junction of Guangdong and Guangxi Provinces: Implications for Early Paleozoic Tectono-Magmatism along the Northern Margin of Yunkai Massif. *Acta Petrologica Sinica*, 29(9): 3115—3130 (in Chinese with English abstract).
- Qin, X.F., Wang, Z.Q., Wang, T., et al., 2015. The Reconfirmation of Age and Tectonic Setting of the Volcanic Rocks of Yingyangguan Group in the Eastern Guangxi: Constraints on the Structural Pattern of the Southwest Segment of Qinzhou-Hangzhou Joint Belt. *Acta Geoscientica Sinica*, 36(3): 283—292 (in Chinese with English abstract).
- Shi, Y.R., Liu, D.Y., Zhang, Z.Q., et al., 2007. SHRIMP Zircon U-Pb Dating of Gabbro and Granite from the Huashan Ophiolite, Qinling Orogenic Belt, China: Neoproterozoic Suture on the Northern Margin of the Yangtze Craton. *Acta Geologica Sinica*, 81(2): 239—243. <https://doi.org/10.1111/j.1755-6724.2007.tb00947.x>
- Sun W.D., Li S.G., Sun Y., et al., 1996. Chronology and Geochemistry of a Lava Pillow in the Erlangping Group at Xixia in the North Qinling Mountains. *Geological Review*, 42(2): 144—153. <https://doi.org/10.16509/j.georeview.1996.02.007> (in Chinese with English abstract).
- Sun, S.S., McDonough, W.F., 1989. Chemical and Isotopic Systematics of Oceanic Basalts: Implications for Mantle Composition and Processes. *Geological Society, London, Special Publications*, 42(1): 313—345. <https://doi.org/10.1144/gsl.sp.1989.042.01.19>
- Wan, J., Liu, C.X., Yang, C., et al., 2016. Geochemical Characteristics and LA-ICP-MS Zircon U-Pb Age of the Trachytic Volcanic Rocks in Zhushan Area of Southern Qinling Mountains and Their Significance. *Geological Bulletin of China*, 35(7): 1134—1143 (in Chinese with English abstract).
- Wang, J.R., Pan, Z.J., Zhang, Q., et al., 2016. Intra-Continental Basalt Data Mining: the Diversity of Their Constituents and the Performance in Basalt Discrimination Diagrams. *Acta Petrologica Sinica*, 32(7): 1919—1933 (in Chinese with English abstract).
- Williams, H., Turner, S., Kelley, S., et al., 2001. Age and Composition of Dikes in Southern Tibet: New Constraints on the Timing of East-West Extension and Its Relationship to Postcollisional Volcanism. *Geology*, 29(4): 339. [https://doi.org/10.1130/0091-7613\(2001\)029-0339](https://doi.org/10.1130/0091-7613(2001)029-0339)
- Winchester, J.A., Floyd, P.A., 1977. Geochemical Discrimination of Different Magma Series and Their Differentiation Products Using Immobile Elements. *Chemical Geology*, 20: 325—343. [https://doi.org/10.1016/0009-2541\(77\)90057-2](https://doi.org/10.1016/0009-2541(77)90057-2)
- Xia, L.Q., Xia, Z.C., Xu, X.Y., 2007. The Discrimination between Continental Basalt and Island Arc Basalt Based on Geochemical Method. *Acta Petrologica et Mineralogica*, 26(1): 77—89 (in Chinese with English abstract). <https://doi.org/10.3969/j.issn.1000-6524.2007.01.011>
- Xiang, Z.J., Yan, Q.R., Song, B., et al., 2016. New Evidence for the Ages of Ultramafic to Mafic Dikes and Alkaline Volcanic Complexes in the North Daba Mountains and Its Geological Implication. *Acta Geologica Sinica*, 90(5): 896—916 (in Chinese with English abstract).
- Xu, X.B., Tang, S., Li, Y., et al., 2015. Characteristics of Neoproterozoic-Early Mesozoic Multiphase Orogenic Activities of Eastern Jiangnan Orogen. *Geology in China*, 42(1): 33—50 (in Chinese with English abstract). <https://doi.org/10.3969/j.issn.1000-3657.2015.01.004>
- Xu, C., Campbell, I.H., Allen, C.M., et al., 2008. U-Pb Zircon Age, Geochemical and Isotopic Characteristics of Carbonatite and Syenite Complexes from the Shaxiongdong, China. *Lithos*, 105(1/2): 118—128. <https://doi.org/10.1016/j.lithos.2008.03.002>
- Xu, Y., Yang, K.G., Polat, A., et al., 2016. The ~860 Ma Mafic Dikes and Granitoids from the Northern Margin of the Yangtze Block, China: A Record of Oceanic Subduction in the Early Neoproterozoic. *Precambrian Research*, 275: 310—331. <https://doi.org/10.13039/501100001809>
- Xue, H.M., Ma, F., 2005. Mineral Chemistry and Geochemistry of Troctolitic Dyke (Sill) Swarms on the Southern Piedmont of the Tongbai Orogenic Belt and Their Genetic Implications. *Acta Petrologica et Mineralogica*, 24(5): 409—417 (in Chinese with English abstract). <https://doi.org/10.3969/j.issn.1000-6524.2005.05.009>
- Yan, Q.R., Wang, Z.Q., Chen, J.L., et al., 2007. Tectonic Setting and SHRIMP Age of Volcanic Rocks in the Xieyuguan and Caotangou Groups: Implications for the North Qinling Orogenic Belt. *Acta Geologica Sinica*, 81(4): 488—500 (in Chinese with English abstract). <https://doi.org/10.3321/j.issn:0001-5717.2007.04.007>

