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赣南南华纪变质沉凝灰岩的碎屑锆石U-Pb年代学及其对裂谷盆地形成时间的限定

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提要:江西省宁都某地新元古代浅变质岩风化壳中赋存离子吸附型稀土矿,文章对某矿区内原定青白口纪库里组的2件变质沉凝灰岩样品进行了碎屑锆石LA-ICP-MS U-Pb年代学研究,获得了88组和110组谐和年龄。2件样品的碎屑锆石年龄区间相似,主要分布在:810~780 Ma,峰值年龄为798 Ma(*n*=55);748~727 Ma,峰值年龄为737 Ma(*n*=127);691~667 Ma,峰值年龄为680 Ma(*n*=6),此外还有少量的年龄分布在2.85~1.08 Ga。认为,变质沉凝灰岩样品的沉积时代可能为南华纪,地层应归属为上施组;物源可能来自江南造山带东段(赣东北—皖南—浙西)青白口纪晚期—南华纪的火山-沉积岩;赣南区域上同时期的巨厚海相火山-碎屑沉积可能形成于华南古大陆裂解之后的裂谷盆地,赣南次级裂谷盆地的沉积时限为810~727 Ma。

关 键 词:南华纪;变质沉凝灰岩;碎屑锆石U-Pb定年;裂谷盆地;地质调查工程;赣南

中图分类号:P578.496;P597.3 **文献标志码**:A **文章编号**:1000-3657(2021)02-0564-16

Detrital zircon U-Pb dating of Nanhua meta-tuffite in South Jiangxi and constraint on the time limit of the rift basin

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Abstract: Ion-adsorption type REE deposits is hosted in regolith of Neoproterozoic epimetamorphic rocks in South Jiangxi, China. LA-ICP-MS U-Pb dating of detrital zircons from two metamorphic tuff samples of the originally identified Kuli Formation of Qingbaikou System in a mine area yielded the harmonic ages of 88 groups and 110 groups respectively. They are predominantly

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Neoproterozoic and have ages ranging from 810 to 667 Ma with three age peaks at ca 798 Ma (*n*=55), 737 Ma (*n*=127) and 680 Ma (*n*=6). There are also a few Meso- to Paleoproterozoic zircon grains with ages scattering from 2.85 Ga to 1.08 Ga. The dating results probably suggest that the sedimentary age of the tuffite may be Nanhua Period. It is speculated that the provenance may be volcanic-sedimentary rocks of late Qingbaikou Period to Nanhua Period in the eastern part of Jiangnan orogenic belt (northeast Jiangxi-southern Anhui-western Zhejiang). The super thick marine volcanic-clastic sediments of the same period in southern Jiangxi might be formed in the rift basin after the breakup of the ancient continent of South China, and the sedimentary time of the secondary rift basin in southern Jiangxi is about 810-727 Ma.

Key words: Nanhua Period; meta-tuffite; detrital zircon U-Pb age; rift basin; geological aurvey engineering; South Jiangxi

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1　引　言

华南新元古代构造-岩浆演化一直存在较大争议。江西地处华南腹地,新元古代地层及岩浆岩出露较好,是研究华南新元古代构造演化的重要地区。赣南广泛出露新元古代浅变质岩系,其原岩为一套海相火山-碎屑沉积,厚度达千米,近年在其风化壳中发现了离子吸附型稀土矿(赵芝等,2017)。目前,对浅变质岩系的研究程度很低,因缺乏精确的同位素年代学依据其沉积时代归属不一致:1:20万宁化幅地质报告中将其归属为震旦纪(福建省冶金工业局,1972❶),而1:5万长胜幅中归属为青白口纪(南方工业学校,1997❷)。对浅变质岩系沉积的构造环境认识也存在分歧:一种观点认为其沉积于裂谷盆地(舒良树,2012;Wang et al., 2013;杨明桂等,2015;邓奇等,2016);另一种观点认为其沉积于弧-盆体系(周博文等,2018)。为了限定江西宁都某离子吸附型稀土矿区内变质沉凝灰岩的沉积时限、探讨其物质来源和沉积盆地的构造性质,本文对矿区内的2件变质沉凝灰岩样品进行了碎屑锆石LA-ICP-MS U-Pb年代学研究。

2　地质概况及样品特征

赣中南地区(F_2萍乡—广丰断裂带以南)零星分布中元古代结晶基底(寻乌岩组片岩、变粒岩和片麻岩)(图1),其上为青白口系—下古生界强烈褶皱的基底,其中青白口系—南华系为浅变质的火山-碎屑沉积,震旦系、寒武系和奥陶系为笔石相碎屑岩系,以韵律状泥砂质岩层为特征(舒良树,2012)。沉积盖层由未变质的上泥盆统、石炭系、二叠系、下三叠统等浅海相碳酸盐岩和泥砂岩以及上三叠统、侏罗系、白垩系和古近系陆相碎屑-火山岩组成,新近系仅零星分布(舒良树等,2006)。

宁都县位于赣南东部、宜黄—定南断裂带以东(图1),出露青白口系—寒武系褶皱基底,缺失奥陶系—泥盆系,零星分布石炭系和侏罗系,白垩系出露较广,印支期和燕山期岩浆活动较为发育(图2)。某地青白口系浅变质岩风化壳中发育离子吸附型稀土矿,矿区出露的地层主要为神山组和库里组,其中神山组呈东西向带状分布,与库里组呈平行不整合接触,岩石类型以千枚岩为主,少量片岩。库里组呈东西向带状展布,与上覆中生代地层呈角度不整合,岩石主要为变沉凝灰岩类和变质砂岩(赵芝等,2018)。

样品采自宁都某地的离子吸附型稀土矿区,2件样品均为原定的青白口纪库里组第一段,ND-b5的采集层位更靠库里组二段,ND-b34的采集层位更靠神山组二段(图3)。ND-b5(图4a、c、e):呈土黄色,变余碎屑结构,变余层理构造,弱风化。显微镜下见少量的石英晶屑和岩屑(<5%),岩屑绢云母化仅残留轮廓;基质多为变质新生的绢云母和经重结晶作用形成的细小的长英质矿物。ND-b34(图4b、d、f),呈土黄色,变余碎屑结构,变余层理构造,弱风化,粒度较ND-b5稍粗一些。显微镜下可见长

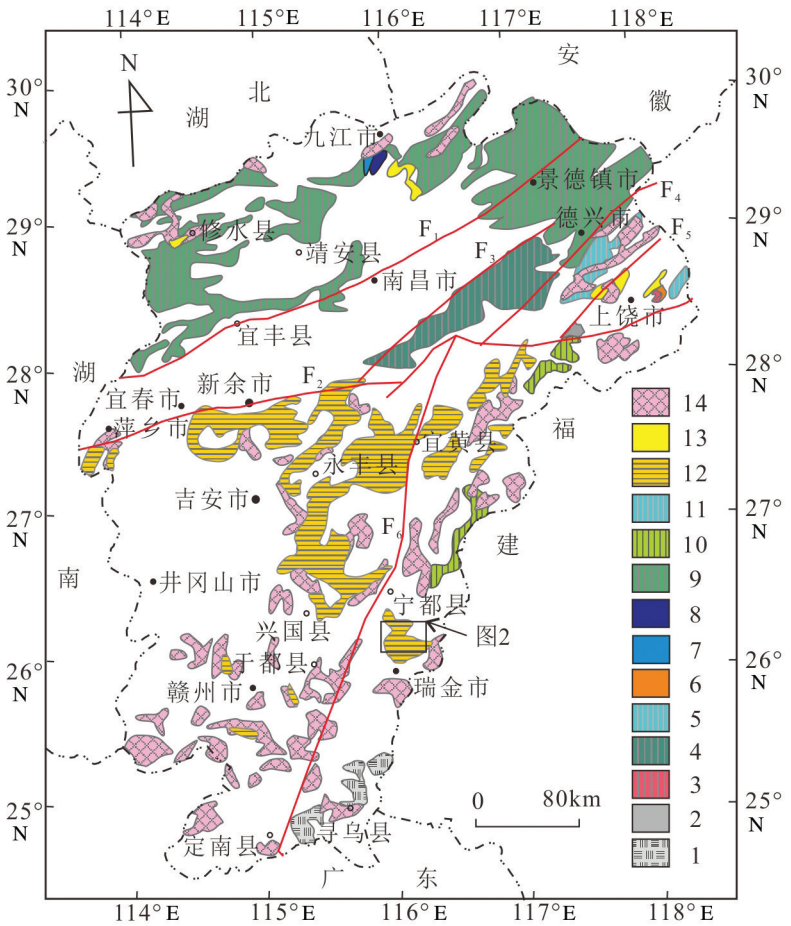

图1 江西省中—新元古代地层分布略图(据刘亚光,1997修改)

1—寻乌岩群(1.8~1.7 Ga, 刘邦秀等,2001);2—铁沙街组(1.13~1.17 Ma,高林志等,2013;张恒等,2015b);3—田里片岩(1.5~1.04 Ga,Li et al., 2007);4—万年群和珍珠山群(860~849 Ma,Le et al.,2010; 刘树文等,2012);5—张村群(860 Ma,高林志等,2014);6—翁家岭组 (841 Ma,张恒等,2015a);7—庐山垄群(840~831 Ma,高林志等,2012a);8—星子群(825~834 Ma,Shu et al.,2008;关俊朋等,2010);9—双桥山群(840~823 Ma,高林志等,2008,2010,2011,2012b;董树文,2010);10—周潭岩群(834~809 Ma,王孝磊等,2013);11—登山群 (≤830 Ma,陈小勇等,2015);12—赣南青白口—南华系(800~737 Ma,郭娜欣,2015;周博文等,2018);13—赣北青白口—南华系 (803~751 Ma,高林志等,2012b;Wang et al.,2013;王剑等,2013);14—震旦系;F_1—宜丰—景德镇断裂带;F_2—萍乡—广丰断裂带;F_3—婺源—丰城断裂带;F_4—德兴—东乡断裂带;F_5—葛源—樟村断裂带;F_6—宜黄—定南断裂带

