

江西九江中更新世红土物质来源研究

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摘 要: 华南地区广泛分布中更新世红土。目前, 对其物质来源尚有争议。九江红土剖面的沉积时代已得到很好限定, 同时由于其沉积连续、地层出露较好, 是开展中更新世红土物质来源研究的理想剖面。通过对九江中更新世红土 2 件碎屑锆石样品的分析, 共获得 177 颗谐和锆石 U-Pb 年龄, 主要峰值集中在新元古代(816 Ma、801 Ma 和 991 Ma)、古元古代(2019 Ma、2022 Ma 和 2481 Ma)和新太古代(2502 Ma), 并具有不显著的中生代峰值(135 Ma)。将其与潜在远源和近源物源区的锆石 U-Pb 年龄组成进行对比, 结果发现中国北方戈壁、沙漠和黄土高原、塔里木盆地、华北平原并不是九江中更新世红土的主要源区。庐山北麓早更新世发育的洪积扇为九江中更新世红土发育提供了充足物质。九江中更新世红土和九江晚更新世黄土的碎屑锆石 U-Pb 年龄组成存在明显差别, 后者主要来自长江河漫滩的碎屑物质。不同的气候条件主导了九江地区红土和黄土的发育, 二者都受控于青藏高原构造隆升产生的环境变化。

关键词: 红土; 中更新世; 九江; 锆石; U-Pb 年龄

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Provenance Tracing of Middle Pleistocene Red Earth in the Jiujiang Area, Jiangxi Province

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Abstract: The Middle Pleistocene red earth is widely distributed in South China. However, its source areas remain controversial. The sedimentary age of the Jiujiang red earth profile has been defined well in previous studies, and it is an ideal region for studying the source of the red earth material in the Middle Pleistocene due to its continuous deposition and good exposure. Through the analysis of two detrital zircon samples from the Middle Pleistocene red earth in Jiujiang, we obtained 177 concordant zircon U-Pb ages. The peak ages are mainly concentrated in the Neoproterozoic (816 Ma, 801 Ma, and 991 Ma), Paleoproterozoic (2019 Ma, 2022 Ma, and 2481 Ma), and Neoproterozoic (2502 Ma), with an insignificant peak age in the Mesozoic (135 Ma). The results show that the Gobi Desert, northern deserts, Loess Plateau, Tarim Basin, and North China Plain in northern China are not the main source regions of the Middle Pleistocene red earth in Jiujiang. The Early Pleistocene diluvial fan at the northern piedmont of Lushan Mountain provided sufficient materials for development of the Middle Pleistocene red earth in Jiujiang. The detrital zircon U-Pb age compositions of the Middle Pleistocene red earth are different from those of the Late Pleistocene loess in Jiujiang. Different climatic conditions dominated the

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development of the red earth in the Middle Pleistocene and the loess in the Late Pleistocene in the Jiujiang area, but both of them were sedimentary responses to environmental changes caused by the tectonic uplift of the Tibetan Plateau.

Key words: red earth; Middle Pleistocene; Jiujiang; Zircon; U-Pb age

广泛分布于华南的红土详细记录了中国亚热带地区早—中更新世古气候变化过程(Hong et al., 2010; Gu et al., 2013; 彭红霞等, 2019; Fan et al., 2021, 图 1)。华南红土的发育在宏观上与东亚行星风系的解体和第四纪季风环流的发展相联系, 微观上受局部水文环境、地形地貌条件、母岩岩性的差异影响(朱丽东, 2007)。网纹红土的母质形成于早更新世晚期至中更新世中期, 均质红土形成于中更新世中晚期至晚更新世早期, 黄棕色土多形成于晚更新世, 它们在时间上具有继承性, 均属风尘沉积(Zhao et al., 2017; 程峰, 2018)。目前, 对华南红土的物质来源尚有争议, 一些研究强调南方红土具有远源属性(李徐生, 2001; Xiong et al., 2002; Hu et al., 2005), 而另一些研究则强调近源物质是加积型红土的主要来源(Hao et al., 2010; Qiao et al., 2011; Guan et al., 2016; Cheng et al., 2018)。因此, 厘定华南红土的物质来源不仅对进一步认识区域内粉尘堆积的驱动因素有十分重要的意义, 还可以和晚更新世黄土的物源示踪结果对比, 进而系统认识华南地区第四纪气候变化过程。江西九江红土(兴城大道、八里坡)和黄土(南湖村、长虹大道)剖面都位于长江二级河流阶地上, 地层沉积连续并且出露良好, 前人已经开展了系统的地层测年工作(蒋复初等, 1997; 程峰, 2018; 李金典, 2019), 因而是结合地层沉积时代开展红土物质来源研究以及红土和黄土物源对比研究的理想剖面。

将沉积区(汇)与潜在物源区(源)进行比较, 是开展风尘沉积物物源示踪研究的基本思路(Jiang et al., 2020; 张玉芬等, 2020; 林旭等, 2021; Zhu et al., 2021)。碎屑锆石是各类沉积物中广泛存在的副矿物, 其 U-Pb 年龄谱对比已被普遍应用于风尘沉积物的物源示踪研究(Cheng et al., 2018; Wang et al., 2018; Baykal et al., 2021; Fasulo and Ridgway, 2021)。经过近 20 年的数据积累, 中国北方戈壁(Che and Li, 2013; Zhang et al., 2016)、沙漠(Stevens et al., 2010; Xie et al., 2012; Zhang et al., 2016; 杨利荣等, 2017; Fan et al., 2019)、黄土高原(Stevens et al., 2010; Pullen et al., 2011; Nie et al., 2014)、华北平原(林旭等, 2020)、江汉平原(林旭等, 2022a)、长江中下游河流沉积物(He et al., 2013; 李小聪等, 2016; Liang et al., 2018)、庐山基岩(李学刚等, 2010; 史志刚, 2014)等潜在物源区的锆石 U-Pb 年龄数据丰富, 为