- Yan, Y.X., 2005. Research on Geochemistry and Sr, Nd and Pb Isotope of the Basic Dyke Swarms in Ziyang-Langao Area, Shaanxi Province (Dissertation). Northwest University, Xi'an (in Chinese with English abstract).
- Ying, Y., Chen, W., Lu, J., et al., 2017. In Situ U-Th-Pb Ages of the Miaoya Carbonatite Complex in the South Qinling Orogenic Belt, Central China. *Lithos*, 290 – 291: 159–171. <https://doi.org/10.13039/501100001809>
- Zhang, B.R., Gao, S., Zhang, H.F., et al., 2002. Geochemistry of Qinling Orogenic Belt. Science Press, Beijing (in Chinese).
- Zhang, C.L., Gao, S., Zhang, G.W., 2002. Geochemical and Geological Significance of Early Paleozoic Alkaline Rock Wall in South Qinling. *Science in China (Series D)*, 32(10): 819–829 (in Chinese with English abstract). <https://doi.org/10.3969/j.issn.1674-7240.2002.10.005>
- Zhang, G.S., Wen, H.J., Qiu, Y.Z., 2004. Geochemistry of the Late Mesozoic Mafic Dikes in Western Fujian Province. *Geochimica*, 33(3): 243–253 (in Chinese with English abstract). <https://doi.org/10.3321/j.issn:0379-1726.2004.03.003>
- Zhang, G.W., Dong, Y.P., Yao, A.P., 1997. The Crustal Compositions, Structures and Tectonic Evolution of the Qinling Orogenic Belt. *Geology of Shaanxi*, 15(2): 1–14 (in Chinese with English abstract).
- Zhang, G.W., Zhang, Z.Q., Dong, Y.P., 1995. Nature of Main Tectono-Lithostratigraphic Units of the Qinling Orogen: Implications for the Tectonic Evolution. *Acta Petrologica Sinica*, 11(2): 101–114 (in Chinese with English abstract).
- Zhang, H. X., Xu, Z. F., Ma, Y. J., et al., 2001. Geochemical Features and Origin of Continental Flood Basalts. *Earth Science*, 26(3): 261–268 (in Chinese with English abstract). <https://doi.org/10.3321/j.issn:1000-2383.2001.03.008>
- Zhang, H. Y., 2006. Structures, Evolution and Tectonic Implications of the Erlangping Group in North Qinling (Dissertation). Chinese Academy of Geological Sciences, Beijing (in Chinese with English abstract).
- Zhang, S.M., Zhang, K.X., Jiang, G.L., et al., 2014. Evolution of Neoproterozoic-Mesozoic Sedimentary Basins in Qinling-Dabie Orogenic Belt. *Earth Science*, 39(8): 1185–1199 (in Chinese with English abstract). <https://doi.org/10.3799/dqkx.2014.103>