Fig.1 Distribution of the Meso−Neoproterozoic strata in Jiangxi Province (modified from Liu Yaguang, 1997)

1−Xunwu rock Group (1.8~1.7 Ga, Liu Bangxiu et al.,2001) ; 2−Tieshajie Formation (1.13~1.17 Ma, Gao Linzhi et al.,2013, Zhang Heng et al., 2015b) ; 3−Tianli schist (1.5~1.04 Ga, Li et al.,2007) ; 4−Wannian and Zhenzhushan Group (860~849 Ma, Le et al.,2010; Liu Shuwen et al.,2012) ; 5−Zhangcun Group (860 Ma, Gao Linzhi et al.,2014); 6−Wengjialing Formation (841Ma, Zhang Heng et al.,2015a) ; 7−Lushanlong Group (840~831Ma, Gao Linzhi et al.,2012a); 8−Xingzi Group (825~834 Ma, Shu et al.,2008; Guan Junpeng et al.,2010) ; 9−Shuangqiaoshan Group (840~823 Ma, Gao Linzhi et al.,2008,2010,2011,2012b; Dong Shuwen et al.,2010) ; 10−Zhoutan rock group (834~809 Ma,Wang Xiaoleng et al.,2013) ; 11−Dengshan Group (≤830 Ma, Chen Xiaoyong et al., 2015) ; 12−Qingbaikou to Nanhua strata in southern Jiangxi (800~737 Ma, Guo Naxin, 2015; Zhou Bowen et al.,2018) ; 13− Qingbaikou to Nanhua strata in northern Jiangxi (803~751 Ma, Gao Linzhi et al.,2012 b; Wang et al.,2013; Wang Jian et al.,2013) ; 14− Sinian strata; F_1− Yifeng− Jingdezhen fault zone; F_2− Pingxiang − Guangfeng fault zone; F_3− Wuyuan − Fengcheng fault zone; F_4−Dexing −Dongxiang fault zone; F_5−Geyuan − Zhangcun fault zone; F_6−Yihuang − Dingnan fault zone

石和石英晶屑(~20%),呈棱角状,边部裂隙发育;基质为变质新生的绢云母和黑云母,以及重结晶作用形成的细小的长英质矿物。

3 测试方法

碎屑锆石由北京中兴美科科技有限公司挑选和制靶,锆石靶子上黏贴的锆石颗粒在200~300颗之间。锆石的阴极发光图像由中国地质科学院矿产资源研究所电子探针实验室技术人员拍摄。笔者在显微镜下观察了锆石的透射和反射光特征并采集了相关图像。在此基础上开展了锆石U−Pb测试,测试工作在中国地质科学院矿产资源研究所

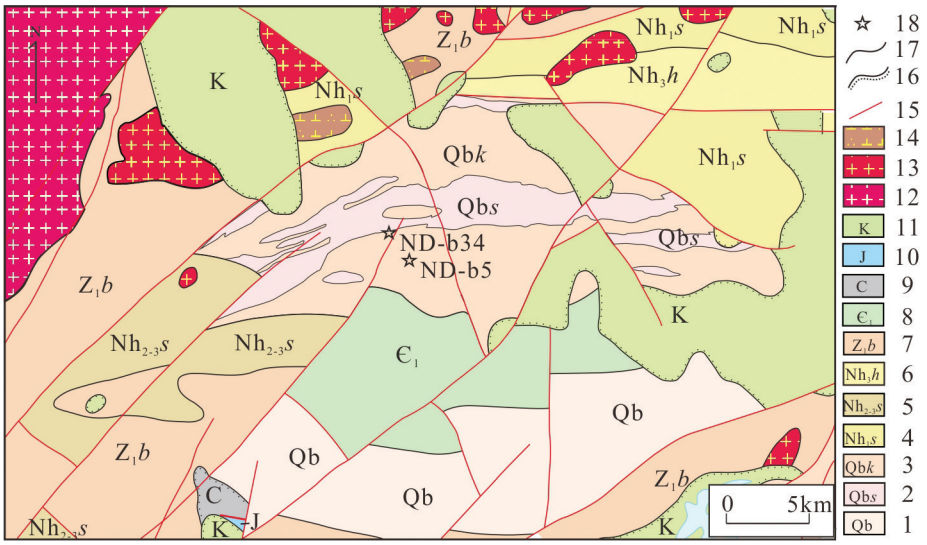

图2 江西省宁都地区地质图(据福建省冶金工业局,1972和南方工业学校,1997修编)

1—青白口系未分组;2—青白口系神山组;3—青白口系库里组;4—南华系上施组;5—南华系沙坝黄组;6—南华系洪山组;7—震旦系坝里组;8—寒武系;9—石炭系;10—侏罗系;11—白垩系;12—早古生代花岗岩;13—侏罗纪花岗岩;14—侏罗纪闪长岩;15—断层;16—角度不整合;17—整合/假整合;18—样品

Fig.2 Geological map of Ningdu County, Jiangxi Province (modified from Fujian Metallurgical Industry Bureau, 1972; Southern Industrial School, 1997)

1−Qingbaikou System; 2−Shenshan Formation; 3−Kuli Formation; 4−Shangshi Formation; 5−Shabahuang Formation; 6−Hongshan Formation; 7−Bali Formation; 8−Cambrian System; 9−Carboniferous System; 10−Jurassic System; 11−Cretaceous System; 12−Early Paleozoic granite; 13−Jurassic granite; 14−Jurassic diorite; 15−Fault; 16−Angular unconformity; 17−Conformity/disconformity; 18−Sampling site

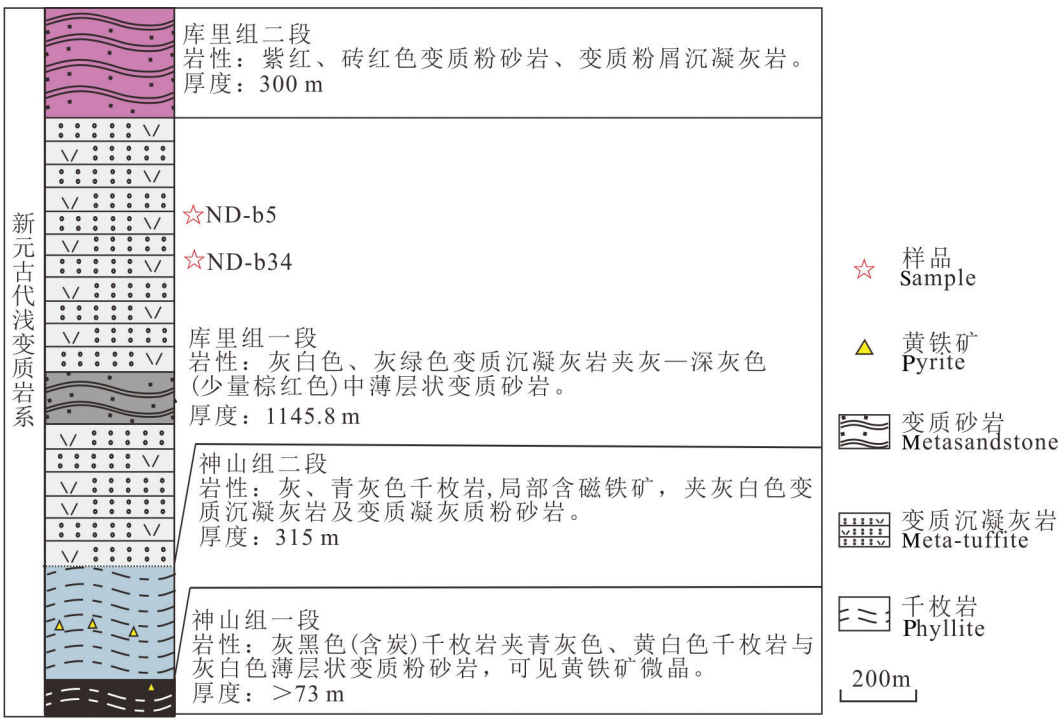

图3用于碎屑锆石U-Pb测年的变质沉凝灰岩样品的采集层位示意图(据南方工业学校,1997绘编)

Fig.3 Sampling locations of meta−tuffite rocks for the detrital zircon U−Pb dating (modified from Southern Industrial School, 1997)