系统开展九江红土的物质来源研究奠定了良好的基础。因而, 我们对九江兴城大道、八里坡中更新世红土开展碎屑锆石 U-Pb 年龄分析, 系统厘定其物质来源。在此基础上, 通过和九江晚更新世黄土的物质来源研究结果进行对比, 提供区域内第四纪详细的物源变化过程。

1 研究区概况

1.1 华南红土

自早更新世以来, 在中国秦岭—淮河以南、青藏高原以东, 特别是长江及珠江流域广泛出现红土沉积物(图 1), 主要分布于丘陵盆地及各级河流阶地上, 具有典型陆相沉积特征(朱丽东, 2007)。这些红土主要由均质红土层、弱网纹红土层、强网纹红土层及下伏砾石层组成(李长安和顾延生, 1997; 黄颖等, 2019; 熊文婷等, 2020), 与下伏中—晚新生代至早第三系红层不整合接触(Zhao et al., 2017)。其分布、成因、来源及理化特征与构造运动的发展、东亚季风的增强及第四纪全球气候变化的纬度效应有着潜在的耦合关系, 是我国南方更新世以来地球环境信息记录的重要载体(Hong et al., 2009; Gu et al., 2013)。

1.2 河流

长江发源于青藏高原, 流经四川盆地、江汉盆地和长江中下游平原, 最后流入东海, 全长约 6300 km(图 1)。长江自西向东在宜昌进入江汉平原, 是江汉平原最主要的输沙河流(林旭等, 2023)。赣江是长江主要支流之一, 江西省最大河流, 源出赣闽边界武夷山西麓, 自南向北纵贯江西省, 长 766 km(李小聪等, 2016)。晚更新世, 中国东部陆架海的海平面发生大幅度下降(赵希涛等, 1979; Yi et al., 2022), 在江汉盆地和鄱阳湖盆地, 以及湖口以东的长江沿岸则分布面积广大的黄土和沙山(Hao et al., 2010; Lai et al., 2010; Jia et al., 2012; 林旭等, 2022b)。

1.3 九江地区地质概况

九江地区位于长江中下游季风三角南缘, 属亚热带季风气候, 夏季高温炎热、冬季低温寒冷, 年降雨量在 1000~1500 mm 之间(程峰, 2018)。区域内长江河流阶地上可见完整的红土和黄土地层发育: 网纹红土剖面底部为磨圆度较好的硅质砾石层。网纹红土基质多为红色粉砂, 网纹为青灰色、灰色、



图 1 华南红土位置分布图

Fig. 1 Distribution of red earth in South China

浅红色,呈根状、树枝状分布于层内,其上部为浅红色-红色均质红土,在各层位交界处常有黑色锰铁质结核密集分布;部分地区均质红土上覆浅黄、棕黄色粉砂土层(李金典, 2019)。

庐山位于九江市内,呈北东向展布,主峰汉阳峰海拔 1474 m。庐山地质时期岩浆活动频繁,中新元古代(860~800 Ma)和中生代(140~120 Ma)火山岩是庐山地区两次主要火山活动期(李学刚等, 2010; 史志刚, 2014)。它们的出现与华夏板块和扬子板块的碰撞拼合时间,以及江南造山带岩石圈大规模减薄的时间吻合。区域内地层发育齐全,出露良好,

从元古代至新生代皆有分布(图 2)。

2 样品采集

九江地区的地形以低山丘陵为主,上覆长青灌木类植物。本次开展研究的两处剖面的底部出现棕红色泥砾石层,杂基支撑,砾石大小不一,磨圆中等。棕红色的网纹红土内部含有灰白色的黏土网纹条带,上覆均质红土和棕黄色土。具体采样时,将剖面表层刮开,采集内部新鲜部位,本次采样的深度分别约为 4 m 和 10 m。

兴城大道(以下简称兴城)剖面位于九江市西侧消防大队侧面(29°39'50.95"N, 115°57'21.12"E, 图 3A),属于修路开挖出露的人工剖面,剖面总体厚度约 10 m,与李金典(2019)开展研究的红土剖面位置相近(图 3B)。其对剖面顶部黄土层采用光释光测年法获得的地层沉积年龄为 44~14 ka;对下部网纹红土采用 ESR 测年法获取的地层沉积年龄为 (1148±282) ka(图 3C-a)。我们的采样点位于棕红色网纹状含铁锰粉砂质黏土层内,因而沉积时代属中更新世。八里坡剖面位于九江市濂溪区(29°41'49.92"N, 116°0'43.56"E, 图 3B),属于建筑工程开挖出露的人工剖面,厚度约为 15 m。网纹红土中部 ESR 测试年龄为(464±46) ka;网纹红土底部(泥砾石层顶部)ESR 年龄为(836±121) ka(李金典, 2019, 图 3C-b)。此次采样点位于网纹红土中部,其沉积时代属于中更新世。九江南湖村 2 个中更新世红土碎屑锆石样品(南湖村 3 和南湖村 4)引自程峰(2018, 图 3C-c),九江晚更新世黄土碎屑锆石样品引用自林旭等(2022b, 图 3C-d)。

