# 川西新元古代苏雄组层型剖面SHRIMP锆石U-Pb年龄及其地质意义

卓皆文[1,2)]，江卓斐[1,2)]，江新胜[1,2)]，王剑[1,2)]，蔡娟娟[3)]，熊国庆[1,2)]，
陆俊泽[1,2)]，崔晓庄[1,2)]，刘建辉[4)]

1）中国地质调查局成都地质调查中心，成都，610081；
2）国土资源部沉积盆地与油气资源重点实验室，成都，610081；
3）中国地质科学院研究生部，北京，100037；　4）北京离子探针中心，北京，102206

**内容提要**：对采自川西新元古代苏雄组层型剖面中上部的英安岩进行SHRIMP锆石U-Pb定年，获得了两组谐和年龄值：838 ± 9 Ma（$n$ = 9，MSWD = 0.80）和780 ± 12 Ma（$n$ = 5，MSWD = 1.2）。其中780 ± 12 Ma解释为苏雄组英安岩的喷发时限，代表康滇裂谷盆地强烈扩张时期的构造岩浆热事件；而838 ± 9 Ma则可能代表康滇裂谷盆地开启前的构造岩浆热事件。综合研究认为，苏雄组位于康滇裂谷半地堑盆地的调节带，为华南新元古代幕式岩浆活动的产物；火山活动和沉积记录均表明，扬子周缘发育与地幔柱相关的裂谷盆地系统，且华南可能是Rodinia超大陆裂解的重要组成单元。

**关键词**：苏雄组；英安岩；SHRIMP锆石U-Pb年龄；新元古代；构造岩浆热事件

扬子周缘新元古代岩浆活动非常强烈，其喷发时代与构造属性对于重建华南在Rodinia超大陆中的位置具有极为重要的意义（Li Xianhua et al.，2003；Li Zhengxiang et al.，2003；Wang Jian and Li Zhengxiang，2003；Cui Xiaozhuang et al.，2015）。一般认为，苏雄组为扬子西缘新元古代康滇裂谷盆地的充填物（图1a），主要分布于小相岭、大相岭、甘洛和西昌螺髻山等地，主体为一套双峰式火山岩（刘鸿允等，1981，1991；Li Xianhua et al.，2002）。然而，限于测年技术的精度，以往获得的苏雄组年龄变化范围大（900 ~ 600 Ma）（刘鸿允等，1981；董榕生与李建林，1981；张盛师，1985；马国干等，1989；刘鸿允等，1991），可靠性欠佳。Li Xianhua等（2002）首次对苏雄组底部流纹岩进行了年龄测定，获得了803 ± 12 Ma的SHRIMP锆石U-Pb年龄；谷志东等（2014a）对四川威远地区威117井花岗岩基底岩芯进行了SHRIMP锆石U-Pb测年，获得了794 ± 11 Ma的年龄数据，罗志立（1986）认为花岗岩可与苏雄组对比。尽管如此，仍需更多可靠年龄数据对苏雄组的喷发时限进行精确限定，进而认识华南的大地构造属性及重建其在Rodinia超大陆中的位置。最近，笔者在川西甘洛地区的苏雄组层型剖面中上部采集了1个英安岩样品（LGP-20N1，N 29°07′10″，E 102°51′21″），进行了SHRIMP锆石U-Pb同位素测定，为确定苏雄组双峰式火山活动的时限和研究扬子的幕式构造岩浆热事件提供了新的年代学资料；并结合扬子周缘新元古代火山活动与沉积记录，探讨了华南的大地构造属性。

## 1　地质背景

苏雄组分布于扬子西缘康滇新元古代裂谷盆地中段宝兴—汉源—西昌—甘洛—盐边一线（四川省地质矿产局，1997），被认为是华南新元古代大火山岩省（LIPs）之一（Ernst et al.，2008；Li Zhengxiang et al.，2008），是康滇裂谷盆地调节带的核心部位（卓皆文等，2013），其喷发时代为新元古代中期（Li Xianhua et al.，2002）。最新研究表明，苏雄组可与开建桥组、澄江组、牛头山组、陆良组上段、莲沱组进

注：本文为国家自然科学基金资助项目（编号：41672112、41030315、41502114）和中国地质调查局项目（编号：DD20160017、12120114067901、1212011121105）的成果。
收稿日期：2015-08-03；改回日期：2016-08-15；责任编辑：章雨旭。Doi：10.16509/j.georeview.2017.01.016
作者简介：卓皆文，男，1980年生。博士，高级工程师，主要从事沉积学与大地构造研究。电话：028 − 83231381；Email：zhuojiewen_1980@163.com。

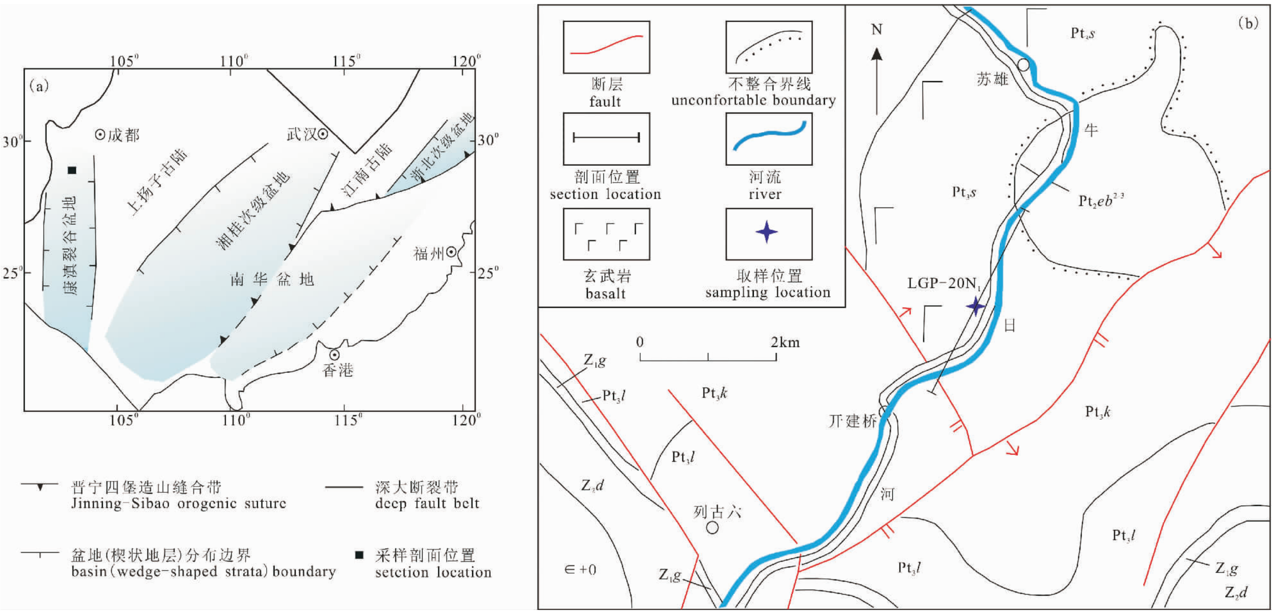


图 1 华南新元古代裂谷次级盆地分布图(a, 据 Wang Jian 与 Li Zhengxiang,2003 修改)和研究区区域地质背景图(b, 据卓皆文等,2015 修改)

Fig. 1 Neoproterozoic rift sub-basins in South China (a, modified after Wang Jian and Li Zhengxiang,2003) and the regional geological setting of studied area (b, modified after Zhuo Jiewen et al. ,2015&)

$Pt_2eb^{2-3}$—中元古界峨边群第二、三段;$Pt_3s$—新元古界苏雄组;$Pt_3k$—新元古界开建桥组;$Pt_3l$—新元古界列古六组;$Z_1g$—下震旦(埃迪卡拉)统观音崖组;$Z_2d$—上震旦(埃迪卡拉)统灯影组;∈+O—寒武系和奥陶系

$Pt_2eb^{2-3}$—No. 2 and 3 Member of the Ebian Group, Mesoproterozoic; Neoproterozoic: $Pt_3s$—Suxiong Formation, $Pt_3k$—Kaijianqiao Formation, $Pt_3l$—Lieguliu Formation; $Z_1g$—Lower Sinian (Ediacaran) Guanyinya Formation; $Z_2d$—Upper Sinian (Ediacaran) Dengying Formation; ∈+O—Cambrian and Ordovician

行对比(江新胜等,2012;陆俊泽等,2013;崔晓庄等,2014,2015;卓皆文等,2013,2015)。

苏雄组层型剖面位于四川西部甘洛县苏雄,沿牛日河至开建桥;下与中元古代峨边群呈角度不整合接触,上与开建桥组呈断层接触(图 1b,2)。在区域上,苏雄组厚数百米至上万米,与开建桥组在横向上呈相互消长关系(杨暹和与陈远德,1981;刘鸿允等,1991;卓皆文等,2015)。笔者对苏雄组层型剖面进行了实测,测得剖面实际厚度为 787 m。苏雄组可分为三段:第 1 ~ 19 层为下段,厚 470 m,以紫灰色、灰绿色厚层状火山碎屑岩为主,夹灰绿色凝灰岩和暗紫色玄武岩、紫灰色英安岩,底部为 10 m 厚的灰色块状砾岩;第 20 ~ 21 层为中段,厚 282 m,以灰白色层状流纹岩和紫灰色厚层块状英安岩等酸性熔岩为主;第 22 ~ 24 层为上段,厚 35 m,主要为灰绿色厚层块状沉凝灰岩和深灰色致密块状玄武岩(图 2)。本文研究样品采自层型剖面第 20 层,为紫灰色厚层块状英安岩(图 2)。