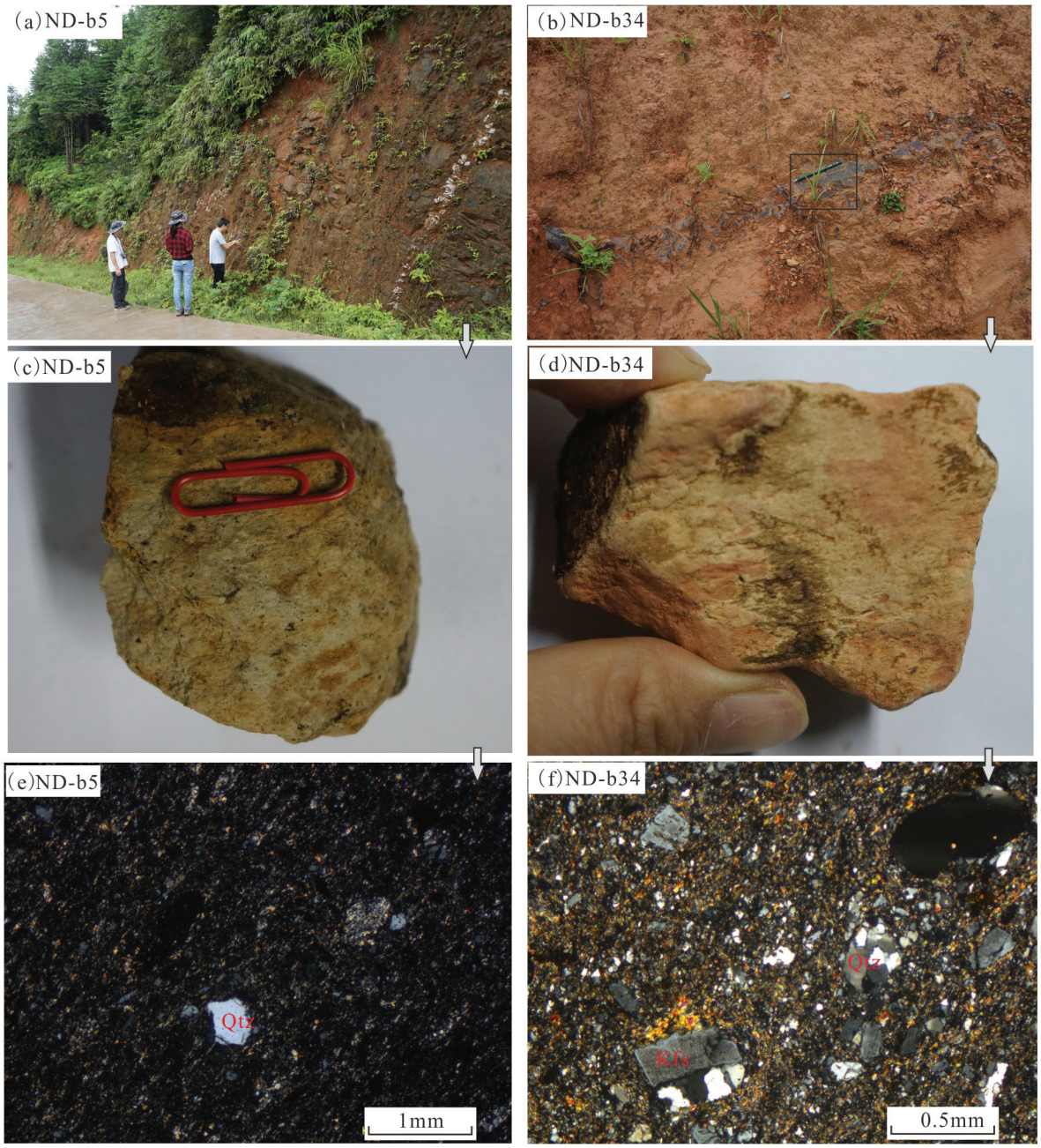

图4 江西省宁都地区变质沉凝灰岩的野外及显微镜下特征

Kfs—钾长石;Qtz—石英

Fig.4 Field and microscopic photographs of the meta-tuffites in Ningdu County of Jiangxi Province

Kfs-Potash feldspar; Qtz-Quartz

LA-MC-ICP-MS实验室完成,所用仪器为Finnigan Neptune型MC-ICP-MS及New Wave UP213激光剥蚀系统。实验中激光剥蚀斑束直径为40 μm,频率为10 Hz,能量密度为2.5 J/cm^2,以He为载气,采样方式为单点剥蚀。锆石逐一测试,仅排除了裂隙和包体发育的锆石,每10个测试点前后各插入一组标样,以确保标样和测试锆石的仪器条件一致。标样顺序为SRM 610(人造硅酸盐玻璃标样)、GJ-1std(锆石标样)、GJ-1std和Plesovice(锆石标样),详细的实验测试过程参见文献(侯可军等,2009)。数据处理采用ICPMS Data Cal程序处理,年龄谐和图用Isoplot3.0程序完成,测试数据误

差为1σ。对于年轻锆石(<1000 Ma)采用$^{206}Pb/^{238}$年龄,对于较老的锆石(>1000 Ma)采用$^{207}Pb/^{206}Pb$年龄。谐和图中所有年龄数据都有显示,加权平均年龄只选择了谐和度≥95%的年龄,谐和图中灰色背景的数据没有参与加权平均年龄的计算,测试结果见表1。

4　测试结果

样品ND-b5中的锆石多呈自形的长柱状,粒度多在50~200 μm,大部分锆石表面脏、被熔蚀,也常见锆石内部含包裹体。阴极发光(CL)图像上锆石边部均有亮色边,且发育程度不同(图5a)。根据CL图像特征可分为两类锆石:第一类锆石发育典型的岩浆震荡环带结构,发光亮度均一;第二类锆石也发育典型的岩浆震荡环带结构,但是环带往往遭受不同程度的破坏,呈现不一样的亮度,这类锆石的年龄往往不谐和。对108颗锆石进行了测年,大部分为第一类锆石,少部分为第二类锆石。其中,88颗锆石的$^{206}Pb/^{238}U$年龄谐和度≥95%,年龄分布在840~667 Ma,集中在3个年龄区间:809~780 Ma,加权平均年龄为797 Ma(n=35);746~728 Ma,加权平均年龄为737 Ma(n=46);685~667 Ma(n=4)(图6a)。18颗锆石的$^{206}Pb/^{238}U$年龄谐和度<95%,未参与加权平均年龄的计算。1颗锆石的$^{206}Pb/^{238}U$年龄为277 Ma,谐和度为99%,呈长柱状、晶形完好且环带结构发育,推测为外来混入锆石,本文不予考虑。1颗锆石的$^{207}Pb/^{206}Pb$年龄为2876 Ma,谐和度为97%,呈浑圆状,环带结构发育,可能经历了较长距离的搬运,推测为物源区的古老锆石。

样品ND-b34中的锆石多呈自形晶,长柱状,粒度为100~250 μm,多为无色,少部分呈淡红色,大部分锆石表面干净,少部分锆石内部含包裹体。CL图像显示个别锆石边部发育亮边,大部分锆石发育典型的岩浆震荡环带结构,亮度均一,也有的锆石环带遭受不同程度的破坏,内部具熔蚀结构(图5b)。对120颗锆石进行了测年,测试的锆石内部无包体、表面较干净。110颗锆石的年龄谐和度≥95%,$^{206}Pb/^{238}U$年龄主要在810~685 Ma(图6c),可划分为两个年龄区间:810~785 Ma,加权平均年龄为798 Ma(n=20);748~727 Ma,加权平均年龄为737 Ma(n=81)。2颗年龄最小的锆石,其年龄分别为691 Ma和686 Ma,与样品ND-b5中最小锆石年龄区间吻合。4颗锆石的$^{207}Pb/^{206}Pb$年龄为1970 Ma、1887 Ma、1789 Ma和1139 Ma均有磨圆,推测为物源区的古老锆石。10颗锆石的年龄谐和度<95%,未参与加权平均年龄的计算。

5　讨　论

5.1　碎屑锆石的年龄意义

赣南青白口纪—南华纪浅变质岩系出露于新余市、永丰县及宁都县等地(图1),自下而上划分为神山组、库里组和上施组。已有的LA-ICP-MS锆石U-Pb年代学资料显示:于都地区库里组变质沉凝灰岩的年龄为(789.6±2.9) Ma(n=105,MSWD=0.52)(郭娜欣,2015),永丰地区上施组凝灰质黏土岩的年龄为(774.1±8.8) Ma(n=38,MSWD=1.6)、(774.3±8.5) Ma(n=26,MSWD=1.02)和(756 ±7.5) Ma(n=30,MSWD=0.58)(周博文等,2018)。本文对宁都某地原定库里组中的变质沉凝灰岩的碎屑锆石LA-ICP-MS U-Pb年代学研究表明,两件样品具有相似的年龄峰值。188颗锆石年龄集中在810~667 Ma,最年轻的一组锆石年龄峰值约为680 Ma(n=6,占3%),次年轻的年龄峰值约为737 Ma(n=127,占67.5%),从统计学的角度考虑后者的年龄更可靠。沉凝灰岩是由火山碎屑物质落入水盆地中与正常沉积物混杂组成,经化学沉积物和黏土杂基胶结与压实作用成岩的火山作用同期产物。因此,沉凝灰岩中最年轻的一组锆石年龄可以代表区域内最晚期的一次火山事件。研究样品中次年轻的一组锆石均呈自形晶,未显示长距离搬运的特征,可能来自距离较近的火山灰,推测矿区内的变质沉凝灰岩成岩于南华纪,地层归属为上施组,而非库里组。由于岩石组合相似,区域上库里组和上施组的地层归属较为混乱。同时,样品中含较多青白口纪晚期的锆石(~798 Ma的峰值年龄,占29%),与于都地区库里组变质沉凝灰岩的年龄一致,推测赣南地区青白口纪—南华纪火山-碎屑沉积建造的形成时限在810~727 Ma。

5.2　碎屑锆石的来源

变质沉凝灰岩的碎屑锆石有两个主要的年龄区间:810~780 Ma和748~727 Ma,暗示2件样品具有相似的物质源区。锆石磨圆程度差,说明沉积物

表1 江西省宁都变质沉凝灰岩的LA-ICPMS碎屑锆石U-Pb年龄测试结果

Table 1 LA-ICPMS detrital zircon U-Pb dating results of the meta-tuffites in Ningdu County of Jiangxi Province