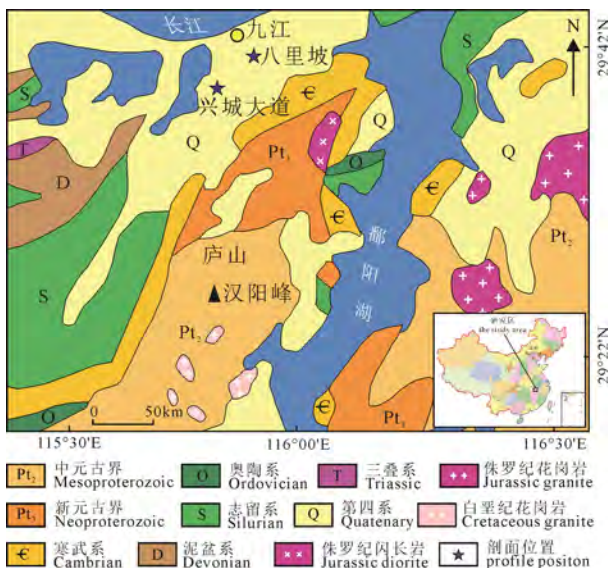
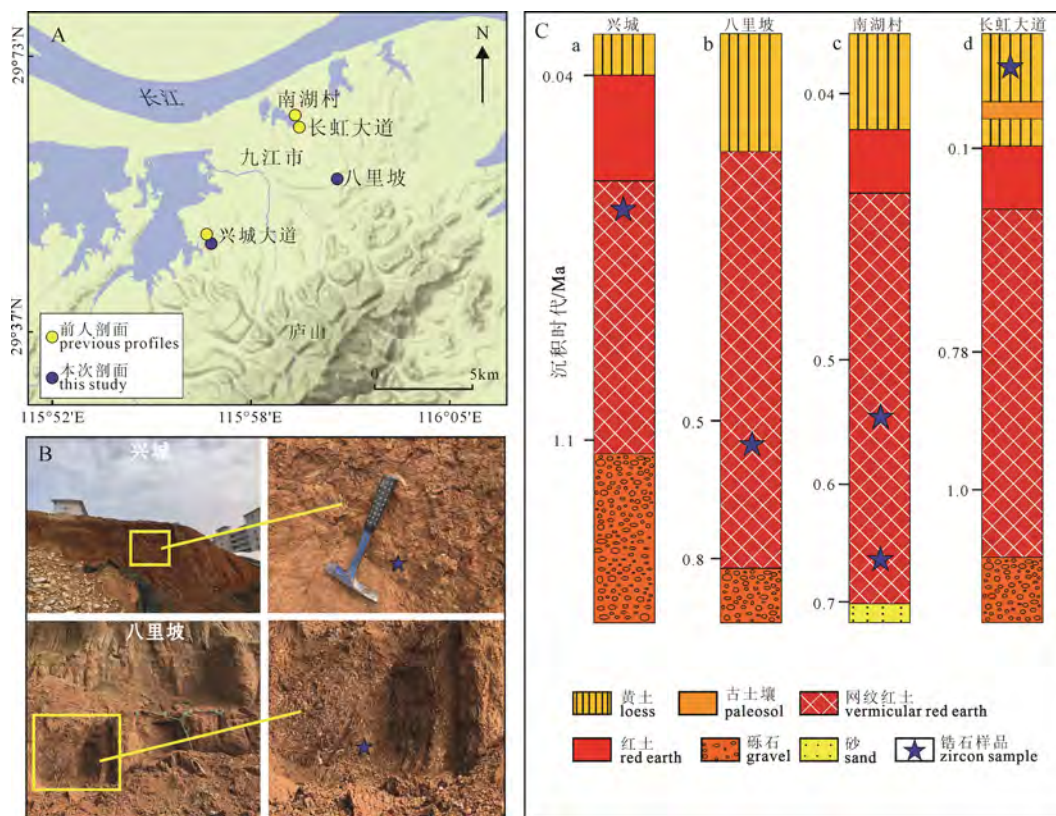


图 2 九江地区地质图(修改自李金典, 2019)

Fig. 2 Geological map of Jiujiang area (modified from LI, 2019)



A—九江红土位置分布图, 前人剖面: 南湖村剖面(程峰, 2018), 长虹大道剖面(蒋复初等, 1997), 兴城大道剖面(李金典, 2019); B—本次研究剖面野外照片, 图中五角星代表样品采集点; C—九江剖面红土和黄土地层柱状图(a—兴城; b—八里坡剖面的地层年龄来自李金典(2019); c—南湖村; d—长虹大道剖面的地层年龄分别来自程峰(2018)和蒋复初等(1997)); 图中五角星代表锆石样品分析层位。
A—location distribution map of Jiujiang red earth, including previous profiles: Nanhucun profile (CHENG, 2018), Changhong Dadao profile (JIANG et al., 1997), Xingcheng Dadao profile (LI, 2019); B—field photographs of the profiles of this study, in which the star represents the sample collection point; C—stratigraphic histogram of red earth and loess in the Jiujiang area (a—Xingcheng; b—Balipo profiles from LI(2019); c—Nanhucun; d—Changhong Dadao profiles from CHENG(2018) and JIANG et al.(1997); the star in the figure represents the analysis horizon of zircon samples.