## 2 样品及分析方法

英安岩呈紫灰色,厚层块状(图 3a)。镜下观察具斑状结构,斑晶含量 10% ~ 15%,主要矿物为长石和石英,副矿物为磁铁矿和锆石;长石主要为钾长石,部分酸性斜长石,多呈板条状、柱粒状;石英以细中粒浑圆状为主,表面干净,个别有熔蚀边;基质具隐晶—微粒结构,含量 85% ~ 90%,主要由长英质微粒和隐晶硅质组成(图 3b)。

将样品粉碎至 60 目以下,先用人工重砂方法富集锆石,然后在双目镜下精选锆石。将挑好的锆石颗粒粘在双面胶上,固定在透明的环氧树脂中,和树脂一起打磨抛光,直至露出锆石的内部以适合分析。对抛光后的锆石进行反射光、透射光显微照相和阴极发光(CL)图像分析,选择代表性的锆石颗粒和区域进行 U—Th—Pb 同位素分析。

SHRIMP 锆石 U—Pb 分析在中国地质科学院地质研究所北京离子探针中心 SHRIMP Ⅱ 上完成。在分析过程中,一次离子流强度为 4 nA,一次离子流

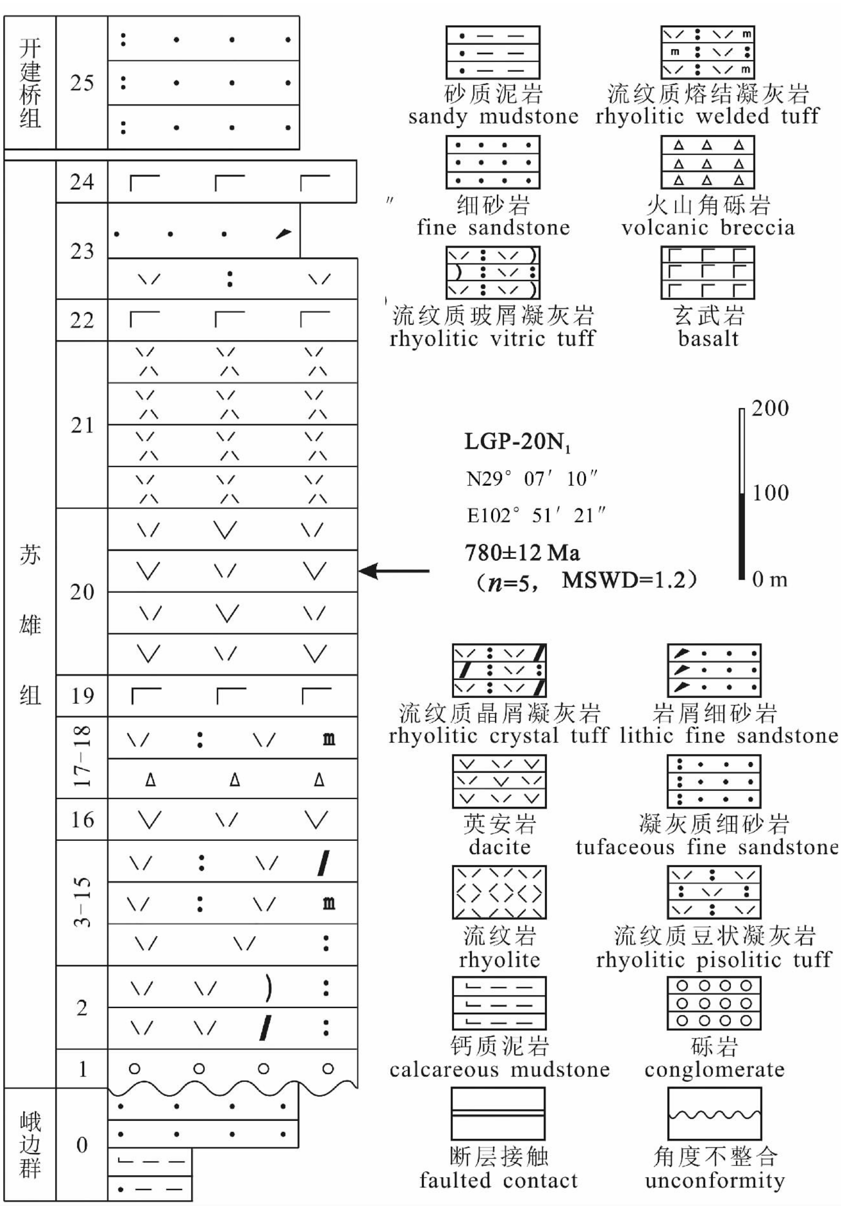


图 2 川西新元古界苏雄组层型剖面柱状图及采样位置

Fig. 2 The sample position and stratotype section of the Neoproterozoic Suxiong Formation in western Sichuan province

束斑为 20 ~ 30 μm。每个测量点由 5 组扫描获得。标样为 M257(U 含量为 840 × $10^{-6}$)(Nasdala et al.,2008)和 TEM(年龄为 417 Ma)(Black et al.,2003),分别用于 U 含量和 $n(^{206}Pb)/n(^{238}U)$ 年龄值校正。为了监测仪器的稳定性和同位素分馏行为,每隔 2 ~ 3 个未知样品测量即进行一次标样测试(TEM),详细的 SHRIMP 分析流程按照 Compston 等(1984)、Williams 与 Claesson(1987)所设计的流程进行。数据处理和年龄计算采用程序 SQUID 1.02 和 ISOPLOT 3.0(Ludwig,2003);衰变常数使用 Steiger 与 Jager(1977)的推荐值;普通铅校正使用直接测定 $^{204}Pb$ 方法(Compston et al.,1984),其组成用 Stacey-Kramers 模式给出的相应时间地壳 Pb 同位素组成平均值(Stacey and Kramers,1975)。本文数据表中(表 1)所列数据均为同一测量点连续 5 次分析的平均值,相对误差为 1σ。样品年龄采用 $n(^{206}Pb)/n(^{238}U)$ 表面年龄的平均值,误差置信度为 95%。

## 3　分析结果

阴极发光影像显示,样品 LGP-20N1 的锆石晶体为自形长柱状,长宽比为 2∶1 ~ 4∶1,晶面光滑,晶棱平直,具清晰的震荡环带结构,为典型岩浆型锆石(图 4)。本文共选择 17 颗锆石进行了 U—Th—Pb 同位素分析,结果列于表 1。

测点 2.1、4.1、8.1、13.1 和 16.1 的 U 含量为 14 × $10^{-6}$ ~ 203 × $10^{-6}$,Th 含量为 8 × $10^{-6}$ ~ 110 × $10^{-6}$,Th/U 比值为 0.53 ~ 0.73(表 1),均大于 0.4;按照 Rubatto(2002)的判别标准,属于典型的岩浆成因锆石。其 U-Pb 年龄值在误差范围内具有很好的一致性,均分布于谐和线上或附近,表明这些锆石几乎没有 U 和 Pb 的丢失或加入,数据可靠性高(图 5)。这 5 个测点的 $n(^{206}Pb)/n(^{238}U)$ 年龄加权平均值为 780 ± 12 Ma(95% 置信度,MSWD = 1.2)(图 5),代表川西苏雄组层型剖面英安岩(LGP-20N1)锆石的结晶年龄,即英安岩的喷发时限。

测点 3.1、5.1 ~ 7.1、10.1、11.1、14.1、15.1、17.1 的 U 含量为 24 × $10^{-6}$ ~ 286 × $10^{-6}$,Th 含量为 17 × $10^{-6}$ ~ 221 × $10^{-6}$,Th/U 比值为 0.41 ~ 1.61(表 1),均大于 0.4,按照 Rubatto(2002)的判别标准,也为典型的岩浆成因锆石。

测试结果表明,其 U-Pb 年龄在误差范围内具有很好的一致性,均分布于谐和线上或附近(图 5),


图 3 川西新元古界苏雄组英安岩采样露头(a)与显微照片(b)

Fig. 3 The outcrop(a) and micro-photograph(b) of the dacite sample from the Neoproterozoic Suxiong Formation in western Sichuan province

F—长石；Q—石英；Mt—磁铁矿 F—feldspar；Q—quartz；Mt—magnetite

表明这些锆石 U 和 Pb 的封闭系统未遭受破坏，数据可靠性高。这 9 个测点的 $n(^{206}Pb)/n(^{238}U)$ 年龄的加权平均值为 838 ± 9 Ma(95% 置信度，MSWD = 0.8)(图 5)，代表康滇裂谷盆地开启前的构造岩浆热事件。测点 12.1 的锆石具有明显的核边结构，由于打点位置位于中心核部，测得的数据可能代表继承年龄，未参与计算。