点号	Pb	$^{232}Th/^{238}U$	同位素比值						表面年龄/Ma						谐和
			$^{207}Pb/^{206}Pb$	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	度%
ND-b34-1	19.30	0.62	0.064270	0.001431	1.073149	0.028216	0.120586	0.001554	750	48	740	14	734	9	99
ND-b34-2	21.17	1.29	0.066335	0.001506	1.089063	0.024010	0.119337	0.001115	817	48	748	12	727	6	97
ND-b34-3	71.54	0.69	0.063816	0.000966	1.065426	0.020111	0.120905	0.001542	744	33	736	10	736	9	99
ND-b34-4	24.97	0.75	0.065270	0.001466	1.092813	0.023866	0.121870	0.001407	783	42	750	12	741	8	98
ND-b34-5	29.17	0.93	0.064631	0.001090	1.085136	0.021488	0.121955	0.001754	761	35	746	10	742	10	99
ND-b34-6	54.35	0.72	0.069331	0.000915	1.286275	0.027861	0.133932	0.002045	909	59	840	12	810	12	96
ND-B34-7	16.41	1.70	0.064322	0.001757	1.078349	0.031268	0.121568	0.001905	754	57	743	15	740	11	99
ND-b34-8	91.34	1.06	0.065736	0.000927	1.106285	0.016001	0.122166	0.001184	798	30	756	8	743	7	98
ND-b34-9	69.20	0.91	0.066148	0.000925	1.109976	0.018949	0.121598	0.001420	811	28	758	9	740	8	97
ND-b34-10	1386.63	1.08	0.343647	0.041147	223.038072	39.047321	1.958537	0.324097	3679	184	5495	179	6992	709	76
ND-b34-11	98.01	0.73	0.066990	0.001126	1.122905	0.021115	0.121698	0.001561	839	-164	764	10	740	9	96
ND-b34-12	12.44	1.10	0.066907	0.002759	1.205497	0.048401	0.131081	0.001542	835	87	803	22	794	9	98
ND-b34-13	40.01	0.88	0.063497	0.001347	1.063171	0.023125	0.121382	0.001139	724	44	735	11	739	7	99
ND-b34-14	79.16	1.01	0.065593	0.000942	1.194746	0.020739	0.131887	0.001312	794	34	798	10	799	7	99
ND-b34-15	102.24	1.84	0.065038	0.001014	1.091590	0.018452	0.121775	0.001323	776	33	749	9	741	8	98
ND-b34-16	63.10	0.71	0.065995	0.001052	1.208897	0.025606	0.133102	0.002258	806	33	805	12	806	13	99
ND-b34-17	105.15	0.73	0.064863	0.000765	1.094575	0.016593	0.122170	0.001221	769	24	751	8	743	7	98
ND-b34-18	43.35	2.46	0.066216	0.001575	1.114296	0.027313	0.122141	0.001258	813	49	760	13	743	7	97
ND-b34-19	52.52	1.10	0.063932	0.001174	1.170650	0.026147	0.132580	0.001642	739	38	787	12	803	9	98
ND-b34-20	68.89	1.25	0.063511	0.001394	1.052614	0.026318	0.120091	0.001732	724	46	730	13	731	10	99
ND-b34-21	15.91	2.45	0.071647	0.003176	1.184036	0.049290	0.121380	0.002595	976	91	793	23	738	15	92
ND-b34-22	80.83	1.11	0.077655	0.001072	1.947383	0.032458	0.181631	0.001977	1139	27	1098	11	1076	11	98
ND-b34-23	64.07	0.63	0.068516	0.001535	1.249290	0.044377	0.130474	0.002327	883	46	823	20	791	13	95
ND-b34-24	58.29	0.74	0.064229	0.000987	1.073928	0.018964	0.121226	0.001371	750	32	741	9	738	8	99
ND-b34-25	69.82	0.92	0.067824	0.001337	1.139457	0.028242	0.121859	0.002104	865	41	772	13	741	12	95
ND-b34-26	37.17	0.76	0.065256	0.001132	1.087267	0.020918	0.120586	0.001079	783	37	747	10	734	6	98
ND-b34-27	50.34	0.92	0.066447	0.001132	1.100439	0.020379	0.119909	0.001223	820	37	754	10	730	7	96
ND-b34-28	52.60	0.62	0.064362	0.001002	1.060192	0.018168	0.119326	0.001171	754	33	734	9	727	7	99
ND-b34-29	43.44	0.71	0.064650	0.001113	1.067527	0.018528	0.119784	0.001158	765	35	738	9	729	7	98
ND-b34-30	20.37	1.05	0.062694	0.001780	1.042308	0.030420	0.120311	0.001127	698	66	725	15	732	6	98
ND-b34-31	70.00	0.82	0.064876	0.001040	1.087429	0.018642	0.121484	0.001216	770	31	747	9	739	7	98
ND-b34-32	55.89	0.82	0.065614	0.001108	1.090972	0.020863	0.120184	0.001113	794	31	749	10	732	6	97
ND-b34-33	62.78	1.12	0.065725	0.001167	1.091957	0.019674	0.120482	0.001089	798	37	749	10	733	6	97
ND-b34-34	12.74	1.23	0.072107	0.002328	1.307778	0.043926	0.131525	0.001649	991	66	849	19	797	9	93
ND-b34-35	33.44	1.16	0.066481	0.001650	1.211519	0.029637	0.133047	0.002032	820	52	806	14	805	12	99
ND-b34-36	24.24	0.88	0.066333	0.001283	1.103478	0.022491	0.120738	0.001451	817	41	755	11	735	8	97
ND-b34-37	65.66	1.75	0.065456	0.000986	1.106315	0.017133	0.122541	0.001059	791	27	756	8	745	6	98
ND-b34-38	37.31	0.32	0.065177	0.001079	1.095728	0.018403	0.122115	0.001297	789	34	751	9	743	7	98
ND-b34-39	151.65	0.60	0.177700	0.003863	9.600356	0.177041	0.391708	0.004769	2632	69	2397	17	2131	22	88
ND-b34-40	101.23	0.65	0.089155	0.001443	1.656303	0.025599	0.134891	0.001127	1409	31	992	10	816	6	80
ND-b34-41	58.50	1.26	0.066481	0.001062	1.119558	0.023051	0.122111	0.001715	820	33	763	11	743	10	97
ND-b34-42	30.32	0.72	0.066921	0.001309	1.128221	0.026836	0.121890	0.001641	835	41	767	13	741	9	96
ND-b34-43	54.21	0.78	0.068234	0.001166	1.258405	0.024352	0.133604	0.001249	876	36	827	11	808	7	97
ND-b34-44	75.20	0.61	0.066206	0.000946	1.068247	0.017869	0.117322	0.001518	813	30	738	9	715	9	96
ND-b34-45	40.24	0.98	0.066960	0.001332	1.115409	0.025113	0.120807	0.001513	837	42	761	12	735	9	96
ND-b34-46	37.94	0.71	0.067165	0.001354	1.124017	0.024896	0.121364	0.001532	843	-158	765	12	738	9	96
ND-b34-47	48.06	0.70	0.063831	0.001270	1.145743	0.024503	0.130378	0.001577	744	42	775	12	790	9	98
ND-b34-48	28.03	1.98	0.064562	0.001750	1.080012	0.028384	0.121999	0.001609	761	57	744	14	742	9	99
ND-b34-49	19.94	0.90	0.067391	0.001948	1.213541	0.038135	0.130871	0.002192	850	60	807	17	793	12	98
ND-b34-50	29.67	0.85	0.066678	0.001588	1.209919	0.029743	0.131647	0.001259	828	50	805	14	797	7	99