图3 样品采集
Fig. 3 Sample collection

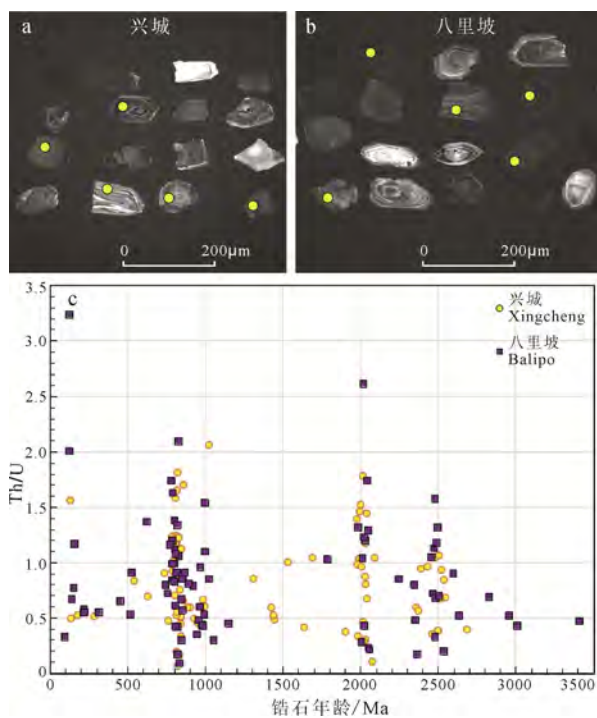
3 实验方法

将野外 3 kg 左右的样品经淘洗、电磁仪分离后, 在双目镜下随机挑选出约 1000 粒锆石颗粒。随机挑选 200 粒各种形态的锆石颗粒使用环氧树脂固结制靶, 以排除人工选择对锆石年龄概率积分结果造成的潜在影响。将锆石靶抛光至颗粒的 1/3 处, 使颗粒内部得以完全暴露。对制好的锆石靶进行显微镜下透射光、反射光拍照, 后喷碳进行阴极发光照相, 以获得锆石颗粒截面及内部的结晶形态和结构信息, 以便选择激光束斑的直径和适宜的测试点位。锆石 U-Pb 同位素定年在南京宏创地质勘查技术服务有限公司微区分析实验室完成, 激光束斑直径 30 μm 、剥蚀频率 5 Hz、能量密度 2 J/cm²。锆石 91500 作为校正标样, GJ-1 作为监测标样, 每隔 10~12 个样品分析 2 个 91500 标样及 1 个 GJ-1 标样。通常采集 20 s 的气体空白, 35~40 s 的信号区间进行数据处理。以 NIST610 作为外标, 91Zr 作为内标计算微量元素含量。选择 $^{206}\text{Pb}/^{238}\text{U}$ (年龄 < 1000 Ma) 或

$^{207}\text{Pb}/^{206}\text{Pb}$ (年龄 > 1000 Ma) 谐和度在 90%~99% 之间的年龄结果。这与以往研究者在中国北方沙漠、戈壁等地区(谢静等, 2007; Stevens et al., 2010; Pullen et al., 2011; Xie et al., 2012; Che and Li, 2013; Nie et al., 2014; Rittner et al., 2016; Zhang et al., 2016; 杨利荣等, 2017; Fan et al., 2019; 林旭等, 2020), 以及程峰(2018)和林旭等(2022b)在九江地区开展的红土和黄土锆石 U-Pb 年龄的筛选方法一致。锆石 U-Pb 年龄频率分布图采用 DensityPlotter 软件完成 (Vermeesch, 2012)。使用 IsoplotR 软件可以有效实现多维尺度(MDS)判别, 实现样品的相似/相异分析 (Vermeesch, 2018)。

4 实验结果

此次分析的九江红土所含锆石颗粒晶形复杂, 主要为自形-半自形颗粒, 多呈长柱状、短柱状、椭圆状等, 并有破碎严重、晶形不完整的颗粒大量出现(图 4a, b)。阴极发光图像清晰显示锆石的内部结构, 主要出现变质成因锆石、继承成因锆石和具有



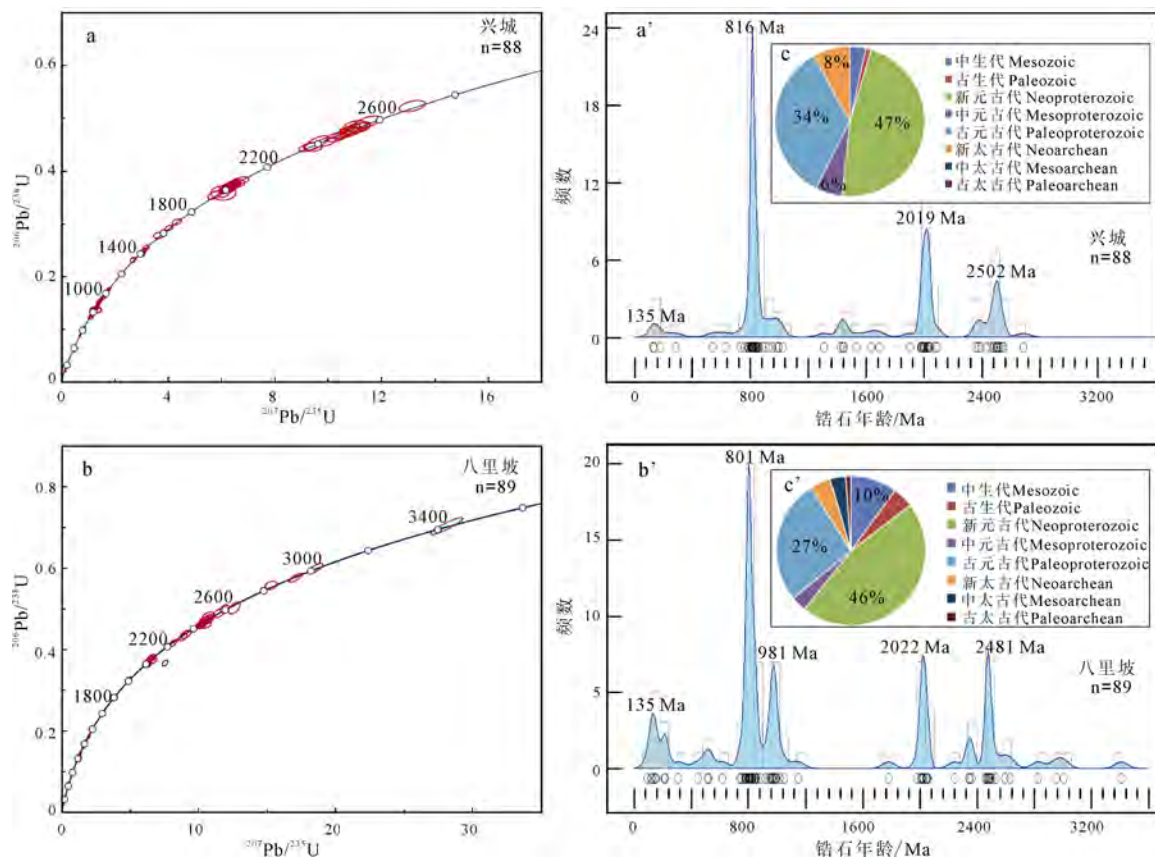
a, b—锆石阴极发光图, 圆圈代表样品测试点;