**表 1 川西新元古界苏雄组英安岩 LGP-20N1 的锆石 U—Th—Pb 同位素分析结果**

**Table 1 Zircon U—Th—Pb isotopic analysis for the LGP-20N1 dacite from the Neoproterozoic Suxiong Formation in western Sichuan province**

| 测点编号 | 元素含量 | | | Th/U | 同位素比值 | | | | | | 同位素年龄(Ma) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $^{206}Pb^*$ | U | Th | | $n(^{207}Pb^*)/n(^{206}Pb^*)$ | | $n(^{207}Pb^*)/n(^{235}U)$ | | $n(^{206}Pb^*)/n(^{238}U)$ | | $n(^{206}Pb)/n(^{238}U)$ | | $n(^{207}Pb)/n(^{206}Pb)$ | |
| | ($\times 10^{-6}$) | | | | 测值 | ±% | 测值 | ±% | 测值 | ±% | 测值 | ±1σ | 测值 | ±1σ |
| 1.1 | 19.70 | 198 | 133 | 0.7 | 0.0683 | 4.4 | 1.081 | 4.7 | 0.1148 | 1.5 | 700.7 | 10 | 877 | 91 |
| 2.1 | 12.00 | 110 | 78 | 0.73 | 0.0676 | 6.6 | 1.176 | 6.7 | 0.1263 | 1.6 | 766 | 11 | 855 | 140 |
| 3.1 | 30.30 | 248 | 126 | 0.53 | 0.0639 | 3.4 | 1.241 | 3.7 | 0.1409 | 1.4 | 850 | 11 | 739 | 73 |
| 4.1 | 16.00 | 138 | 70 | 0.53 | 0.0571 | 8.7 | 1.036 | 8.9 | 0.1315 | 1.6 | 796 | 12 | 497 | 190 |
| 5.1 | 34.00 | 286 | 179 | 0.65 | 0.0703 | 3.2 | 1.33 | 3.4 | 0.1372 | 1.3 | 829 | 10 | 938 | 65 |
| 6.1 | 17.50 | 142 | 221 | 1.61 | 0.075 | 7.9 | 1.45 | 8 | 0.1402 | 1.5 | 846 | 12 | 1068 | 160 |
| 7.1 | 25.80 | 219 | 126 | 0.59 | 0.0701 | 3.6 | 1.315 | 3.9 | 0.1361 | 1.4 | 822 | 11 | 931 | 74 |
| 8.1 | 1.69 | 14 | 8 | 0.6 | 0.061 | 84 | 1.08 | 84 | 0.1295 | 6.8 | 785 | 51 | 630 | 180 |
| 9.1 | 21.10 | 160 | 71 | 0.46 | 0.0768 | 6.6 | 1.59 | 6.8 | 0.1504 | 1.5 | 903 | 13 | 1116 | 130 |
| 10.1 | 3.13 | 24 | 17 | 0.72 | 0.076 | 22 | 1.5 | 22 | 0.1423 | 4 | 858 | 32 | 1101 | 440 |
| 11.1 | 13.30 | 108 | 43 | 0.41 | 0.051 | 25 | 0.98 | 25 | 0.1378 | 2.1 | 832 | 17 | 262 | 57 |
| 12.1 | 44.80 | 358 | 192 | 0.55 | 0.0677 | 2.7 | 1.356 | 3 | 0.1452 | 1.3 | 874 | 10 | 860 | 56 |
| 13.1 | 3.71 | 33 | 23 | 0.71 | 0.055 | 22 | 0.95 | 22 | 0.1252 | 2.6 | 761 | 19 | 422 | 49 |
| 14.1 | 30.90 | 254 | 123 | 0.5 | 0.0646 | 3.5 | 1.254 | 3.8 | 0.1409 | 1.3 | 850 | 11 | 761 | 74 |
| 15.1 | 13.40 | 109 | 86 | 0.82 | 0.077 | 13 | 1.48 | 13 | 0.1392 | 1.8 | 840 | 14 | 1129 | 260 |
| 16.1 | 22.90 | 203 | 110 | 0.56 | 0.0622 | 5.2 | 1.115 | 5.4 | 0.1299 | 1.6 | 787 | 12 | 682 | 110 |
| 17.1 | 26.30 | 216 | 116 | 0.55 | 0.0662 | 11 | 1.26 | 11 | 0.1378 | 1.6 | 832 | 12 | 814 | 230 |

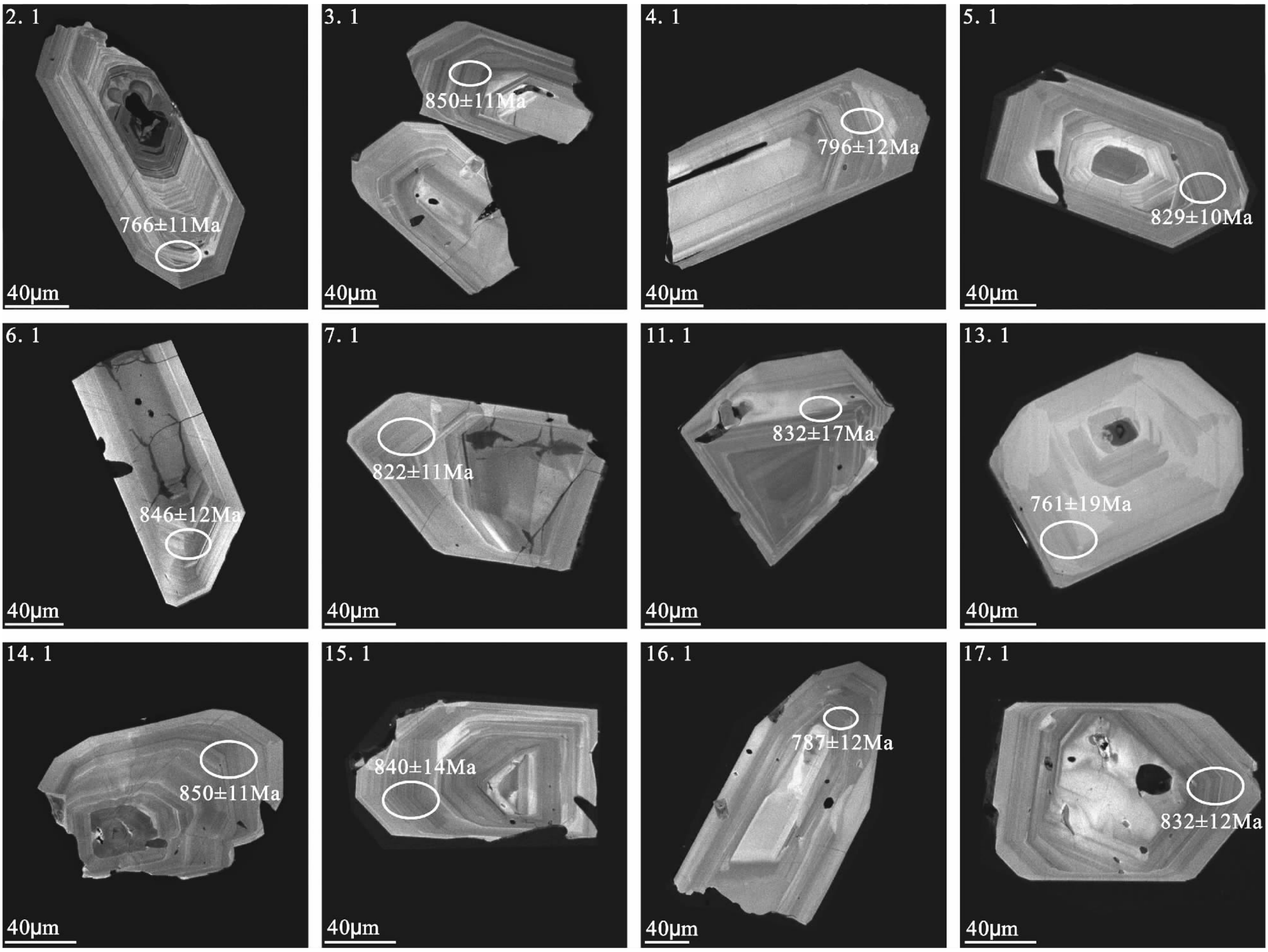


图 4 川西新元古界苏雄组英安岩锆石的阴极发光图像及相应年龄

Fig. 4 Zircon CL images and ages of the dacite from the Neoproterozoic Suxiong Formation in western Sichuan province

# 4　讨论

## 4.1　苏雄组的幕式喷发

Li Xianhua 等(2002)、谷志东等(2014a)在苏雄组底部分别获得了 803 ± 12 Ma、794 ± 11 Ma 两个高精度年龄数据,结合本文在苏雄组中上部获得的 780 ± 12 Ma 的 SHRIMP 锆石 U－Pb 年龄,及殷继成(1984)测得苏雄组顶部玄武岩 759 Ma 的 K－Ar 年龄,表明苏雄组并非一次性喷发的产物,而是与华南新元古代的幕式构造岩浆热事件(825 Ma、800 Ma、780 Ma 和 755 Ma 四幕岩浆活动)(Ernst et al., 2008)密切相关。本文在扬子西缘新元古代康滇裂谷盆地获得苏雄组英安岩 780 ± 12 Ma 的 SHRIMP 锆石 U－Pb 年龄,应属于华南第二幕(800 Ma)构造岩浆热事件的延续。事实上,在扬子西缘广泛发生的 780 Ma 左右的岩浆活动(表 2),均是华南新元古代幕式构造岩浆热事件的表现。

对于苏雄组双峰式火山岩的成因,一直存在着不同的认识。刘鸿允等(1991)、Li Xianhua 等(2002)、谷志东与汪泽成(2014b)认为其与陆内裂谷有关,周朝宪等(1998)认为其形成于后造山环境。根据卓皆文等(2013)研究表明,新元古代康滇裂谷盆地属于大陆裂谷半地堑盆地,由主边界断裂、裂谷肩、裂谷基和调节带组成,川西苏雄组位于其调节带。调节带是裂谷盆地非常重要的组成部分,由一系列斜交裂谷轴的转换断层组成,是半地堑盆地极性反转的过渡地带;其特点表现为,地形上高于盆地基底,时间上晚于裂谷初始期,因此苏雄组缺乏第一幕(825 Ma)的岩浆活动,这点在前人于苏雄组及相当地层底部获得的相关年代学资料(800 Ma 左右)得到了证明(Li Xianhua et al., 2002;谷志东等, 2014a;崔晓庄等, 2015;卓皆文等, 2015)。