续表1

点号	Pb	$^{232}Th/^{238}U$	同位素比值						表面年龄/Ma						谐和度/%
			$^{207}Pb/^{206}Pb$	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	
ND-b34-51	16.06	2.31	0.071441	0.002154	1.202270	0.039980	0.122085	0.001697	970	62	802	18	743	10	92
ND-b34-52	71.90	0.77	0.066180	0.000985	1.111470	0.021180	0.121743	0.001522	813	27	759	10	741	9	97
ND-b34-53	69.66	0.43	0.065627	0.000877	1.111144	0.019290	0.122653	0.001338	794	33	759	9	746	8	98
ND-b34-54	49.14	0.81	0.065512	0.001037	1.108331	0.018106	0.123100	0.001395	791	33	757	9	748	8	98
ND-b34-55	67.09	0.82	0.064918	0.000942	1.082068	0.018421	0.120740	0.001021	772	229	745	9	735	6	98
ND-b34-56	36.97	1.06	0.066403	0.001234	1.103017	0.023567	0.120578	0.001637	820	34	755	11	734	9	97
ND-b34-57	90.91	0.97	0.065581	0.000924	1.094469	0.014883	0.121323	0.001070	794	34	751	7	738	6	98
ND-b34-58	103.26	0.49	0.067369	0.000895	1.128920	0.018260	0.121720	0.001488	850	28	767	9	740	9	96
ND-b34-59	62.06	2.03	0.066067	0.000965	1.103238	0.017591	0.121117	0.001061	809	31	755	8	737	6	97
ND-b34-60	59.84	0.89	0.064782	0.001085	1.080735	0.019523	0.121151	0.001261	769	234	744	10	737	7	99
ND-b34-61	141.85	1.20	0.120921	0.001330	5.836179	0.087585	0.349832	0.003981	1970	20	1952	13	1934	19	99
ND-b34-62	32.51	1.15	0.063831	0.001267	1.074895	0.023517	0.122196	0.001495	744	42	741	12	743	9	99
ND-b34-63	30.53	2.43	0.066108	0.001673	1.100442	0.028372	0.120765	0.001209	809	47	754	14	735	7	97
ND-b34-64	39.27	0.82	0.065551	0.001291	1.090062	0.022672	0.120723	0.001280	791	42	749	11	735	7	98
ND-b34-65	35.84	1.08	0.063457	0.001135	1.061940	0.021502	0.121461	0.001521	724	37	735	11	739	9	99
ND-b34-66	57.18	0.89	0.066370	0.001051	1.107811	0.018456	0.121056	0.001202	818	33	757	9	737	7	97
ND-b34-67	74.41	1.56	0.066775	0.000954	1.128880	0.021079	0.122281	0.001480	831	-169	767	10	744	9	96
ND-b34-68	56.32	1.02	0.064347	0.001029	1.080046	0.019078	0.121571	0.001154	754	33	744	9	740	7	99
ND-b34-69	73.55	0.86	0.066053	0.000990	1.097141	0.016379	0.120365	0.000910	809	31	752	8	733	5	97
ND-b34-70	159.18	1.26	0.284381	0.019892	12.647947	1.142798	0.335560	0.022919	3387	109	2654	85	1865	111	65
ND-b34-71	36.33	1.10	0.064191	0.001399	1.080862	0.024373	0.122263	0.001492	748	46	744	12	744	9	99
ND-b34-72	23.85	0.78	0.068810	0.001579	1.145537	0.029589	0.120259	0.001341	894	42	775	14	732	8	94
ND-b34-73	29.45	0.94	0.108707	0.001878	4.597880	0.088295	0.306723	0.003762	1789	31	1749	16	1725	19	98
ND-b34-74	88.40	0.78	0.064923	0.000774	1.075370	0.013869	0.119997	0.001005	772	26	741	7	731	6	98
ND-b34-75	40.35	0.78	0.065577	0.001205	1.183867	0.022563	0.130773	0.001073	794	39	793	10	792	6	99
ND-b34-76	41.17	0.61	0.064576	0.001035	1.179497	0.024153	0.132175	0.001834	761	33	791	11	800	10	98
ND-b34-77	237.70	0.67	0.070967	0.000743	1.115607	0.012903	0.113905	0.000961	967	-11	761	6	695	6	91
ND-b34-78	110.87	0.77	0.069920	0.000882	1.080083	0.014979	0.112151	0.001287	928	26	744	7	685	7	91
ND-b34-79	53.92	1.00	0.065981	0.001268	1.094365	0.021266	0.120223	0.001064	806	45	751	10	732	6	97
ND-b34-80	168.92	1.68	0.070517	0.001310	1.191530	0.021310	0.122502	0.001005	943	38	797	10	745	6	93
ND-b34-81	106.05	1.11	0.065310	0.000906	1.083711	0.016038	0.120460	0.001289	783	30	745	8	733	7	98
ND-b34-82	42.55	0.97	0.068498	0.001503	1.251521	0.031972	0.132598	0.002172	883	44	824	14	803	12	97
ND-b34-83	15.43	0.87	0.065380	0.001878	1.084869	0.030721	0.121549	0.001903	787	66	746	15	739	11	99
ND-b34-84	42.91	0.83	0.064344	0.001197	1.077412	0.021633	0.121409	0.001137	754	34	742	11	739	7	99
ND-b34-85	28.12	0.79	0.064839	0.001304	1.182227	0.030196	0.132532	0.002438	769	42	792	14	802	14	98
ND-b34-86	48.89	0.71	0.066090	0.000981	1.110878	0.018862	0.121946	0.001322	809	25	759	9	742	8	97
ND-b34-87	13.39	1.53	0.065940	0.002465	1.096879	0.041550	0.120763	0.001416	806	79	752	20	735	8	97
ND-b34-88	104.83	0.73	0.064232	0.000776	1.002171	0.013638	0.113147	0.001018	750	26	705	7	691	6	98
ND-b34-89	57.25	0.89	0.066595	0.001172	1.188641	0.023275	0.129463	0.001247	833	37	795	11	785	7	98
ND-b34-90	13.96	0.54	0.063498	0.001532	1.058209	0.027823	0.121248	0.001976	724	52	733	14	738	11	99
ND-b34-91	39.42	1.00	0.064733	0.001332	1.072050	0.022714	0.120329	0.001194	765	44	740	11	732	7	99
ND-b34-92	174.31	0.65	0.064724	0.000693	1.076006	0.013911	0.120526	0.000988	765	22	742	7	734	6	98
ND-b34-93	59.38	1.12	0.063509	0.001006	1.063997	0.018819	0.121522	0.001137	724	33	736	9	739	7	99
ND-b34-94	78.50	1.21	0.065053	0.000985	1.075957	0.018001	0.120158	0.001284	776	33	742	9	731	7	98
ND-b34-95	70.85	1.45	0.065442	0.000915	1.099071	0.018515	0.121751	0.001266	789	29	753	9	741	7	98
ND-b34-96	51.51	0.93	0.064251	0.001126	1.165132	0.025636	0.131709	0.001918	750	32	784	12	798	11	98
ND-b34-97	51.72	0.49	0.261381	0.039774	5.342105	0.693094	0.173485	0.010127	3255	242	1876	111	1031	56	41
ND-b34-98	70.48	0.55	0.064531	0.000897	1.080012	0.017623	0.121412	0.001318	759	29	744	9	739	8	99
ND-b34-99	27.64	0.99	0.068271	0.001828	1.132307	0.031141	0.120236	0.001095	876	56	769	15	732	6	95
ND-b34-100	79.88	1.57	0.063449	0.000954	1.058941	0.019311	0.121056	0.001551	724	27	733	10	737	9	99

续表1

点号	Pb	$^{232}Th/^{238}U$	同位素比值						表面年龄/Ma						谐和度/%
			$^{207}Pb/^{206}Pb$	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	
ND-b34-101	65.31	0.98	0.063052	0.00145	0.968722	0.019672	0.112206	0.001511	709	53	688	10	686	9	99
ND-b34-102	59.91	0.91	0.063245	0.000958	1.048541	0.018188	0.120178	0.001292	717	33	728	9	732	7	99
ND-b34-103	36.86	1.21	0.064796	0.001469	1.081594	0.026807	0.120812	0.001224	769	47	744	13	735	7	98
ND-b34-104	32.37	0.83	0.068271	0.001537	1.142447	0.02393	0.121994	0.001423	876	47	774	11	742	8	95
ND-b34-105	62.75	0.81	0.062902	0.001178	1.049519	0.020365	0.12091	0.001215	706	40	729	10	736	7	99
ND-b34-106	83.18	0.69	0.065376	0.000825	1.087724	0.016975	0.120532	0.001341	787	26	747	8	734	8	98
ND-b34-107	50.39	0.88	0.063856	0.001082	1.06983	0.020709	0.121444	0.001465	737	35	739	10	739	8	99
ND-b34-108	35.05	2.16	0.063743	0.001392	1.05987	0.022724	0.120814	0.001487	733	51	734	11	735	9	99
ND-b34-109	78.6	0.96	0.066511	0.000921	1.110898	0.019109	0.120927	0.001448	833	28	759	9	736	8	96
ND-b34-110	65.73	1.32	0.064229	0.001045	1.067358	0.019798	0.120309	0.001293	750	31	737	10	732	7	99
ND-b34-111	26.06	1.29	0.064508	0.001558	1.163846	0.029804	0.131221	0.00198	767	52	784	14	795	11	98
ND-b34-112	136.31	0.65	0.11534	0.001246	5.275441	0.080571	0.330741	0.003579	1887	20	1865	13	1842	17	98
ND-b34-113	40.78	0.83	0.065272	0.001374	1.091933	0.023642	0.121339	0.001269	783	44	749	11	738	7	98
ND-b34-114	28.18	0.82	0.063103	0.001517	1.145684	0.025852	0.132061	0.001511	722	50	775	12	800	9	96
ND-b34-115	30.63	1.39	0.064357	0.001468	1.078411	0.026044	0.121597	0.001415	754	247	743	13	740	8	99
ND-b34-116	21.65	0.57	0.066757	0.001458	1.118684	0.027054	0.121255	0.001306	831	46	762	13	738	8	96
ND-b34-117	129	0.51	0.064937	0.000742	1.079472	0.014341	0.120593	0.001127	772	24	743	7	734	6	98
ND-b34-118	42.29	0.89	0.065669	0.001254	1.093512	0.024583	0.121029	0.001773	796	40	750	12	736	10	98
ND-b34-119	27.49	1.05	0.0669	0.001683	1.118389	0.032119	0.121369	0.001997	835	53	762	15	738	11	96
ND-b34-120	31.72	0.92	0.066617	0.001411	1.227198	0.030249	0.133394	0.001505	826	48	813	14	807	9	99
ND-b5-1	24.01	0.88	0.067337	0.001726	1.232566	0.033573	0.132959	0.001602	850	54	816	15	805	9	98
ND-b5-2	45.16	0.84	0.064758	0.001004	1.176739	0.020624	0.131674	0.001262	766	27	790	10	797	7	99
ND-b5-3	83.03	0.99	0.065684	0.000807	1.180924	0.015339	0.130463	0.001126	798	26	792	7	791	6	99
ND-b5-4	36.99	0.97	0.064199	0.001238	1.229559	0.023587	0.139229	0.001466	750	42	814	11	840	8	96
ND-b5-5	67.94	0.96	0.066915	0.000952	1.216904	0.019801	0.131891	0.001494	835	30	808	9	799	9	98
ND-b5-6	72.25	0.58	0.066869	0.001012	1.2056	0.01794	0.130713	0.001051	835	-168	803	8	792	6	98
ND-b5-7	82.64	0.99	0.065767	0.000893	1.184055	0.01583	0.130444	0.000955	798	29	793	7	790	5	99
ND-b5-8	44.87	0.93	0.067361	0.001177	1.238728	0.024179	0.133057	0.001328	850	36	818	11	805	8	98
ND-b5-9	37.72	0.97	0.07847	0.004072	1.427129	0.076039	0.131641	0.001424	1159	102	900	32	797	8	87
ND-b5-10	108.3	1.28	0.06683	0.001029	1.217683	0.021132	0.13169	0.00119	831	-168	809	10	798	7	98
ND-b5-11	23.84	1.02	0.06883	0.001631	1.227444	0.033615	0.12869	0.001825	894	49	813	15	780	10	95
ND-b5-12	40.17	1.69	0.068472	0.001337	1.239293	0.025438	0.130982	0.001489	883	41	819	12	793	8	96
ND-b5-13	58.88	0.68	0.065629	0.001195	1.207884	0.027271	0.13292	0.001861	794	32	804	13	805	11	99
ND-b5-14	16.94	0.95	0.066807	0.001811	1.206313	0.035389	0.130637	0.001917	831	56	804	16	792	11	98
ND-b5-15	69.77	0.55	0.066147	0.000951	1.217491	0.023151	0.133456	0.002237	811	27	809	11	808	13	99
ND-b5-16	63.23	1.13	0.067081	0.001152	1.200244	0.021908	0.129631	0.001892	840	35	801	10	786	11	98
ND-b5-17	61.2	1.04	0.066465	0.001024	1.201757	0.019681	0.130769	0.001141	820	33	801	9	792	7	98
ND-b5-18	45.75	0.81	0.066586	0.001186	1.20651	0.025199	0.131533	0.002218	833	37	804	12	797	13	99
ND-b5-19	42.23	1.08	0.06453	0.001163	1.171546	0.02227	0.131482	0.001382	759	39	787	10	796	8	98
ND-b5-20	73.59	1.09	0.07326	0.001163	1.333031	0.028698	0.131119	0.00156	1020	33	860	12	794	9	92
ND-b5-21	19.83	0.82	0.065945	0.001986	1.190713	0.039432	0.130501	0.002285	806	64	796	18	791	13	99
ND-b5-22	53	1.22	0.06661	0.001033	1.100259	0.01968	0.11946	0.001157	826	31	753	10	727	7	96
ND-b5-23	88.86	1.81	0.064909	0.001	1.079599	0.016224	0.120754	0.001379	772	32	743	8	735	8	98
ND-b5-24	68.79	1.07	0.064668	0.000961	1.075287	0.019001	0.120379	0.001285	765	31	741	9	733	7	98
ND-b5-25	11.97	0.5	0.052142	0.001372	0.31574	0.008393	0.043955	0.000488	300	59	279	6	277	3	99
ND-b5-26	51.27	1.19	0.063875	0.00118	1.152001	0.024083	0.130493	0.001229	739	39	778	11	791	7	98
ND-b5-27	250.41	1.32	0.091026	0.000838	2.508028	0.054111	0.199704	0.004195	1447	18	1274	16	1174	23	91
ND-b5-28	86.26	1.25	0.066003	0.000863	1.209658	0.018155	0.132924	0.00146	806	23	805	8	805	8	99
ND-b5-29	53.03	0.85	0.06574	0.00098	1.197366	0.023721	0.131776	0.001641	798	31	799	11	798	9	99
ND-b5-30	87.69	0.9	0.064573	0.000845	1.079621	0.018082	0.121184	0.001445	761	28	743	9	737	8	99
ND-b5-31	32.83	0.87	0.06484	0.001199	1.173015	0.028543	0.13082	0.002008	769	39	788	13	793	11	99
ND-b5-32	56.67	0.9	0.069153	0.001331	1.280537	0.036945	0.133083	0.002032	903	39	837	16	805	12	96
ND-b5-33	45.42	0.95	0.065339	0.001056	1.085325	0.020174	0.120495	0.001463	787	35	746	10	733	8	98
ND-b5-34	19.27	0.73	0.067281	0.001711	1.134447	0.033036	0.12211	0.001919	856	52	770	16	743	11	96
ND-b5-35	44.65	0.87	0.066649	0.001112	1.118786	0.020213	0.121785	0.001305	828	35	762	10	741	8	97
ND-b5-36	62.44	1.12	0.066155	0.000936	1.115395	0.017625	0.122651	0.001677	813	30	761	8	746	10	98
ND-b5-37	48.29	0.86	0.063682	0.001059	1.150056	0.023014	0.130907	0.001608	731	35	777	11	793	9	97
ND-b5-38	53.24	0.77	0.163599	0.010545	3.308015	0.236759	0.146459	0.008092	2494	109	1483	56	881	46	49
ND-b5-39	73.44	0.83	0.128684	0.003518	2.51734	0.081723	0.141469	0.001707	2080	48	1277	24	853	10	60
ND-b5-40	45.78	0.92	0.065873	0.001481	1.112386	0.033373	0.121418	0.001792	1200	48	759	16	739	10	97