c—锆石 U-Pb 年龄与 Th/U 结果散点图。

a, b—cathodoluminescence images of zircon grains with circles representing sample analysis points; c—Scatter plot of zircon U-Pb ages and Th/U ratios.

图 4 实验结果

Fig. 4 Experimental results



a, b—锆石谐和年龄图; a', b'—锆石年龄谱组成图。

a, b—zircon concordant age maps; a', b'—U-Pb age spectra of detrital zircon.

图 5 实验结果

Fig. 5 Experimental results

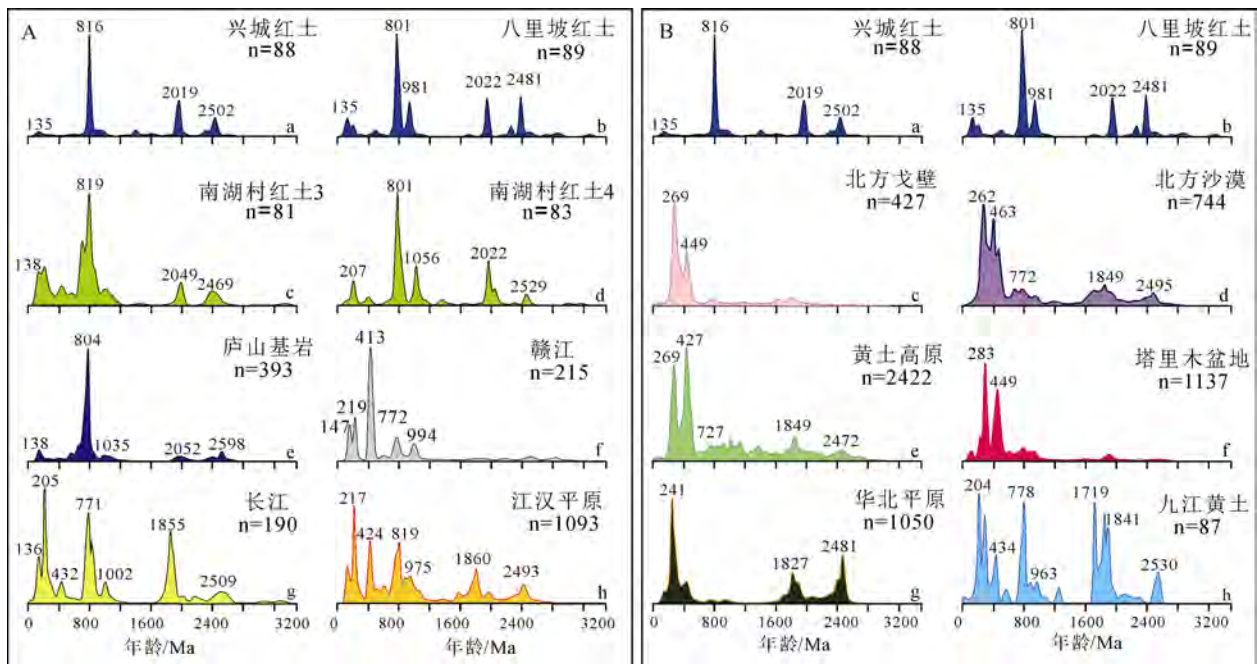
震荡环带的岩浆锆石。锆石中的 Th、U 含量及 Th/U 比值与锆石的成因有关。一般而言, 岩浆锆石中 Th、U 含量较高, Th/U 值 > 0.4 ; 变质锆石中 Th、U 含量低, Th/U 值 < 0.1 (Wu and Zheng, 2004)。本次分析的九江红土锆石有 180 颗, 除有 3 颗锆石的 Th/U 值 < 0.1 外, 其余锆石大都是岩浆来源锆石(图 4c)。