值得一提的是,最近 Jiang Zhuofei 等(2016)在川西甘洛开建桥组层型剖面顶部的凝灰质粉砂岩和

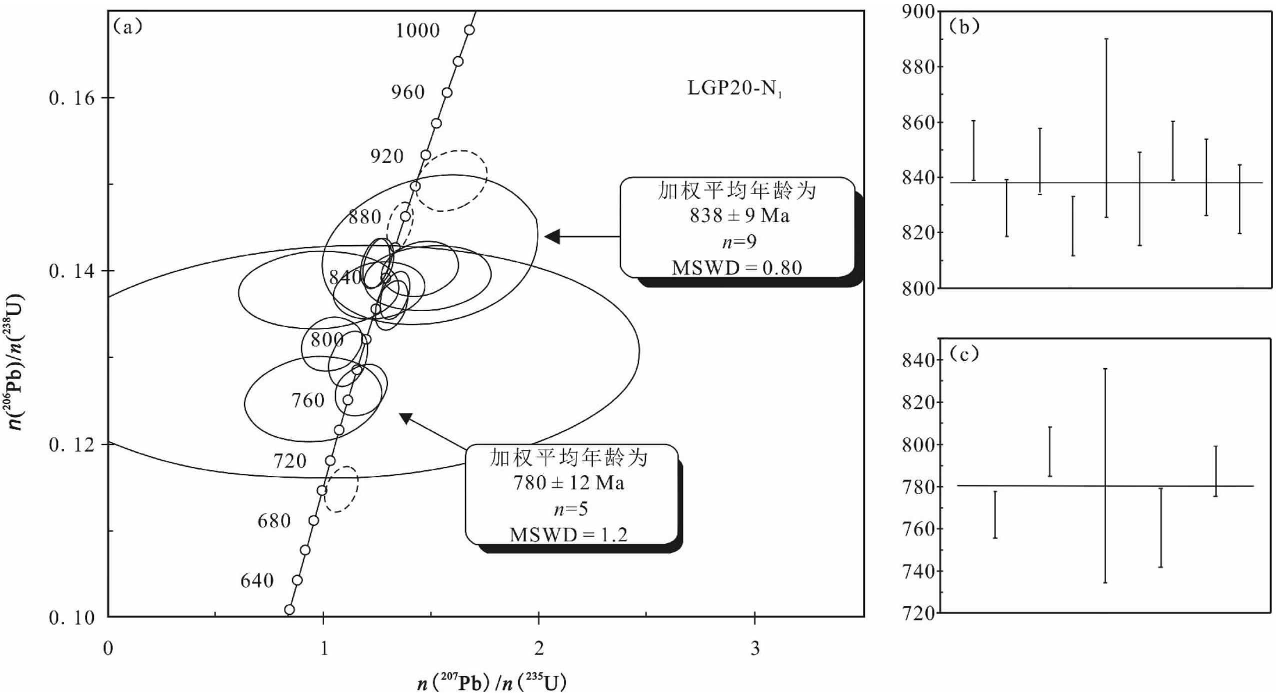


图 5 川西新元古界苏雄组英安岩锆石 U—Pb 谐和图(a)和 $n(^{206}Pb)/n(^{238}U)$ 年龄图(b、c)

Fig. 5 Zircon U—Pb concordance(a) and $n(^{206}Pb)/n(^{238}U)$ ages(b、c) of the dacite from the Neoproterozoic Suxiong Formation in western Sichuan province

凝灰岩分别获得 721 ± 7 Ma、717 ± 7 Ma 的 LA－ICP－MS 锆石 U－Pb 年龄值,认为开建桥组的顶界时限为 717 Ma。苏雄组和开建桥组为同时异相关系,两者可以完全进行对比(卓皆文等,2015)。因此,苏雄组的幕式喷发(800 Ma、780 Ma、755 Ma、720 Ma)可以与导致 Rodinia 超大陆裂解的地幔柱幕式岩浆活动(Ernst et al. ,2008)相对应,进一步表明其为华南新元古代幕式岩浆活动的产物。

### 4.2 华南大地构造属性

华南很好地保存了 850 ~ 720 Ma 的岩浆活动和沉积记录(Li Xianhua et al. ,2003;Wang Jian and Li Zhengxiang,2003)。然而,针对这些广泛发育岩浆事件的构造背景还存在着很大的争议。Li Zhengxiang 等(2003,2008)、Ling Wenli 等(2003)、Wang Jian 与 Li Zhengxiang(2003)、Ernst 等(2008)、Cui Xiaozhuang 等(2015)认为该岩浆活动形成于陆内裂谷环境,与导致 Rodinia 超大陆裂解的地幔柱幕式岩浆活动有关;Zhou Meifu 等(2002,2006)则认为其形成于岛弧环境,与洋壳岩石圈向东插入扬子板块下有关;Wang Xiaolei 等(2004,2006)认为其形成于碰撞后垮塌环境。

裂谷观点(Wang Jian and Li Zhengxiang,2003;Li Zhengxiang et al. ,2003,2008)认为,华南新元古代的岩浆活动具有 3 个显著的特点:双峰式、多幕式和广泛性。晋宁期约 830 ~ 745 Ma 的岩浆事件被认为是扬子对新元古代地幔柱作用的响应,其中 830 ~ 795 Ma 和 780 ~ 745 Ma 分别对应 Rodinia 超大陆开始张裂和最终裂解两个演化阶段(Li Zhengxiang et al. ,2003)。Li Zhengxiang 等(2008)进一步指出,约 850 ~ 740 Ma 之间的剧烈裂谷岩浆活动是幕式(825 Ma、780 Ma 和 750 Ma)地幔柱活动事件形成。Ernst 等(2008)将分布在全球不同地区的元古界火山岩浆岩群称为相应的大火成岩省,并认为 825 Ma、800 Ma、780 Ma 和 755 Ma(可能还包括 720 Ma)岩浆事件与 Rodinia 超大陆裂解相关。

年代学研究表明,在扬子西缘、北缘和东南缘,均发育 780 Ma 的岩浆事件(表 2),为华南裂谷盆地裂解高峰(800 Ma)的延续。且该岩浆事件与北美西部 780 Ma 的巨型岩墙群(Jefferson and Parrishi,1989;Park et al. ,1995)和澳大利亚南部 783 Ma 的 Boucaut 火山岩(Preiss,2000)的时代也是一致的,表明华南新元古代裂谷盆地的幕式岩浆活动和 Rodinia 超大陆裂解是同步的。

沉积学研究表明,华南新元古代裂谷的沉降与

**表 2 华南新元古代裂谷盆地系统的火成岩锆石 U-Pb 年龄统计表**

**Table 2 Zircon U-Pb ages about igneous rocks of Neoproterozoic rift basins in South China**

| 构造部位 | 采样位置 | 岩石单元 | 样品岩性 | 测试方法 | 年龄(Ma) | 数据来源 |
|---|---|---|---|---|---|---|
| 扬子西缘 | 四川冕宁 | 康定群 | 花岗质片麻岩 | SHRIMP | 772 ± 15<br>773 ± 11 | 陈岳龙等,2004 |
| | 四川攀枝花 | 康定群 | 奥长花岗岩 | SHRIMP | 778 ± 11 | 杜利林等,2006 |
| | 四川泸定 | 康定群 | 花岗岩 | SHRIMP | 779 ± 6 | 林广春等,2006 |
| | 四川盐边 | 荒田组 | 玄武岩 | SHRIMP | 782 ± 53 | 杜利林等,2005 |
| | 四川米易 | 康定群 | 石英闪长岩 | SHRIMP | 775 ± 8 | Li Zhengxiang 等,2003 |
| | 四川金口河 | 烂包坪组 | 凝灰岩 | SHRIMP | 779 ± 16 | 熊国庆等,2013 |
| | 四川喜德 | 登相营群 | 基性岩墙群 | SHRIMP | 774 ± 10 | 任光明等,2013 |
| | 四川甘洛 | 开建桥组 | 凝灰质岩 | LA-ICP-MS | 780 ± 3 | Jiang Zhuofei 等,2016 |
| | 云南巧家 | 澄江组 | 凝灰岩 | SHRIMP | 785 ± 12 | 陆俊泽等,2013 |
| | 云南澄江 | 澄江组 | 凝灰岩 | SHRIMP | 781 ± 11 | 崔晓庄等,2013 |
| 扬子东南缘 | 贵州铜仁 | 鹅家坳组 | 凝灰岩 | SHRIMP | 782 ± 8<br>785 ± 8 | 汪正江等,2010 |
| | 贵州清镇 | 鹅家坳组 | 凝灰岩 | SHRIMP | 780 ± 9 | 汪正江等,2010 |
| | 浙江道林山 | 岩 体 | 花岗岩 | LA-ICP-MS<br>SHRIMP | 780 ± 5<br>775 ± 13 | Wang Qiang 等,2010 |
| | 广西罗城 | 拱洞组 | 凝灰岩 | SHRIMP | 786 ± 6 | 高林志等,2013 |
| | 广西三江 | 长安组 | 凝灰岩 | SHRIMP | 778 ± 5 | 高林志等,2013 |
| | 贵州雷山 | 清水江组 | 凝灰岩 | SHRIMP | 774 ± 8 | 高林志等,2010 |
| | 贵州锦屏 | 隆里组 | 凝灰岩 | LA-ICP-MS | 785 ± 8 | 汪正江等,2013 |
| | 广西三江 | 拱洞组 | 凝灰岩 | LA-ICP-MS | 775 ± 13 | 汪正江等,2013 |
| | 广西合桐 | 拱洞组 | 凝灰岩 | LA-ICP-MS | 781 ± 5 | 崔晓庄等 ,2016 |
| | 湖南中部 | 砖墙湾组 | 凝灰岩 | LA-ICP-MS | 775 ± 3 | 马慧英等,2013 |
| | 贵州锦屏 | 清水江组 | 凝灰岩 | SIMS | 774 ± 5 | Wang Xuance 等,2012 |
| | 贵州刚边 | 岩 体 | 花岗斑岩 | LA-ICP-MS | 785 ± 4 | 陈建书等,2014 |
| | 贵州宰便 | 岩 体 | 辉绿岩 | TIMS | 788 ± 3 | 陈建书等,2014 |
| | 安徽南部 | 井潭组 | 凝灰岩 | LA-ICP-MS | 779 ± 7 | 吴荣新等,2007 |
| | 安徽南部 | 井潭组 | 英安岩 | SHRIMP | 773 ± 7 | 吴荣新等,2007 |
| | 安徽石耳山 | 岩 体 | 花岗类岩石 | SHRIMP | 779 ± 11 | Li Zhengxiang 等,2003 |
| | 安徽石耳山 | 岩 体 | 花岗类岩石 | SHRIMP | 778 ± 11 | 吴荣新等,2005 |
| | 安徽石耳山 | 岩 体 | 花岗类岩石 | LA-ICP-MS | 776 ± 6<br>777 ± 11 | 吴荣新等,2005 |
| | 浙江建德 | 志棠组 | 凝灰岩 | SHRIMP | 780 ± 10 | 尹崇玉等,2007 |
| 扬子北缘 | 湖北三峡 | 莲沱组 | 凝灰岩 | SHRIMP | 787 ± 7 | 高维与张传恒,2009 |
| | 湖北大洪山 | 莲沱组 | 凝灰岩 | SHRIMP | 779 ± 12 | Du Qiuding 等,2013 |
| | 湖北三都坪 | 莲沱组 | 凝灰质粉砂岩 | SIMS U-Pb | 772 ± 4<br>777 ± 4 | Lan Zhongwu 等,2015 |
| | 甘肃碧口 | 碧口群 | 中酸性火山岩 | SHRIMP | 776 ± 13 | 闫全人等,2003 |
| | 陕西西乡 | 大石沟组 | 凝灰岩 | LA-ICP-MS | 789 ± 4 | 邓奇等,2013 |
| | 陕西毕玑沟 | 岩 体 | 辉长岩 | SHRIMP | 782 ± 10 | Zhou Meifu 等,2002 |
| | 陕西五堵门 | 岩 体 | 英云闪长岩 | LA-ICP-MS | 789 ± 10 | 凌文黎等,2006 |
| | 陕西南郑 | 岩 体 | 花岗斑岩 | LA-ICP-MS | 776 ± 6 | 夏林圻等,2009 |