续表1

点号	Pb	$^{232}Th/^{238}U$	同位素比值						表面年龄/Ma						谐和度/%
			$^{207}Pb/^{206}Pb$	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	
ND-b5-41	82.2	1.23	0.063346	0.000874	1.070091	0.018611	0.122388	0.001449	720	25	739	9	744	8	99
ND-b5-42	75.24	1.03	0.069663	0.001406	1.166527	0.030718	0.120997	0.00148	918	43	785	14	736	9	93
ND-b5-43	44.3	0.87	0.062837	0.001148	1.062639	0.020203	0.122729	0.001259	702	39	735	10	746	7	98
ND-b5-44	64.11	1.37	0.063812	0.000883	1.068854	0.016565	0.121447	0.001192	744	30	738	8	739	7	99
ND-b5-45	70.32	1.29	0.06651	0.001147	1.208248	0.020215	0.131968	0.001234	833	35	804	9	799	7	99
ND-b5-46	62.97	0.63	0.065154	0.00085	1.10026	0.019772	0.122212	0.001458	789	27	753	10	743	8	98
ND-b5-47	73.62	0.83	0.066257	0.001001	1.192446	0.019374	0.130388	0.001036	815	36	797	9	790	6	99
ND-b5-48	32.95	0.95	0.063899	0.001307	0.960783	0.020159	0.109021	0.000965	739	47	684	10	667	6	97
ND-b5-49	97.38	1.12	0.064967	0.000789	1.092077	0.01577	0.121732	0.001061	772	26	750	8	741	6	98
ND-b5-50	91.48	1.05	0.065538	0.000812	1.101809	0.015697	0.121748	0.000995	791	26	754	8	741	6	98
ND-b5-51	53.48	0.77	0.064664	0.000935	1.168208	0.021481	0.130864	0.001644	765	31	786	10	793	9	99
ND-b5-52	35.68	1.57	0.065908	0.001109	1.098387	0.020168	0.120927	0.001297	803	35	753	10	736	7	97
ND-b5-53	52.29	0.9	0.067252	0.000959	1.122176	0.020211	0.120789	0.001321	856	30	764	10	735	8	96
ND-b5-54	46.39	1.22	0.075411	0.002708	1.265347	0.049245	0.121043	0.001129	1080	72	830	22	737	6	88
ND-b5-55	72.84	0.79	0.068058	0.001126	1.143821	0.023738	0.121819	0.001574	870	35	774	11	741	9	95
ND-b5-56	36.92	0.85	0.065636	0.001162	1.093703	0.02253	0.120693	0.001463	794	32	750	11	735	8	97
ND-b5-57	29.35	0.7	0.063482	0.001367	1.058227	0.022522	0.121083	0.001214	724	44	733	11	737	7	99
ND-b5-58	88.04	0.99	0.064243	0.000818	1.0763	0.016659	0.121357	0.001171	750	26	742	8	738	7	99
ND-b5-59	18.06	0.91	0.065811	0.002663	1.004772	0.03678	0.111235	0.001419	1200	81	706	19	680	8	96
ND-b5-60	41.38	1.07	0.065814	0.001167	1.103922	0.023781	0.121529	0.001606	1200	38	755	11	739	9	97
ND-b5-61	43.4	1.08	0.064926	0.001098	1.07351	0.020054	0.120243	0.001551	772	31	740	10	732	9	98
ND-b5-62	71.99	0.88	0.066186	0.001062	1.107249	0.022402	0.120988	0.001324	813	33	757	11	736	8	97
ND-b5-63	39.49	1.15	0.066775	0.001221	1.111251	0.023491	0.120402	0.001146	831	43	759	11	733	7	96
ND-b5-64	47.09	0.65	0.063992	0.000907	1.055812	0.017289	0.11959	0.001207	743	31	732	9	728	7	99
ND-b5-65	76.93	0.9	0.063614	0.000974	1.063472	0.019705	0.120984	0.001168	728	33	736	10	736	7	99
ND-b5-66	38.05	0.57	0.064541	0.001255	1.063094	0.019668	0.119612	0.000995	761	42	735	10	728	6	99
ND-b5-67	61.2	0.67	0.069657	0.001271	1.161459	0.024207	0.120718	0.001016	918	38	783	11	735	6	93
ND-b5-68	102.93	2.26	0.064411	0.00078	0.996534	0.012518	0.11219	0.000743	755	30	702	6	685	4	97
ND-b5-69	80.86	0.79	0.065301	0.000873	1.081623	0.016908	0.120188	0.001291	783	23	744	8	732	7	98
ND-b5-70	10.55	0.87	0.069854	0.002711	1.162927	0.040922	0.121958	0.001944	924	84	783	19	742	11	94
ND-b5-71	81.58	1.13	0.065064	0.000977	1.086256	0.019955	0.121011	0.001363	776	31	747	10	736	8	98
ND-b5-72	39.49	1.2	0.070495	0.00201	1.176625	0.043426	0.120196	0.001563	943	64	790	20	732	9	92
ND-b5-73	44.95	0.97	0.063077	0.001029	1.052417	0.020665	0.120827	0.00143	711	35	730	10	735	8	99
ND-b5-74	69.82	0.68	0.064853	0.000795	1.069658	0.015969	0.119553	0.001227	769	26	739	8	728	7	98
ND-b5-75	57.69	0.83	0.063441	0.000984	1.069026	0.018902	0.122208	0.001362	724	33	738	9	743	8	99
ND-b5-76	246.52	0.69	0.206128	0.001676	15.259719	0.158516	0.536737	0.004984	2876	13	2832	10	2770	21	97
ND-b5-77	8.85	1.89	0.066555	0.002139	1.103666	0.033464	0.121719	0.002074	833	72	755	16	740	12	98
ND-b5-78	20.26	3.22	0.064257	0.001906	1.066303	0.030355	0.12119	0.001694	750	63	737	15	737	10	99
ND-b5-79	138.82	1.48	0.065475	0.000751	1.096137	0.013712	0.121155	0.000775	791	24	751	7	737	4	98
ND-b5-80	29	0.88	0.067491	0.001621	1.126266	0.029702	0.12171	0.002541	854	-149	766	14	740	15	96
ND-b5-81	28.14	0.77	0.065246	0.001642	1.103506	0.033342	0.122082	0.001577	783	54	755	16	743	9	98
ND-b5-82	74.72	1.08	0.074145	0.001991	1.38273	0.053755	0.132724	0.001849	1056	54	882	23	803	11	90
ND-b5-83	48.26	0.92	0.067612	0.001398	1.256529	0.03747	0.133778	0.002034	857	43	826	17	809	12	97
ND-b5-84	59.87	1.03	0.122394	0.004877	2.370521	0.109576	0.136648	0.002086	1992	70	1234	33	826	12	60
ND-b5-85	31.81	1.08	0.0659	0.001665	1.100373	0.029871	0.120857	0.001261	803	53	754	14	735	7	97
ND-b5-86	85.04	0.83	0.06606	0.001011	1.215319	0.02469	0.132844	0.001278	809	31	808	11	804	7	99
ND-b5-87	54.93	0.96	0.075588	0.00134	1.501565	0.026608	0.144178	0.00168	1084	35	931	11	868	9	93
ND-b5-88	56.09	0.88	0.065864	0.001178	1.20655	0.020454	0.132947	0.001096	1200	37	804	9	805	6	99
ND-b5-89	29.21	1.71	0.070194	0.002242	1.131452	0.040728	0.116631	0.002262	1000	60	768	19	711	13	92
ND-b5-90	103.71	1.34	0.064051	0.000828	1.071119	0.020461	0.121018	0.001761	743	28	739	10	736	10	99
ND-b5-91	39.56	0.91	0.0653	0.001209	1.089403	0.021234	0.121124	0.001366	783	44	748	10	737	8	98
ND-b5-92	34.54	0.68	0.065615	0.00109	1.195066	0.022278	0.131821	0.001185	794	34	798	10	798	7	99
ND-b5-93	64.47	1.01	0.06471	0.001025	0.980799	0.023181	0.109697	0.002057	765	33	694	12	671	12	96
ND-b5-94	52.67	1.01	0.064728	0.000846	1.077425	0.016198	0.12055	0.001172	765	28	742	8	734	7	98
ND-b5-95	38.48	1.03	0.067856	0.001089	1.125652	0.020631	0.119935	0.000919	865	33	766	10	730	5	95
ND-b5-96	65.2	1.06	0.063335	0.000951	1.157115	0.019467	0.132246	0.001156	720	31	781	9	801	7	97
ND-b5-97	10.05	1.29	0.062885	0.001775	1.046157	0.028514	0.121269	0.001612	706	61	727	14	738	9	98
ND-b5-98	36.74	0.93	0.067692	0.001606	1.140041	0.029585	0.121749	0.001245	859	50	773	14	741	7	95
ND-b5-99	57.15	1.13	0.064814	0.000983	1.086165	0.019702	0.121277	0.001383	769	28	747	10	738	8	98
ND-b5-100	55.79	0.65	0.063434	0.000997	1.073153	0.019434	0.122549	0.001427	724	33	740	10	745	8	99
ND-b5-101	48.1	1.1	0.065597	0.001177	1.067039	0.020466	0.117918	0.001435	794	38	737	10	719	8	97
ND-b5-102	53.34	0.86	0.349969	0.023581	9.89423	1.03161	0.192895	0.008368	3707	70	2425	96	1137	45	27
ND-b5-103	29.16	1	0.126932	0.009641	2.335255	0.178813	0.134556	0.002501	2057	134	1223	54	814	14	59
ND-b5-104	23.03	0.58	0.10736	0.01009	0.714953	0.06317	0.049327	0.00103	1755	173	548	37	310	6	44
ND-b5-105	55.13	1.12	0.084516	0.002775	1.523825	0.047435	0.131287	0.001193	1306	65	940	19	795	7	83
ND-b5-106	56.08	1.08	0.066279	0.001053	1.207119	0.021312	0.131903	0.00106	817	32	804	10	799	6	99
ND-b5-107	19.88	1.01	0.062331	0.001397	1.127738	0.030645	0.130908	0.00178	687	47	767	15	793	10	96
ND-b5-108	34.33	0.96	0.06593	0.001216	1.202824	0.023243	0.132357	0.001177	806	39	802	11	801	7	99