- Zhang, T.L., 2014. Petrogenesis and Tectonic Implications of Early Paleozoic Alkaline Bimodal Dikes (Sills) in the Daba Mountain, South Qinling (Dissertation). China University of Geosciences, Wuhan (in Chinese with English abstract).
- Zhao, J., Chen, D.L., Tan, Q.H., 2012. Zircon LA-ICP-MS U-Pb Dating of Basic Volcanics from Erlangping Group of the North Qinling, Eastern Qinling Mountains and Its Geological Implications. *Earth Science Frontiers*, 19(4): 118–125 (in Chinese with English abstract).
- Zhou, L. L., Wei, J. Q., Wang, F., 2017. Optimization of the Working Parameters of LA-ICP-MS and Its Application to Zircon U-Pb Dating. *Rock and Mineral Analysis*, 36(4): 350–359 (in Chinese with English abstract). <https://doi.org/10.15898/j.cnki.11-2131/td.201701160007>
- Zhu, J., Wang, L., Peng, S., et al., 2016. U-Pb Zircon Age, Geochemical and Isotopic Characteristics of the Miaoya Syenite and Carbonatite Complex, Central China. *Geological Journal*, 52(6): 938–954. <https://doi.org/10.13039/501100004613>
- Zou, X.W., Duan, Q.F., Tang, C.Y., 2011. SHRIMP Zircon U-Pb Dating and Lithogeochemical Characteristics of Diabase from Zhenping Area in North Daba Mountain. *Geology in China*, 38(2): 282–291 (in Chinese with English abstract).
- ## 附中文参考文献
- 湖北省地质局区域地质测量队, 1982. 1: 20 万宜城幅(H-49-V)、随县幅(H-49-M)区域地质调查报告. 武汉: 湖北省地质调查院.
- 曹亮, 张权绪, 胡尚军, 等, 2015. 大巴山南部房县东河辉绿玢岩 LA-ICP-MS 锆石 U-Pb 测年及其构造意义. 地质学报, 89(12): 2314–2322.
- 曹强, 刘家军, 李龙吟, 等, 2015. 秦岭造山带南缘莽麦冲金矿床正长斑岩锆石 U-Pb 年龄及其地质意义. 中国地质, 42(5): 1303–1323.
- 陈超, 毛新武, 胡正祥, 等, 2017a. 鄂北大洪山地区 ~817 Ma 洋岛玄武岩的发现及意义. 地质科技情报, 36(6): 22–31.
- 陈超, 熊保成, 胡正祥, 等, 2017b. 扬子北缘新元古代洋陆转换事件刍议. 资源环境与工程, 31(6): 659–668.
- 陈超, 周涛, 胡维云, 等, 2016. 滇东南建水火山岩 LA-ICP-MS 锆石 U-Pb 测年、地球化学特征及地质意义. 大地构造与成矿学, 40(1): 161–173.
- 陈公信, 金经炜, 1996. 全国地层多重划分对比研究——湖北省岩石地层. 武汉: 中国地质大学出版社.
- 陈隽璐, 徐学义, 王宗起, 等, 2008. 西秦岭太白地区岩湾—鹦鸽咀蛇绿混杂岩的地质特征及形成时代. 地质通报, 27(4): 500–509.
- 董云鹏, 周鼎武, 张国伟, 等, 1998a. 秦岭造山带南缘早古生代基性火山岩地球化学特征及其大地构造意义. 地球化学, 27(5): 432–441.