充填过程具有强烈的阶段性,可划分为四个旋回(Wang Jian and Li Zhengxiang, 2003; 江新胜等, 2012;崔晓庄等,2014;Wang Jian et al. ,2015)。第Ⅰ旋回始于 820 Ma,以基性玄武岩喷发为主,盆地基底快速沉降为特征,沉积范围非常局限,沉积体呈楔状,底部为少量火山岩、火山碎屑岩和大量的洪冲积扇沉积,主体部分为饥饿盆地深灰色页岩、碳质页岩沉积。第Ⅱ旋回始于 800 Ma,以双峰式火山岩强烈喷发、沉积范围快速扩展为标志,沉积体呈面状,底部为厚层双峰式火山岩堆积,主体为移地滨岸相冲积扇、河流、湖泊及滨海沉积;780 Ma 和 755 Ma 为裂解高峰的延续。第Ⅲ旋回的起始时间为 725 Ma,以冰川作用开始为标志,形成了大陆冰盖和盆地冰水沉积。第Ⅳ旋回沉积始于 635 Ma,以冰川作

用结束,海平面上升,全面海侵作用为标志,形成了以碳酸盐岩为主的陆表海沉积。华南新元古代裂谷盆地的沉积—层序演化特征,与南澳、北美西部新元古代裂谷盆地的沉积—层序演化特征极为相似,且四个大的层序旋回基本可以相互对比(王剑,2000;Wang Jian and Li Zhengxiang,2001,2003)。

综上所述,扬子周缘发育与地幔柱相关的新元古代裂谷盆地系统,且华南可能是 Rodinia 超大陆裂解的重要组成单元。因此,本文研究结果支持华南处于 Rodinia 超大陆"核心"位置,是连接北美大陆和澳大利亚—南极大陆之间的桥梁(Li Zhengxiang et al.,1995,2008)。华南广泛发育的岩浆活动和沉积记录不支持岛弧模式和碰撞后垮塌模式。

## 5 结论

(1)川西苏雄组中上部英安岩的喷发时限为 780 ± 12 Ma。

(2)苏雄组位于康滇裂谷半地堑盆地调节带,为华南新元古代幕式岩浆活动的产物。

(3)火山活动和沉积记录均表明,扬子周缘发育与地幔柱相关的裂谷盆地系统,且华南可能是 Rodinia 超大陆裂解的重要组成单元。

**致谢**:锆石挑选和岩矿鉴定工作分别得到了苏俊周研究员和闵际坤研究员的帮助;阴极发光照像和 SHRIMP 同位素分析得到了北京离子探针中心有关老师的帮助,在此作者表示衷心地感谢!

### 参 考 文 献 / References

(The literature whose publishing year followed by a "&" is in Chinese with English abstract; the literature whose publishing year followed by a "#" is in Chinese without English abstract)

陈建书,戴传固,彭成龙,杨凯迪,王敏,卢定彪. 2014. 黔东从江地区新元古代下江期花岗斑岩的特征及其地质意义. 沉积与特提斯地质,34(1):61 ~ 71.

陈岳龙,罗照华,赵俊香,李志红,张宏飞,宋彪. 2004. 从锆石 SHRIMP 年龄及岩石地球化学特征论四川冕宁康定杂岩的成因. 中国科学 D 辑:地球科学,34(8):687 ~ 697.

崔晓庄,江新胜,王剑,卓皆文,熊国庆,陆俊泽,邓奇,伍皓,刘建辉. 2013. 滇中新元古代澄江组层型剖面锆石 U-Pb 年代学及其地质意义. 现代地质,27(3):547 ~ 556.

崔晓庄,江新胜,王剑,卓皆文,伍皓,熊国庆,陆俊泽,邓奇,江卓斐. 2014. 滇中新元古代裂谷盆地充填序列及演化模式:对 Rodinia 超大陆裂解的响应. 沉积学报,32(3):399 ~ 409.

崔晓庄,江新胜,王剑,卓皆文,江卓斐,伍皓,邓奇,魏亚楠. 2015. 扬子西缘澄江组底部玄武岩形成时代新证据及其地质意义. 岩石矿物学杂志,34(1):1 ~ 13.

崔晓庄,江新胜,邓奇,王剑,卓皆文,任光明,蔡娟娟,伍皓,江卓斐. 2016. 桂北地区丹洲群锆石 U-Pb 年代学及对华南新元古代裂谷作用期次的启示. 大地构造与成矿学,40(5):1049 ~ 1063.

邓奇,王剑,汪正江,江新胜,杜秋定,伍皓,杨菲,崔晓庄. 2013. 扬子北缘西乡群大石沟组和三郎铺组凝灰岩锆石 U-Pb 年龄及其地质意义. 吉林大学学报(地球科学版),43(3):797 ~ 819.

董榕生,李建林. 1981. 论乌斯大桥群. 成都地质学院学报,(2):1 ~ 5.

杜利林,耿元生,杨崇辉,王新社,任留东,周喜文,石玉若,杨铸生. 2005. 扬子地台西缘盐边群玄武质岩石地球化学特征及 SHRIMP 锆石 U-Pb 年龄. 地质学报,79(6):805 ~ 813.

杜利林,耿元生,杨崇辉,王新社,任留东,周喜文,王彦斌,杨铸生. 2006. 扬子地台西缘新元古代 TTG 的厘定及其意义. 岩石矿物学杂志,25(4):273 ~ 281.

高林志,戴传固,刘燕学,王敏,王雪华,陈建书,丁孝忠. 2010. 黔东地区下江群凝灰岩锆石 SHRIMP U-Pb 年龄及其地层意义. 中国地质,37(4):1071 ~ 1080.

高林志,陆济璞,丁孝忠,王汉荣,刘燕学,李江. 2013. 桂北地区新元古代地层凝灰岩锆石 U-Pb 年龄及地质意义. 中国地质,40(5):1443 ~ 1452.

高维,张传恒. 2009. 长江三峡黄陵花岗岩与莲沱组凝灰岩的锆石 SHRIMP U-Pb 年龄及其构造地层意义. 地质通报,28(1):4 ~ 50.

谷志东,张维,袁苗. 2014a. 四川盆地威远地区基底花岗岩锆石 SHRIMP U-Pb 定年及其地质意义. 地质科学,49(1):202 ~ 213.

谷志东,汪泽成. 2014b. 四川盆地川中地块新元古代伸展构造的发现及其在天然气勘探中的意义. 中国科学:地球科学,44(10):2210 ~ 2220.

江新胜,王剑,崔晓庄,卓皆文,熊国庆,陆俊泽,刘建辉. 2012. 滇中新元古代澄江组锆石 SHRIMP U-Pb 年代学研究及其地质意义. 中国科学:地球科学,42(10):1496 ~ 1507.

林广春,李献华,李武显. 2006. 川西新元古代基性岩墙群的 SHRIMP 锆石 U-Pb 年龄、元素和 Nd—Hf 同位素地球化学:岩石成因与构造意义. 中国科学 D 辑:地球科学,36(7):630 ~ 645.

凌文黎,高山,程建萍,江麟生,袁洪林,胡兆初. 2006. 扬子陆块与陆缘新元古代岩浆事件对比及其构造意义——来自黄陵和汉南侵入杂岩 ELA-ICP MS 锆石 U-Pb 同位素年代学的约束. 岩石学报,22(2):387 ~ 396.

刘鸿允,胡华光,胡世玲,戚中林. 1981. 从 Rb-Sr 及 K-Ar 年龄测定讨论某些前寒武系及中生代火山岩地层的时代. 地质科学,(4):303 ~ 313.

刘鸿允等. 1991. 中国震旦系. 北京:科学出版社:1 ~ 388.