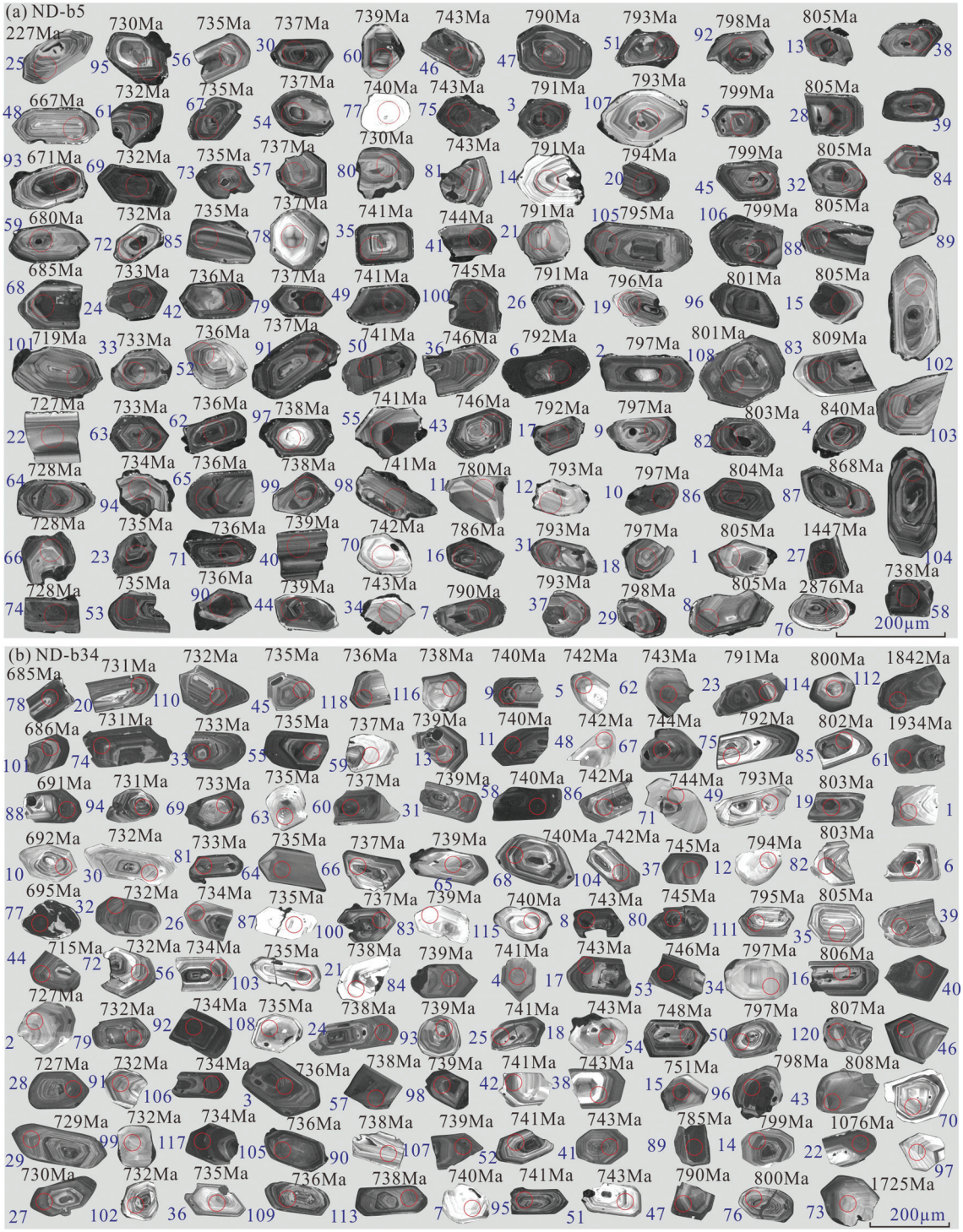

图5 江西省宁都地区变质沉凝灰岩中碎屑锆石阴极发光图像及年龄

Fig. 5 Detrital zircon cathodoluminescence images and U−Pb ages of the meta−tuffites in Ningdu County of Jiangxi Province

源区较近。赣南周潭群分布于弋阳、余江及金溪等地(图1),为一套高绿片岩相—低角闪岩相变质岩,主要由灰黑色斜长片麻岩、斜长变粒岩夹绿泥石阳起石片岩、斜长角闪岩组成,原岩为一套海相富铝质泥砂质建造(吴新华等,2001),厚度大于1200 m,未见底。王孝磊等(2013)对其进行了碎屑锆石U−Pb定年,3件样品最年轻的年龄峰值分别为843 Ma、830 Ma和809 Ma,且有大量1800~1500 Ma和