- 董云鹏,张国伟,柳小明,等,1998b.鄂北大洪山地区“花山群”的解体.中国区域地质,17(4):371—376.
- 何卫红,唐婷婷,乐明亮,等,2014.华南南华纪一二叠纪沉积大地构造演化.地球科学,39(8):929—953.<https://doi.org/10.3799/dqkx.2014.087>
- 胡正祥,陈超,毛新武,等,2015.鄂北大洪山晋宁期岛弧火山岩和增生杂岩的厘定及地质意义.资源环境与工程,29(6):757—766.
- 胡正祥,陈超,毛新武,等,2017.扬子北缘青白口系土门岩组岛弧火山—碎屑岩的定义及意义.地层学杂志,41(3):304—317.
- 黄月华,任有祥,夏林圻,等,1992.北大巴山早古生代双模式火成岩套:以高滩辉绿岩和蒿坪粗面岩为例.岩石学报,8(3):243—256.
- 孔令耀,毛新武,陈超,等,2017.扬子北缘大洪山地区中元古代打鼓石群碎屑锆石年代学及其地质意义.地球科学,42(4):485—501.
- 李夫杰,2009.陕南镇巴东部地区基性岩墙群和正长斑岩脉的岩石地球化学特征及其构造意义(硕士学位论文).西安:长安大学.
- 李宏博,张招崇,吕林素,等,2012.岩墙群的岩石学、地球化学和几何学特征及其大地构造意义.岩石矿物学杂志,31(1):91—103.
- 李怀坤,田辉,周红英,等,2016.扬子克拉通北缘大洪山地区打鼓石群与神农架地区神农架群的对比:锆石SHRIMP U-Pb年龄及Hf同位素证据.地学前缘,23(6):186—201.
- 李怀坤,张传林,相振群,等,2013.扬子克拉通神农架群锆石和斜锆石U-Pb年代学及其构造意义.岩石学报,29(2):673—697.
- 廖明芳,谢应波,李琳静,等,2016.湖北省大洪山地区三里岗岩体成因及时代探讨.资源环境与工程,30(2):143—150,158.
- 刘浩,徐大良,魏运许,等,2017.湖北大洪山打鼓石群沉积时限——来自碎屑锆石U-Pb年龄的证据.地质通报,36(5):715—725.
- 龙井山,张贵山,韩文华,等,2016.北大巴山紫阳地区正长斑岩岩墙地球化学特征与锆石SHRIMP U-Pb定年.矿物岩石地球化学通报,35(4):681—691.
- 陆松年,于海峰,李怀坤,等,2006.“中央造山带”早古生代缝合带及构造分区概述.地质通报,25(12):1368—1380.
- 路远发,2004.GeoKit:一个用VBA构建的地球化学工具软件包.地球化学,33(5):459—464.
- 雒昆利,端木和顺,2001.大巴山区早古生代基性火成岩的形成时代.中国区域地质,20(3):262—266.
- 马昌前,余振兵,许聘,等,2004.桐柏一大别山南缘的志留纪A型花岗岩类:SHRIMP锆石年代学和地球化学证据.中国科学(D辑),34(12):1100—1110.
- 马天芳,李小莉,陈永君,等,2011.X射线荧光光谱分析方法的共享.岩矿测试,30(4):486—490.
- 倪世钊,杨德骊,杨振强,等,1994.东秦岭东段南带古生代地层及沉积相.武汉:中国地质大学出版社,1—80.
- 彭松柏,刘松峰,林木森,等,2016a.华夏早古生代俯冲作用(I):来自糯垌蛇绿岩的新证据.地球科学,41(5):765—778.
- 彭松柏,刘松峰,林木森,等,2016b.华夏早古生代俯冲作用(II):大爽高镁—镁质安山岩新证据.地球科学,41(6):931—947.
- 覃小锋,王宗起,胡贵昂,等,2013.两广交界地区壶垌片麻状复式岩体的年代学和地球化学:对云开地块北缘早古生代构造—岩浆作用的启示.岩石学报,(9):3115—3130.
- 覃小锋,王宗起,王涛,等,2015.桂东鹰扬关群火山岩时代和构造环境的重新厘定:对钦杭结合带西南段构造格局的制约.地球学报,36(3):282—291.
- 孙卫东,李曙光,孙勇,等,1996.北秦岭西峡二郎坪群枕状熔岩中一个岩枕的年代学和地球化学研究.地质论评,42(2):144—153.
- 万俊,刘成新,杨成,等,2016.南秦岭竹山地区粗面质火山岩地球化学特征、LA-ICP-MS锆石U-Pb年龄及其大地构造意义.地质通报,35(7):1134—1143.
- 王金荣,潘振杰,张旗,等,2016.大陆板内玄武岩数据挖掘:成分多样性及在判别图中的表现.岩石学报,32(7):1919—1933.
- 夏林圻,夏祖春,徐学义,等,2007.利用地球化学方法判别大陆玄武岩和岛弧玄武岩.岩石矿物学杂志,26(1):77—89.
- 向忠金,闫全人,宋博,等,2016.北大巴山超基性、基性岩墙和碱质火山杂岩形成时代的新证据及其地质意义.地学报,90(5):896—916.
- 徐先兵,汤帅,李源,等,2015.江南造山带东段新元古代至早中生代多期造山作用特征.中国地质,42(1):33—50.
- 薛怀民,马芳,2005.桐柏山造山带南麓橄榄质岩墙(床)群的矿物化学、地球化学特征与成因意义.岩石矿物学杂志,24(5):409—417.
- 闫全人,王宗起,陈隽璐,等,2007.北秦岭斜峪关群和草滩沟群火山岩成因的地球化学和同位素约束、SHRIMP年代及其意义.地质学报,81(04):488—500.
- 晏云翔,2005.陕西紫阳—岚皋地区碱—基性岩墙群的岩石地球化学及Sr、Nd、Pb同位素地球化学研究(硕士学位论文).西安:西北大学.
- 张本仁,高山,张宏飞,等,2002.秦岭造山带地球化学.北京:科学出版社.
- 张成立,高山,张国伟,等,2002.南秦岭早古生代碱性岩墙群的地球化学及其地质意义.中国科学(D辑),32(10):819—829.