陆俊泽,江新胜,王剑,卓皆文,熊国庆,崔晓庄. 2013. 滇东北巧家地区新元古界澄江组 SHRIMP 锆石 U-Pb 年龄及其地质意义. 矿物岩石,33(2):65 ~ 71.

罗志立. 1986. 川中是一个古陆核吗. 成都地质学院学报,13(3):65 ~ 73.

马国干,张自超,李华芹,陈平,黄照先. 1989. 扬子地台震旦系同位素年代地层学的研究. 中国地质科学院宜昌地质矿产研究所所刊,(14):83 ~ 124.

马慧英,孙海清,黄建中,马铁球. 2013. 湘中地区高涧群凝灰岩 LA-ICP-MS 锆石 U-Pb 年龄及其地质意义. 矿产勘查,4(1):69 ~ 74.

任光明,庞维华,孙志明,尹福光,肖启亮. 2013. 扬子西缘登相营群基性岩墙锆石 U-Pb 年代学及岩石地球化学特征. 成都理工大学学报(自然科学版),40(1):66 ~ 79.

四川省地质矿产局. 1997. 四川省岩石地层. 武汉:中国地质大学出

版社:1 ~ 417.
王剑. 2000. 华南新元古代裂谷盆地沉积演化——兼论与 Rodinia 解体的关系. 北京:地质出版社:1 ~ 146.
汪正江,王剑,段太忠,谢渊,卓皆文,杨平. 2010. 扬子克拉通内新元古代中期酸性火山岩的年代学及其地质意义. 中国科学:地球科学,40(11):1543 ~ 1551.
汪正江,许效松,杜秋定,杨菲,邓奇,伍皓,周小琳. 2013. 南华冰期的底界讨论:来自沉积学与同位素年代学证据. 地球科学进展,28(4):477 ~ 489.
吴荣新,郑永飞,吴元保. 2005. 皖南石耳山新元古代花岗岩锆石 U-Pb 定年以及元素和氧同位素地球化学研究. 高校地质学报,11(3):364 ~ 382.
吴荣新,郑永飞,吴元保. 2007. 皖南新元古代井潭组火山岩锆石 U-Pb 定年和同位素地球化学研究. 高校地质学报,13(2):282 ~ 296.
夏林圻,夏祖春,马中平,徐学义,李向民. 2009. 南秦岭中段西乡群火山岩岩石成因. 西北地质,42(2):1 ~ 37.
熊国庆,江新胜,崔晓庄,卓皆文,陆俊泽,刘建辉,汪正江,王剑. 2013. 扬子西缘元古宙峨边群烂包坪组地层归属及其锆石 SHRIMP U-Pb 年代学证据. 地学前缘,20(4):350 ~ 360.
闫全人,王宗起,闫臻,Andrew D H,Peter A D,刘敦一,宋彪,简平,王涛. 2003. 碧口群火山岩的时代——SHRIMP 锆石 U-Pb 测年结果. 地质通报,22(6):456 ~ 458.
杨暹和,陈远德. 1981. 西南地区地层总结,震旦系. 重庆:重庆出版社:12 ~ 16.
尹崇玉,柳永清,高林志,王自强,唐烽,刘鹏举. 2007. 震旦(伊迪卡拉)纪早期磷酸盐化动物群——瓮安生物群特征及其环境演化. 北京:地质出版社:1 ~ 132.
殷继成. 1984. 四川西南部震旦系的划分和对比. 成都地质学院学报,32(增刊 1):1 ~ 93.
张盛师. 1985. 四川西南部苏雄组及其相当地层的时代和划分对比. 四川地质学报,(0):112 ~ 122.
周朝宪,魏春生,李朝阳. 1998. 扬子西南缘下震旦系火成岩系研究. 矿物学报,18(4):401 ~ 410.
卓皆文,江新胜,王剑,崔晓庄,熊国庆,陆俊泽,刘建辉,马铭珠. 2013. 华南扬子古大陆西缘新元古代康滇裂谷盆地的开启时间与充填样式. 中国科学:地球科学,43(12):1952 ~ 1963.
卓皆文,江新胜,王剑,崔晓庄,伍皓,熊国庆,陆俊泽,江卓斐. 2015. 川西新元古界开建桥组底部沉凝灰岩锆石 SHRIMP U-Pb 年龄及其地质意义. 矿物岩石,35(1):91 ~ 99.
Black L P, Kamo S L, Allen C M, Aleinikoff J N, Davis D W, Korsch R J, and Foudoulis C. 2003. TEMORA 1: A new zircon standar for Phanerozoic U-Pb geochronology. Chemical Geology, 200: 155 ~ 170.
Chen Jianshu, Dai Chuangu, Peng Chenglong, Yang Kaidi, Wang Min, Lu Dingbiao. 2014#. Characteristics and geological implications of the Xiajiangan ( Neoproterozoic ) granite porphyry in the Congjiang region, southeastern Guizhou. Sedimentary Geology and Tethyan Geology, 34(1):61 ~ 71.
Chen Yuelong, Luo Zhaohua, Zhao Junxiang, Li Zhihong, Zhang Hongfei, Song Biao. 2004 #. Petrogenesis and dating of the Kangding complex, Sichuan Province. Science in China, Series D: Earth Sciences, 34(8):687 ~ 697.
Compston W, Williams I S, and Mayer C. 1984. U-Pb geochronology of zircons from Lunar Breccia 73217 using a Sensitive High Mass-Resolution Ion Microprobe. Proceedings of Fourteenth Lunar and Planetary Science Conference, Part 2. Journal of Geophysical Research, 89(Supp): B525 ~ B534.
Cui Xiaozhuang, Jiang Xinsheng, Wang Jian, Zhuo Jiewen, Xiong Guoqing, Lu Junze, Deng Qi, Wu Hao, Liu Jianhui. 2013&. Zircon U-Pb geochronology for the stratotype section of the Neoproterozoic Chengjiang Formation in central Yunnan and its geological significance. Geoscience, 27(3):547 ~ 556.
Cui Xiaozhuang, Jiang Xinsheng, Wang Jian, Zhuo Jiewen, Wu Hao, Xiong Guoqing, Lu Junze, Deng Qi, Jiang Zhuofei. 2014&. Filling sequence and evolution model of the Neoproterozoic rift basin in central Yunnan province, South China: Response to the breakup of Rodinia supercontinent. Acta Sedimentologica Sinica, 32(3): 399 ~ 409.
Cui Xiaozhuang, Jiang Xinsheng, Wang Jian, Zhuo Jiewen, Jiang Zhuofei, Wu Hao, Deng Qi, Wei Yanan. 2015&. New evidence for the formation age of basalts from the lowermost Chengjiang Formation in the western Yangtze Block and its geological implications. Acta Petrologica Et Mineralogica, 34(1):1 ~ 13.
Cui Xiaozhuang, Jiang Xinsheng, Wang Jian, Wang Xuance, Zhuo Jiewen, Deng Qi, Liao Shiyong, Wu Hao, Jiang Zhuofei, and Wei Yanan. 2015. Mid-Neoproterozoic diabase dykes from Xide in the western Yangtze Block, South China: New evidence for continental rifting related the breakup of Rodinia supercontinent. Precambrian Research, 268: 339 ~ 356.
Cui Xiaozhuang, Jiang Xinsheng, Deng Qi, Wang Jian, Zhuo Jiewen, Ren Guangming, Cai Juanjuan, Wu Hao, Jiang Zhuofei. 2016&. Zircon U – Pb geochronological results of Danzhou Group in northern Guangxi Province and their implications for the Neoproterozoic rifting stages in South China. Geotectonica et Metallogenia, 40(5):1049 ~ 1063.
Deng Qi, Wang Jian, Wang Zhengjiang, Jiang Xinsheng, Du Qiuding, Wu Hao, Yang Fei, Cui Xiaozhuang. 2013&. Zircon U-Pb ages for tuffs from the Dashigou and Sanlangpu Formations of the Xixiang Group in the northern margin of Yangtze Block and their geological significance. Journal of Jinlin University (Earth Science Edition), 43(3):797 ~ 819.
Dong Rongsheng, Li Jianlin. 1981#. Comment on the Wusidaqiao Group. Journal of Chengdu College of Geology, (2):1 ~ 5.
Du Lilin, Geng Yuansheng, Yang Chonghui, Wang Xinshe, Ren Liudong, Zhou Xiwen, Shi Yuruo, Yang Zhusheng. 2005&. Geochemistry and SHRIMP U-Pb zircon chronology of basalts from the Yanbian Group in the western Yangtze block. Acta Geologica Sinica, 79(6):805 ~ 813.
Du Lilin, Geng Yuansheng, Yang Chonghui, Wang Xinshe, Ren Liudong, Zhou Xiwen, Wang Yanbing, Yang Zhusheng. 2006&. The stipulation of Neoproterozoic TTG in western Yangtze block and its significance. Acta Petrologica Et Mineralogica, 25(4):273 ~ 281.
Du Qiuding, Wang Zhengjiang, Wang Jian, Qiu Yansheng, Jiang Xinsheng, Deng Qi, and Yang Fei. 2013. Geochronology and paleoenvironment of the pre-Sturtian glacial strata: Evidence from the Liantuo Formation in the Nanhua rift basin of the Yangtze Block, South China. Precambrian Research, 233: 118 ~ 131.
Ernst R E, Wingate M T D, Buchan K L, and Li Zhengxiang. 2008. Global record of 1600 ~ 700 Ma Large Igneous Provinces (LIPs): Implications for the reconstruction of the proposed Nuna (Columbia) and Rodinia supercontinent. Precambrian Research, 160: 159 ~ 178.
Gao Linzhi, Dai Chuangu, Liu Yanxue, Wang Min, Wang Xuehua, Chen Jianshu, Ding Xiaozhong. 2010&. Zircon SHRIMP U-Pb dating of the tuffaceous bed of Xiajiang Group in Guizhou Province and its

stratigraphic implication. Geology in China,37(4):1071 ~ 1080.