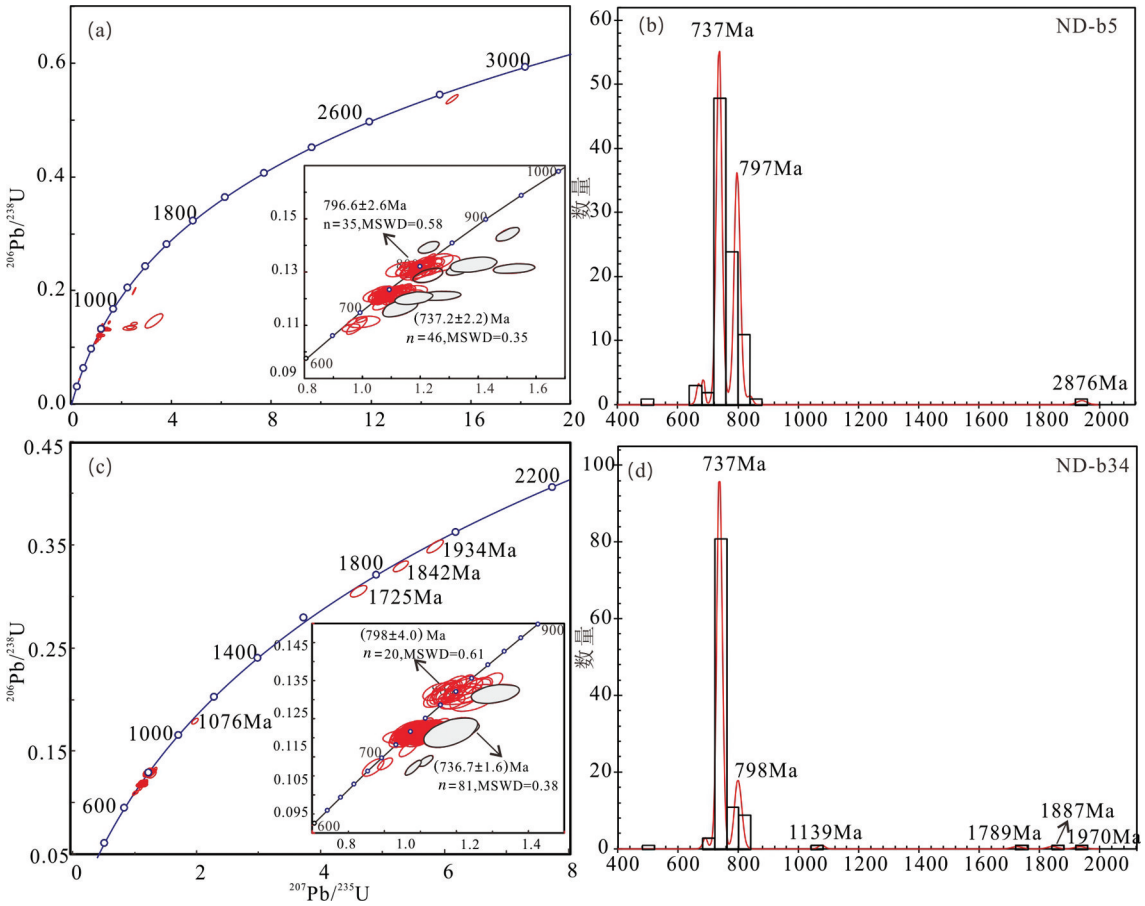

图6 江西省宁都地区变质沉凝灰岩中的碎屑锆石U-Pb年龄谐和图(a, c)及相对频率图(b, d)

Fig. 6　Detrital zircon U-Pb concordia diagram (a, c) and relative frequency plot (b, d) of the meta-tuffites in Ningdu County of Jiangxi Province

2500~2300 Ma的老锆石。本文样品中缺失843 Ma和830 Ma的峰值年龄,暗示赣南浅变质岩系和周潭群的物质源区存在较大差异。研究显示,赣东北—皖南—浙西北一带普遍存在810~780 Ma和748~727 Ma的火山岩。如,赣东北青白口纪晚期—南华纪自下而上由桃源组(上墅组)、罗村组和听门组组成(张恒等,2015a)(图7)。其中,桃源组为陆相凝灰岩、流纹岩、玄武岩、火山碎屑岩及火山角砾岩,流纹岩的锆石U-Pb年龄为803 Ma(王剑等,2013)。罗村组以砾岩、泥岩及粉砂质泥岩为主。听门组以砾岩、杂砂岩夹粉砂岩、粉砂质泥岩、页岩为主。皖南地区同期火山-沉积岩由历口群和休宁组组成,沉积厚度约1600 m(图7)(邓奇等,2019)。历口群下部邓家组由石英砂岩、粉砂岩和板岩组成,上部铺岭组为火山岩,其中流纹岩和凝灰岩的锆石年龄介于765~751 Ma(Wang et al., 2012)。浙西地区同期火山-沉积岩由虹赤村组/上墅组(二者为同期异相)和休宁组组成(图7)(邓奇等,2019),沉积厚度超过4300 m。虹赤村组以岩屑砂岩为主夹少量火山岩,火山岩的锆石U-Pb年龄为797 Ma(Li et al., 2003)。上墅组为双峰式火山岩组合,锆石U-Pb年龄在802~773 Ma(Li et al., 2008; Zheng et al., 2008; Wang et al., 2012)。休宁组主要为凝灰质砂岩、凝灰质粉砂岩、凝灰岩及凝灰质、硅质泥岩相互交替,底部为紫红色砾岩和砂砾岩,其中凝灰岩的锆石U-Pb年龄为785 Ma和727 Ma(邓奇等,2019)。江南造山带中800~790 Ma和760~750 Ma的岩浆活动存在明显差别,早期基性岩主要为岩石圈地幔来源,晚期为岩石圈地幔和软流圈地幔双重来源,代表两期不同构造背景下的岩浆事件(邓奇等,2016)。由此推测,本文变质沉凝灰岩样品中810~780 Ma的锆石来自赣东北—皖南—浙北一带

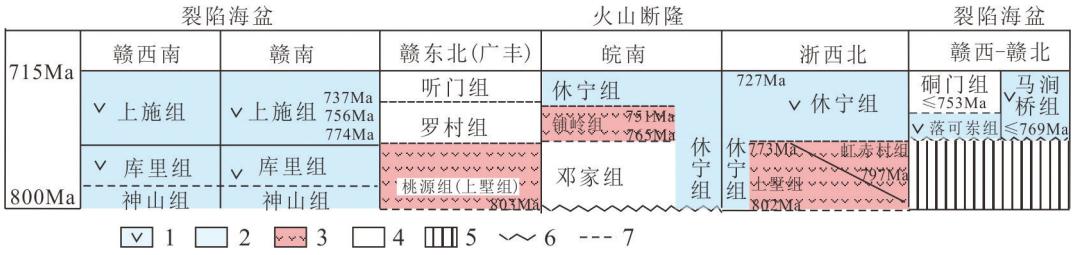

图7 江西及其周边青白口纪—南华纪地层对比

1—海相火山-碎屑沉积;2—海相沉积;3—陆相火山岩;4—沉积岩;5—地层缺失;6—角度不整合;7—平行不整合

Fig.7 Stratigraphic correlation of Qingbaikou System with Nanhua system in Jiangxi and its adjacent regions

1-Volcano-clastic marine sediments; 2-Marine sediments; 3-Terrestrial volcanic rocks; 4-Sedimentary rock; 5-Stratigraphic break; 6-Angular unconformity; 7-Parallel unconformity

同期火山岩-沉积岩,748~727 Ma 的锆石主要来自同期的火山灰。

5.3 赣南青白口纪晚期—南华纪沉积盆地的性质

赣南青白口纪—南华纪(810~727 Ma)出露一套巨厚的海相火山-碎屑沉积建造,其中神山组以黑色炭质或含炭千枚岩、含炭粉砂质千枚岩或板岩为主,夹少许千枚岩和变余细砂岩,新余地区厚度大于1050 m,未见底,其上被库里组平行不整合覆盖。库里组以千枚岩、凝灰质千枚岩和千枚状沉凝灰岩为主,新余地区厚2425 m,永丰地区主要为浅灰白色变沉凝灰岩夹多层中酸性熔岩,偶夹炭质绢云千枚岩,厚1186 m,被上施组整合覆盖。上施组为一套变质凝灰质砂岩、变质沉凝灰岩及凝灰质板岩互层,区域上岩性较稳定,宜春地区厚983 m,宁都地区厚544 m,整合于库里组之上。宜春—永丰一带下伏于古家组,宁都一带下伏于沙坝黄组(刘亚光,1997)。神山组黑色岩系及含黄铁矿构造与饥饿盆地的主要沉积相似,这种黑色岩系在湘桂次级裂谷盆地中广泛分布(王剑等,2001),库里组和上施组为海相火山岩相组合,可能是盆地堆积、充填的产物。江南造山带发育的800~750 Ma的岩浆岩形成于陆内裂谷盆地(徐先兵等,2015;邓奇等,2016)。从沉积序列和岩浆特征推测赣南青白口纪—南华纪火山-碎屑沉积形成于次级裂谷盆地。从赣南至赣北,南华纪沉积物由单向物源为主,即同期火山喷发物为主,改变为双向物源,即古老的陆源物质和早期—同期的火山物源(王孝磊等,2013;Wang et al., 2013;陈小勇等,2015),反映了南华纪海、陆古地理单元差异的特征。区域上湘桂次级裂谷盆地于沉积时限在819~814Ma(周汉文等,2002;Wang et al., 2003),赣东北江南次级裂谷盆地于803 Ma开始沉积(王剑等,2013),浙北次级裂谷盆地约807 Ma开启(王剑,2000)。680 Ma之后,华南进入稳定的陆缘滨海—浅海斜坡相沉积环境(舒良树,2012)。

6 结 论

(1)碎屑锆石LA-ICP-MS U-Pb测年结果表明,江西省宁都某离子吸附型稀土矿床中的2件变质沉凝灰岩样品具有相似的锆石年龄组成,主要分布在810~780 Ma、748~727 Ma和691~667 Ma三个年龄区间,峰值年龄分别为798 Ma(n=55)、737 Ma(n=127)和680 Ma(n=6),其次含有少量2.85~1.08 Ga的古老锆石。最年轻的一组碎屑锆石可能为同期火山灰携带的岩浆锆石,可代表沉凝灰岩的形成时代,即南华纪,地层应归属于上施组,而非库里组。

(2)赣南青白口纪晚期至南华纪巨厚的海相火山-沉积建造可能代表了华南古大陆解体之后的裂谷盆地沉积,宁都某地变质沉凝灰岩的碎屑锆石年龄约束了赣南次级裂谷盆地的沉积时限,即798~680 Ma。

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注释

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