剔除不谐和年龄, 九江兴城和八里坡红土剖面共计获得 177 个谐和锆石 U-Pb 年龄(图 5a, b)。九江兴城红土剖面的碎屑锆石 U-Pb 谐和年龄出现 135 Ma、816 Ma、2019 Ma 和 2502 Ma 等 4 个主要峰值(图 5a')。中生代年龄占 3%, 古生代年龄占 1%, 新元古代年龄占 47%, 中元古代占 6%, 古元古代占 34%, 新太古代占 8%。九江八里坡红土剖面的碎屑锆石 U-Pb 谐和年龄由中生代(135 Ma)、新元古代(801 Ma 和 991 Ma)、古元古代(2022 Ma 和 2481 Ma)组成(图 5b')。中生代年龄占 10%, 古生代年龄占 4%, 新元古代年龄占 46%, 中元古代占 3%, 古元古代占 27%, 新太古代占 4%, 中太古代占 3%, 古太古代占 1%。

5 讨论

5.1 九江中更新世红土来自近源物源区

将九江地区的中更新世红土与潜在近源和远



A—a, b—九江红土(本次研究); c, d—九江红土(程峰, 2018); e—庐山基岩(李学刚等, 2010; 史志刚, 2014); f—赣江(李小聪等, 2016); g—长江(He et al., 2013; Liang et al., 2018); h—江汉平原(林旭等, 2022a); B—a, b—九江红土(本次研究); c—北方戈壁(Che and Li, 2013; Zhang et al., 2016); d—北方沙漠(Stevens et al., 2010; Xie et al., 2012; Zhang et al., 2016; 杨利荣等, 2017; Fan et al., 2019); e—黄土高原(Stevens et al., 2010; Pullen et al., 2011; Nie et al., 2014); f—塔里木盆地(谢静等, 2007; Rittner et al., 2016); g—华北平原(林旭等, 2020); h—九江黄土(林旭等, 2022b)。

A—a, b—Jiujiang red earth (this study); c, d—Jiujiang red earth (CHENG, 2018); e—Lushan bedrock (LI et al., 2010; SHI, 2014); f—Ganjiang River (LI et al., 2016); g—Yangtze River (He et al., 2013; Liang et al., 2018); h—Jiangnan Plain (LIN et al., 2022a); B—a, b—Jiujiang red earth (this study); c—Northern China Gobi (Che and Li, 2013; Zhang et al., 2016); d—Northern China deserts (Stevens et al., 2010; Xie et al., 2012; Zhang et al., 2016; YANG et al., 2017; Fan et al., 2019); e—Loess Plateau (Stevens et al., 2010; Pullen et al., 2011; Nie et al., 2014); f—Tarim Basin (XIE et al., 2007; Rittner et al., 2016); g—North China Plain (LIN et al., 2020); h—Jiujiang Loess (LIN et al., 2022b)。

图6 九江红土与近源(A)和远源(B)潜在物源区锆石 U-Pb 年龄对比图

Fig. 6 Comparison of zircon U-Pb ages of Jiujiang red earth with potential provenances from near (A) and far (B) source areas

源物源区的碎屑锆石 U-Pb 峰值年龄进行对比, 结合 MDS 判定结果可以有效约束具体的物源区。九江兴城和八里坡红土剖面的碎屑锆石 U-Pb 年龄组成基本相似(图 6A-a, b), 主要以新元古代(816 Ma, 801 Ma)和古元古代—新太古代(2019 Ma 和 2022 Ma, 2502 Ma 和 2481 Ma)峰值为主, 同时都存在不明显中生代峰值(135 Ma)。将兴城和八里坡红土剖面与九江南湖村剖面(图 6A-c, d)的碎屑锆石 U-Pb 峰值组成进行对比(程峰, 2018), 可以看到后者的锆石 U-Pb 峰值组成同样以新元古代(819 Ma, 801 Ma)和古元古代—新太古代(2049 Ma 和 2022 Ma, 2469 Ma 和 2529 Ma)峰值为主, 都存在不明显中生代峰值(138 Ma 和 207 Ma)(程峰, 2018)。这说明中更新世时期, 九江地区的红土沉积物质来源相对一致。

将九江地区中更新世红土与庐山基岩的锆石 U-Pb 峰值年龄进行对比(李学刚等, 2010; 史志刚, 2014), 明显能看到后者存在中生代(138 Ma)、新元古代(804 Ma)、古元古代(2052 Ma)和新太古代(2598 Ma)峰值(图 6A-e), 二者之间的峰值组成相似。赣江的碎屑锆石 U-Pb 年龄存在显著的早古生

代峰值(413 Ma, 李小聪等, 2016), 但古元古代和新太古代峰值不明显(图 6A-f)。九江地区中更新世红土的早古生代峰值年龄不明显。长江中下游的碎屑锆石 U-Pb 年龄组成复杂(He et al., 2013), 存在明显的中生代(136 Ma)、早古生代(205 Ma)、新元古代(771 Ma)、古元古代(1855 Ma)和新太古代(2509 Ma)峰值(图 6A-g)。尽管九江南湖村 4 红土剖面的锆石 U-Pb 峰值年组成出现 207 Ma 的峰值(程峰, 2018; 图 6A-d), 但与长江中下游相比(205 Ma, He et al., 2013, 图 6A-g), 前者并不显著。长江中下游的碎屑锆石 U-Pb 年龄的新元古代峰值集中在 771 Ma, 而九江红土剖面都集中在 801~819 Ma。此外, 长江中下游河流沉积物和九江红土的古元古代峰值也存在差异, 前者集中在 1855 Ma, 后者集中在 2019 Ma 和 2049 Ma。江汉盆地的碎屑物质主要来自长江(林旭等, 2022a), 其锆石 U-Pb 年龄组成和长江更为接近(图 6A-h)。因而, 九江中更新世红土与长江中下游和江汉盆地的碎屑锆石 U-Pb 年龄组成不同, 而是和近源的庐山基岩更为相似。