Gao Linzhi, Lu Jipu, Ding Xiaozhong, Wang Hanrong, Liu Yanxue, Li Jiang. 2013&. Zircon U-Pb dating of Neoproterozoic tuff in South Guangxi and its implications for stratigraphic correlation. Geology in China,40(5):1443 ~ 1452.

Gao Wei,Zhang Chuanheng. 2009&. Zircon SHRIMP U-Pb ages of the Huangling granite and tuff beds from Liantuo Formation in the Three Gorges area of Yangtze River,China and its geological significance. Geological Bulletin of China,28(1):45 ~ 50.

Gu Zhidong, Zhang Wei, Yuan Miao. 2014a&. Zircon SHRIMP U-Pb dating of basal granite and its geological significance in Weiyuan area of Sichuan Basin. Chinese Journal of Geology,49(1):202 ~ 213.

Gu Zhidong, Wang Zecheng. 2014b#. The discovery of Neoproterozoic extensional structures and its significance for gas exploration in the Central Sichuan Block,Sichuan Basin,South China. Science China: Earth Sciences,44(10):2210 ~ 2220.

Jefferson C W,and Parrishi R R. 1989. Late Proterozoic stratigraphy,U-Pb ages and rift tectonics of Mechenzie Mountains, northwestern Canada. Canada Journal of Earth Science,26:1784 ~ 1801.

Jiang Xinsheng, Wang Jian, Cui Xiaozhuang, Zhuo Jiewen, Xiong Guoqing, Lu Junze, Liu Jianhui. 2012#. Zircon SHRIMP U-Pb geochronology of the Neoproterozoic Chengjiang Formation in central Yunnan Province (SW China) and its geological significance. Science China:Earth Sciences,55(11):1815 ~ 1826.

Jiang Zhuofei,Cui Xiaozhuang,Jiang Xinsheng,Wang Jian,Zhuo Jiewen, Xiong Guoqing, Lu Junze, Wu Hao, and Wei Yanan. 2016. New zircon U-Pb ages of the pre-Sturtian rift successions from the western Yangtze Block, South China and their geological significance. International Geology Review, 58(9):1064 ~ 1075.

Lan Zhongwu, Li Xianhua, Zhu Maoyan, Zhang Qirui, and Li Qiuli. 2015. Revisiting the Liantuo Formation in Yangtze Block, South China:SIMS U-Pb zircon age constraints and regional and global significance. Precambrian Research,263:123 ~ 141.

Li Xianhua, Li Zhengxiang, Zhou Hanwen, Liu Ying, and Kinny P D. 2002. U-Pb zircon geochronology, geochemistry and Nd isotopic study of Neoproterozoic bimodal volcanic rocks in the Kangdian Rift of South China: Implications for the initial rifting of Rodinia. Precambrian Research,113:135 ~ 154.

Li Xianhua,Li Zhengxiang,Ge Wenchun,Zhou Hanwen,Li Wuxian,Liu Ying,and Wingate M T D. 2003. Neoproterozoic granitoids in South China: Crustal melting above a mantle plume at ca. 825 Ma. Precambrian Research,122:45 ~ 83.

Li Zhengxiang,Zhang Linghua,and Powell C M. 1995. South China in Rodinia:Part of the missing link between Australia—East Antarctica and Laurentia. Geology,23(5):407 ~ 410.

Li Zhengxiang,Li Xianhua,Kinny P D,Wang Jian,Zhang Shihong,and Zhou Hanwen. 2003. Geochronology of Neoproterozoic syn-rift magmatism in the Yangtze Craton,South China and correlations with other continents: Evidence for a mantle superplume that broke up Rodinia. Precambrian Research,122:85 ~ 109.

Li Zhengxiang,Bogdanova S V,Collins A S,Davidson A,De Waele B, Ernst R E,Fitzsimons I C W,Fuck R A,Gladkochub D P,Jacobs J, Karlstrom K E,Lu Songnian,Natapov L M,Pease V,Pisarevsky S A, Thrane K,and Vernikovsky V. 2008. Assembly,configuration,and break-up history of Rodinia: A synthesis. Precambrian Research, 160:179 ~ 210.

Lin Guangchun,Li Xianhua,Li Wuxian. 2006#. SHRIMP U-Pb zircon age, geochemistry and Nd—Hf isotopes of Neoproterozoic mafic dykes swarms in western Sichuan: Petrogenesis and tectonic significance. Science in China Series D:Earth Sciences,36(7):630 ~ 645.

Ling Wenli,Gao Shan,Cheng Jianping,Jiang Linsheng,Yuan Honglin,Hu Zhaochu. 2006&. Neoproterozoic magmatic events within the Yangtze continental interior and along its northern margin and their tectonic implication: Constraint from the ELA-ICP MS U-Pb geochronology of zircons from the Huangling and Hannan complexes. Acta Petrologica Sinica,22(2):387 ~ 396.

Ling Wenli,Gao Shan,Zhang Benren,Li Huimin,Liu Ying,and Cheng Jianping. 2003. Neoproterozoic tectonic evolution of the northwestern Yangtze craton, South China: Implications for amalgamation and break-up of the Rodinia Supercontinent. Precambrian Research,122:111 ~ 140.

Liu Hungyun, Hu Huaguang, Hu shiling, Qi Zhonglin. 1981&. Discussion on ages of some Precambrian rocks and Mesozoic volcanic series from Rb-Sr and K-Ar dating. Scientia Geologica Sinica,(4): 303 ~ 313.

Liu Hongyun et al. 1991#. Sinian System of China. Beijing:Science Press:1 ~ 388.

Lu Junze,Jiang Xinsheng,Wang Jian,Zhuo Jiewen,Xiong Guoqing,Cui Xiaozhuang. 2013&. SHRIMP zircon U-Pb age and its geological significance of Neoproterozoic Chengjiang Formation in Qiaojia area, northeast Yunnan. Journal of Mineralogy and Petrology,33(2):65 ~ 71.

Ludwig K R. 2003. User's Manual for Isoplot 3.00:A Geochronological Toolkit for Microsoft Excel. Berkeley: Berkeley Geochronology Center Special Publication:1 ~ 70.

Luo Zhili. 1986&. Is there a paleocontinental neucleus in central Sichuan. Journal of Chengdu College of Geology,13(3):65 ~ 73.

Ma Guogan, Zhang Zichao, Li Huaqin, Chen Ping, Huang Zhaoxian. 1989&. A geochronostratigraphical study of the Sinian System in Yangtze platform. Bulletin of Yichang Institute of Geology and Mineral Resources,(14):83 ~ 124.

Ma Huiying,Sun Haiqing,Huang Jianzhong,Ma Tieqiu. 2013&. U-Pb dating of zircon from the Gaojian Group tuff in central Hunnan Province and its geological implication. Mineral Exploration,4(1): 69 ~ 74.

Nasdala L,Hofmeister W,Norberg N,Mattinson J M,Corfu F,Dörr W, Kamo S L,Kennedy AK,Kronz A,Reiners P W,Frei D,Kosler J, Wan Yusheng,Götze J,Häger T,Kröner A,and Valley J W. 2008. Zircon M257——A homogeneous natural reference material for the ion microprobe U-Pb analysis of zircon. Geostandards and Geoanalytical Research,32:247 ~ 265.

Park J K,Buchan K L,and Harlan S S. 1995. A proposed giant radiating dyke swarm fragmented by the separation of Laurentia and Australia based on paleomagnetism of ca. 780 Ma mafic intrusions in western North America. Earth and Planetary Science Letters,132:129 ~ 139.

Preiss W V. 2000. The Adelaide Geosyncline of South Australia and its significance in Neoproterozoic continental reconstruction. Precambrian Research,100:21 ~ 63.

Ren Guangming,Pang Weihua,Sun Zhiming,Yin Fuguang,Xiao Qiliang. 2013&. Zircon U-Pb geochronology and geochemistry of mafic dyke swarms in Dengxiangying Group on west margin of Yangtze Block, China. Journal of Chengdu University of Technology (Science & Technology Edition),40(1):66 ~ 79.

Rubatto D. 2002. Zircon trace element geochemistry: Partitioning with garnet and the link between U-Pb ages and metamorphism. Chemical Geology,184:123 ~ 138.

Sichuan Bureau of Geology and Mineral Resources. 1997 #. Lithostratigraphy of Sichuan Province. Wuhan: China University of Geosciences Press:1 ~ 417.

Stacey J S, and Kramers J D. 1975. Approximation of terrestrial lead isotope evolution by a two-stage model. Earth and Planetary Science Letters,26:207 ~ 221.

Steiger R H, and Jager E. 1977. Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology. Earth and Planetary Science Letters,36:359 ~ 362.

Wang Jian. 2000&. Neoproterozoic Rifting History of South China: Significance to Rodinia Breakup. Beijing: Geological Publishing House:1 ~ 146.

Wang Jian, and Li Zhengxiang. 2001. Sequence stratigraphy and evolution of the Neoproterozoic marginal basins along southeastern Yangtze Craton,South China. Gondwana Research,4(1):17 ~ 26.

Wang Jian, and Li Zhengxiang. 2003. History of Neoproterozoic rift basins in South China: Implications for Rodinia break-up. Precambrian Research,122:141 ~ 158.

Wang Jian,Zhou Xiaolin, Deng Qi, Fu Xiugen, Duan Taizhong, and Guo Xiumei. 2015. Sedimentary successions and the onset of the Neoproterozoic Jiangnan sub-basin in the Nanhua rift,South China. International Journal of Earth Sciences,104:521 ~ 539.