张贵山,温汉捷,裴渝卓,2004.闽西晚中生代基性岩脉的地球化学研究.地球化学,33(3): 243—253.

张国伟,董云鹏,姚安平,1997.秦岭造山带基本组成与结构及其构造演化.陕西地质,15(2): 1—14.

张国伟,张宗清,董云鹏,1995.秦岭造山带主要构造岩石地层单元的构造性质及其大地构造意义.岩石学报,11(2): 101—114.

张宏远,2006.北秦岭二郎坪群的结构、演化与区域构造意义(博士学位论文).北京:中国地质科学院.

张鸿翔,徐志方,马英军,等,2001.大陆溢流玄武岩的地球化学特征及起源.地球科学,26(3): 261—268.

张思敏,张克信,姜高磊,等,2014.秦岭一大别新元古代—

中生代沉积盆地演化.地球科学,39(8): 1185—1199.

张太乐,2014.南秦岭大巴山早古生代碱性双峰式岩墙(博士学位论文).武汉:中国地质大学(武汉).

赵姣,陈丹玲,谭清海,等,2012.北秦岭东段二郎坪群火山岩锆石的 LA-ICP-MS U-Pb 定年及其地质意义.地学前缘,19(4): 118—125.

周亮亮,魏均启,王芳,等,2017.LA-ICP-MS 工作参数优化及在锆石 U-Pb 定年分析中的应用.岩矿测试,36(4): 350—359.

邹先武,段其发,汤朝阳,等,2011.北大巴山镇坪地区辉绿岩锆石 SHRIMP U-Pb 定年和岩石地球化学特征.中国地质,38(2): 282—291.