中国西北内陆分布着面积广大的戈壁、沙漠和

黄土, 这些碎屑物质在东亚冬季风的作用下, 同样可以成为九江红土的潜在远源源区(Chen et al., 2007; Zhao et al., 2019)。而通过对比可以看到, 九江兴城和八里坡红土剖面(图 6B-a, b)以及南湖村红土剖面(图 6A-c, d)中出现的中生代锆石 U-Pb 年龄峰值, 在北方戈壁(Che and Li, 2013; Zhang et al., 2016; 图 6B-c)、北方沙漠(Stevens et al., 2010; Xie et al., 2012; Zhang et al., 2016; 杨利荣等, 2017; Fan et al., 2019; 图 6B-d)、黄土高原(Stevens et al., 2010; Pullen et al., 2011; Nie et al., 2014; 图 6B-e)和塔里木盆地(谢静等, 2007; Rittner et al., 2016; 图 6B-f)都不明显。另外, 在九江红土中占优势的新元古代峰值年龄在上述区域中同样也不显著。这样的情形也出现在华北平原的碎屑锆石 U-Pb 年龄峰值中(林旭等, 2020; 图 6B-g)。因而九江红土与中国北方戈壁、沙漠、黄土和华北平原之间不存在明显的物源联系。在 MDS 判定图中, 除了南湖村 3 样品外, 大部分九江红土样品与庐山基岩的分布距离较近(图 7)。以往开展的全岩地球化学(黄颖等, 2019)、重矿物和碎屑锆石 U-Pb 年龄(张晓等, 2022)物源示踪结果表明, 九江中更新世红土以近源物质为主。九江红土碎屑锆石粒径主要分布于 40~200 μm , 总体大于洛川风成黄土-古土壤沉积物(50~70 μm), 程峰(2018)认为九江红土来源于长江流域内出露的土地壳岩体及早期形成的陆源碎屑沉积建造经表生风化作用剥蚀后, 由风力作用经短途搬运而成。早更新世以后, 九江盆地处于稳定沉积阶段, 此时盆地充填物主要来源于庐山, 在盆地南部边缘形成了广泛的冲积扇沉积(李金典, 2019, 图 8)。因而, 我们认

为九江红土的物质主要来自庐山北麓山前冲积扇物质经东亚冬季风搬运形成, 但不能完全排除长江中下游河漫滩碎屑物质的贡献。

晚更新世时期, 风成黄土呈披覆式大量沉积于九江地区(蒋复初等, 1997; 程峰, 2018; 黄颖等, 2019; 张晓等, 2022), 其碎屑锆石 U-Pb 峰值年龄组成(图 6B-h)却与九江红土存在明显差异(图 6A-a, b, c, d), 这主要体现在九江黄土的新生代峰值集中在 204 Ma, 新元古代峰值年龄集中在 778 Ma, 同时还存在明显的早古生代峰值年龄(434 Ma)。因而, 九江黄土和长江中下游的碎屑锆石 U-Pb 年龄组成更

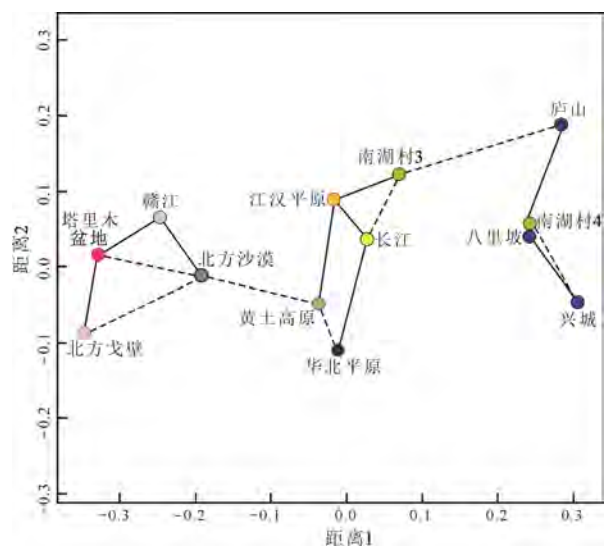


图 7 锆石 U-Pb 年龄 MDS 判定图
(实线和虚线代表最近和第二近距离)
Fig. 7 Zircon U-Pb age MDS determination diagram with solid and dotted lines represent the nearest and the second-closest distance, respectively