Wang Qiang, Wyman D A, Li Zhengxiang, Bao Zhiwei, Zhao Zhenhua, Wang Yixian, Jiang Ping, Yang Yueheng, and Chen Linli. 2010. Petrology, geochronology and geochemistry of ca. 780 Ma A-type granites in South China: Petrogenesis and implications for crustal growth during the breakup of the supercontinent Rodinia. Precambrian Research,178:185 ~ 208.

Wang Xiaolei, Zhou Jincheng, Qiu Jiansheng, and Gao Jianfeng. 2004. Geochemistry of the Meso- to Neoroterozoic basic-acid rocks from Hunan Province, South China: Implications for the evolution of the western Jiangnan orogen. Precambrian Research,135(1 ~ 2):79 ~ 103.

Wang Xiaolei, Zhou Jincheng, Qiu Jiansheng, Zhang Wenlan, Liu Xiaoming, and Zhang Guilin. 2006. LA-ICP-MS U-Pb zircon geochronology of the Neoproterozoic igneous rocks from Northern Guangxi, South China: Implications for tectonic evolution. Precambrian Research,145:111 ~ 130.

Wang Zhengjiang, Wang Jian, Duan Taizhong, Xie Yuan, Zhuo Jiewen, Yang Ping. 2010#. Geochronology of middle Neoproterozoic volcanic deposits in Yangtze Craton interior of South China and its implications to tectonic settings. Science China: Earth Sciences,40(11):1543 ~ 1551.

Wang Zhengjiang, Xu Xiaosong, Du Qiuding, Yang Fei, Deng Qi, Wu Hao,Zhou Xiaolin. 2013&. Discussion on the bottom of Nanhua System: Evidences from sedimentology and isotopic geochronology. Advances in Earth Science,28(4):477 ~ 489.

Wang Xuance,Li Xianhua,Li Zhengxiang,Li Qiuli,Tang Guoqiang,Gao Yuya,Zhang Qirui,and Liu Yu. 2012. Episodic Precambrian crust growth: Evidence from U-Pb ages and Hf—O isotopes of zircon in the Nanhua Basin,central South China. Precambrian Research,222 ~ 223:386 ~ 403.

Williams I S, and Claesson S. 1987. Isotopic evidence for the Precambrian provenance and Caledonian metamorphism of high-grade paragneisses from the Deve Nappes, Scandinavian Caledonides. II: Ion microprobe zircon U—Th—Pb. Contributions to Mineralogy and Petrology,97(2):205 ~ 217.

Wu Rongxin, Zheng Yongfei, Wu Yuanbao. 2005&. Zircon U—Pb element and oxygen isotope geochemistry of Neoproterozoic granites at Shier shan in South Anhui Province. Geological Journal of China Universities,11(3):364 ~ 382.

Wu Rongxin,Zheng Yongfei,Wu Yuanbao. 2007&. Zircon U-Pb age and isotope geochemistry of Neoproterozoic Jingtan volcanics in south Anhui. Geological Journal of China Universities, 13(2):282 ~ 296.

Xia Linqi,Xia Zuchun,Ma Zhongping,Xu Xueyi,Li Xiangmin. 2009&. Petrogenesis of volcanic rocks from Xixiang Group in middle part of south Qinling Mountains. Northwestern Geology,42(2):1 ~ 37.

Xiong Guoqing,Jiang Xinsheng,Cui Xiaozhuang,Zhuo Jiewen,Lu Junze, Liu Jianhui,Wang Zhengjiang,Wang Jian. 2013&. Strata location of the Lanbaoping Formation of the Proterozoic E'bian Group in the Western Yangtze Block and its chronological evidence of zircon SHRIMP U-Pb age. Earth Science Frontiers,20(4):350 ~ 360.

Yan Quanren,Wang Zongqi,Yan Zhen,Hanson A D,Druschke P A,Liu Dunyi,Song Biao,Jian Ping,Wang Tao. 2003#. SHRIMP zircon U-Pb dating from volcanics of Bikou Group. Geological Bulletin of China,22(6):456 ~ 458.

Yang Xuanhe,Chen Yuande. 1981#. Stratum Summary of Southwestern China:Sinian System. Chongqing:Chongqing Press:12 ~ 16.

Yin Chongyu,Liu Yongqing,Gao Linzhi,Wang Ziqiang,Tang Feng,Liu Pengju. 2007 #. Phosphatized Biota in Early Sinian (Ediacaran)——Weng'an Biota and Its Environment. Beijing: Geological Publishing House:1 ~ 132.

Yin Jicheng. 1984&. The stratigraphic division and correlation of Sinian in Southwest Sichuan. Journal of Chengdu College of Geology,32(Supp 1):1 ~ 93.

Zhang Shengshi. 1985 #. Age, division and correlation of Suxiong Formation and its equivalent strata in Southwestern Sichuan. Acta Geologica Sichuan,(0):112 ~ 122.

Zhou Chaoxian, Wei Chunsheng, Li Chaoyang. 1998&. Lower Sinian igneous rock suits along the southwestern margin of the Yangtze block. Acta Mineralogica Sinica,18(4):401 ~ 410.

Zhou Meifu,Kennedy A K,Sun Min,Malpas J,and Lesher C M. 2002. Neoproterozoic arc-related mafic intrusions along the Northern Margin of South China: Implications for the accretion of Rodinia. The Journal of Geology,110(5):611 ~ 618.

Zhou Meifu,Ma Yuxiao,Yan Danping,Xia Xiaoping,Zhao Junhong,and Sun Min. 2006. The Yanbian Terrane(Southern Sichuan Province, SW China):A Neoproterozoic arc assemblage in the western margin of the Yangtze Block. Precambrian Research,144:19 ~ 38.

Zhuo Jiewen, Jiang Xinsheng, Wang Jian, Cui Xiaozhuang, Xiong Guoqing,Lu Junze,Liu Jianhui,Ma Mingzhu. 2013&. Opening time and filling pattern of the Neoproterozoic Kangdian Rift Basin,western Yangtze Continent,South China. Science China: Earth Sciences,56(10):1664 ~ 1676.

Zhuo Jiewen,Jiang Xinsheng,Wang Jian,Cui Xiaozhuang,Wu Hao,Xiong Guoqing,Lu Junze,Jiang Zhuofei. 2015&. Zircon SHRIMP U-Pb age of sedimentary tuff at the bottom of Neoproterozoic Kaijiangqiao Formation in western Sichuan,and its geological implication. Journal of Mineralogy and Petrology,35(1):91 ~ 99.

# SHRIMP Zircon U-Pb Ages for the Stratotype Section of Neoproterozoic Suxiong Formation in Western Sichuan Province and Their Geological Significance

ZHUO Jiewen[1, 2], JIANG Zhuofei[1, 2], JIANG Xinsheng[1, 2], WANG Jian[1, 2], CAI Juanjuan[3], XIONG Guoqing[1, 2], LU Junze[1, 2], CUI Xiaozhuang[1, 2], LIU Jianhui[4]

1) *Chengdu Center, China Geological Survey, Chengdu*, 610081;

2) *Key Laboratory for Sedimentary Basin and Oil and Gas Resources, Ministry of Land and Resources, Chengdu*, 610081;

3) *Graduate Faculty of Chinese Academy of Geological Science, Beijing*, 100037;

4) *Beijing SHRIMP Center, Beijing*, 102206

**Objectives**: The age and tectonic setting of extensive Neoproterozoic volcanic activities around the margin of Yangtze Block were of great significance for reconstructing the position of South China Block in the Rodinia supercontinent. At present, only a few precise ages were obtained from the volcaniclastics of Suxiong Formation in the western margin of Yangtze Block. Therefore, a dacite sample for the stratoype section was collected from Suxiong Formation, with the purpose of determinating the high-precise age in western Sichuan province.

**Methods**: The zircon SHRIMP U-Pb analysis was used to determinate the age of the dacite sample from the Suxiong Formation, which was carried out by SHRIMP Ⅱ in Beijing SHRIMP Center, Chinese Academy of Geological Sciences.

**Results**: Two precise ages of 838 ± 9 Ma and 780 ± 12 Ma were obtained.

**Conclusions**: Among them, the younger one, 780 ± 12 Ma, was interpreted as the eruption age of the dacite sample, which could represented the tectonic—magma event of the Kangdian rift basin during the period of strong extension, and the older one, 838 ± 9 Ma, represented the tectonic—magma event before the opening of the Kangdian rift basin. Through the comprehensive analysis, the Suxiong Formation was regarded as the product of episodic magmatic activity, locating at the accommodation zones of the Kangdian half graben. Consequently, a series of rift basins, which were related to the mantle plume that led to the breakup of Rodinia supercontinent, should be developed around the margin of Yangtze Block, while the South China Block could be a member of Rodinia supercontinent breakup, through the analysis of volcanic activities and sedimentary records.

**Keywords**: Suxiong Formation; dacite; SHRIMP zircon U-Pb age; Neoproterozoic; tectonic—magma event

**Acknowledgements**: This study was financially supported by the Natural Science Foundation of China (No. 41672112, 41030315, 41502114) and Chinese Geological Survey (No. DD20160017, 12120114067901, 1212011121105). We thank Prof. Min Jikun for help with her lithologic expertise, Prof. Su Junzhou for help with zircon separation, and the experts in the Beijing SHRIMP center for help with CL images and SHRIMP U-Pb isopote analysis. Thanks are also given to the anonymous reviewers who have given us very precious comments, suggestions and corrections that greatly improved our paper.

**First author**: ZHUO Jiewen, male, born in 1980, doctor, senior engineer, mainly engaged in sedimentology and tectonics. Email: zhuojiewen_1980@163.com

Manuscript received on: 2015-08-03; Accepted on: 2016-08-15; Edited by: ZHANG Yuxu.

**Doi**: 10.16509/j.georeview.2017.01.016