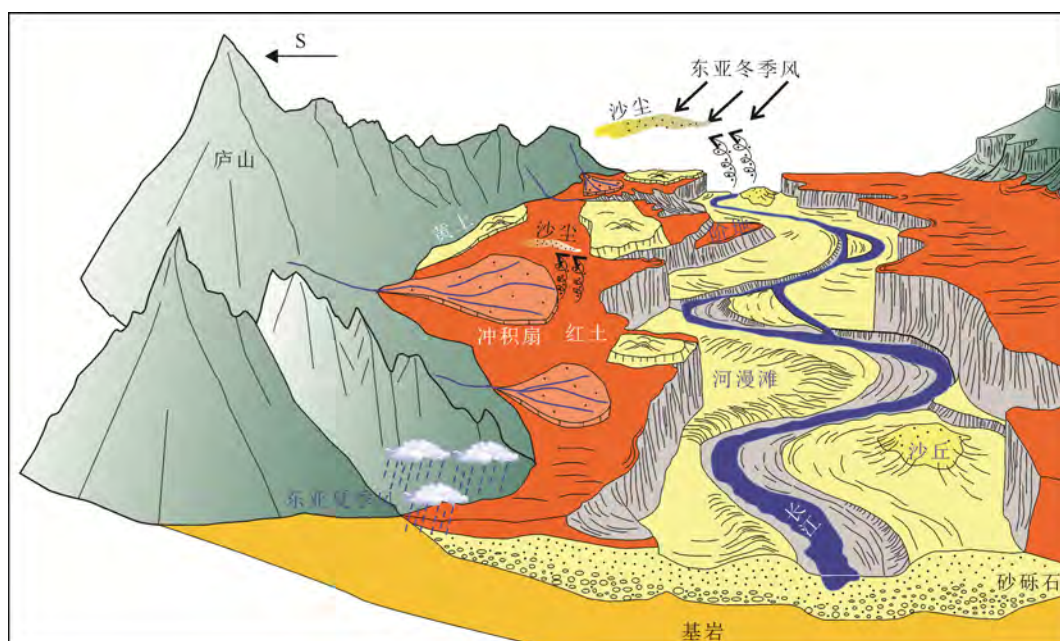


图 8 九江中更新世红土和晚更新世黄土形成模式图
Fig. 8 Formation patterns of Middle Pleistocene red earth and Late Pleistocene loess of the Jiujiang area

相似。林旭等(2022b)对长江中下游晚更新世黄土和沙山的物源开展了系统的分析,结果表明这些物质主要来自长江中下游的河漫滩物质。这与以往长江下游沿岸下蜀黄土的物源示踪研究结果一致(Hao et al., 2010; Qiao et al., 2011; Wang et al., 2018; Zhang and Jia, 2019; Wu et al., 2021)。因而,九江地区中更新世红土和晚更新世黄土虽然都以近源物质组成为主,但后者主要来自长江的河漫滩物质。

5.2 中更新世红土和晚更新世黄土物源变化的指示意义

青藏高原隆起是新生代最为重要的地质事件之一,对中国第四纪环境格局的形成具有深远影响(Sun and Liu, 2000)。青藏高原在第四纪经历了多次阶段性抬升后成为地球上平均海拔最高的高原,使中国大气环流东西和南北方向的运行都受到明显干扰,引起东亚乃至全球大气环流格局的明显变化(Clark et al., 2006)。早更新世末至中更新世初(0.7~0.4 Ma),青藏高原经历一次强烈的隆升(Liu et al., 2010),平均海拔接近现在的 4000 m,促使高原面上的高山发育山麓冰川(Zhou et al., 2006)。高耸的青藏高原阻挡了来自印度洋的湿润气流深入中国西北内陆,导致该地区在冬季干冷,夏季干热,当地环境不断向干旱化方向发展,驱动大面积戈壁和沙漠出现,在其下风区堆积了面积广厚度深的黄土(Guo et al., 2000)。同时,随着北极冰盖的不断发育,西伯利亚-蒙古冷高压不断增强,加大了与太平洋和印度洋的热力性差异,增强了东亚季风和南亚季风(Ding et al., 1995; Cheng et al., 2016),导致青藏高原以东和长江以南出现面积广大的红土沉积(李长安和顾延生, 1997; 朱丽东, 2007; Hong et al., 2010; Cheng et al., 2018)。结合华南板块在中更新世广泛分布的红土具有风尘沉积物的特点,并且物源区都以近源为主(程峰, 2018),说明这些红土主要来自东亚冬季风就近吹拂碎屑物质堆积而成,而这些近源碎屑沉积物主要来自增强的东亚和南亚夏季风产生的降水对华南板块内部基岩的侵蚀。华南红土中更新世同时还受东亚夏季风的影响,经历强烈的化学风化过程(Yin and Guo, 2006)。因而,华南中更新世红土的广泛出现,是东亚冬季风和东亚、南亚夏季风共同作用下出现的,是对青藏高原此时的构造隆升产生的环境变化的沉积响应。

进入晚更新世(0.12 Ma),中国西北内陆的沙漠进一步扩展,黄土高原接受新一期大面积的黄土沉积(Yang and Ding, 2004)。此时,华南板块长江中下游地区不仅出现广泛的黄土沉积,还出现高大沙山。这些黄土和沙山的物质主要来自近源长江干流河漫滩物质。一方面说明华南地区晚更新世风尘沉

积物再次大面积出现,沉积物的色调以棕黄色为主,较之中更新红土的棕红色明显不同,指示中国北方和南方都处于干冷状态,高大沙山的出现证明干冷的东亚冬季风较之中更新世的冬季风的搬运能力更强。另一方面表明晚更新世长江中下游的水位更低,裸露的河床碎屑物质较之中更新世更丰富,为流域沿岸的黄土和沙山提供了充足的碎屑物质。这反过来可以理解为,在中更新世华南地区的东亚夏季风对区域内的影响占主导地位,冬季时长江河床碎屑物质由于受到水体的覆盖,未大面积出露,因而并不是沿岸红土的主要物源区。

6 结论

通过对九江中更新世红土进行碎屑锆石 U-Pb 年龄分析,与潜在物源区碎屑锆石 U-Pb 年龄进行对比,我们得到如下结论:九江中更新世红土物质主要来自庐山北麓的冲积扇,具有近源堆积的特征,其与中国北方沙漠、戈壁和黄土高原没有明显的物源联系。九江中更新世红土与九江晚更新世黄土的物源区不同,其出现都受控于青藏高原构造隆升产生的环境变化。

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