四川乐山震旦系灯影组火山碎屑岩锆石 LA-ICP-MS U-Pb 定年及盆地裂陷演化讨论

资金平[1)],贾东[1)],魏国齐[2)],杨振宇[3)],张勇[1)],胡晶[1)],沈淑鑫[1)]

1) 南京大学内生金属矿床成矿机制研究国家重点实验室,南京,210023;

2) 中国石油勘探开发研究院廊坊分院,河北廊坊,065007; 3) 首都师范大学,北京,100048

内容提要: 四川盆地中部晚震旦(埃迪卡拉)世—早寒武世克拉通内裂陷与安岳震旦(埃迪卡拉)系—寒武系特大气田的形成关系密切,年代学研究对认识克拉通内裂陷构造意义重大。对四川盆地乐山先锋剖面灯影组三段火山碎屑岩进行锆石 LA-ICP-MS U-Pb 定年,研究结果表明四川盆地灯影组三段火山碎屑岩的锆石 U-Pb 年龄为(539.6±1.4) Ma,年代学结果表明四川盆地灯三段与灯四段属于寒武系。基于灯影组底界(551.1 Ma)、含火山碎屑岩的灯三段(539.6 Ma)、含小壳化石的麦地坪组(535.2 Ma)和下寒武统 Ni—Mo 多金属硫化物富集层(521.0 Ma)四个等时面构建了克拉通内裂陷演化的时间框架。在此基础上认为四川盆地中部晚震旦(埃迪卡拉)世—早寒武世隆坳构造的形成主要受边界断裂控制,断层活动使裂陷内水体加深,少量灯四段含硅质白云岩沉积后,麦地坪组与筇竹寺组开始沉积,麦地坪组与灯四段的界线在裂陷内与裂陷两侧并不等时,裂陷内麦地坪组、筇竹寺组与裂陷两侧灯影组四段为同期异相沉积。

关键词: 四川盆地; 寒武纪; 震旦(埃迪卡拉)纪; 灯影组; 锆石定年; 克拉通内裂陷

四川盆地油气储量丰富,开采潜力巨大(王世谦等, 2005; 李世臻等, 2013; 何洪春等, 2015; 邹才能等, 2015)。2011年7月,川中高石1井在寒武系龙王庙组与震旦(埃迪卡拉)系灯影组取得重大勘探突破(杜金虎等, 2014)。位于四川盆地中部呈近南北向展布的隆坳构造格局是形成区域有利勘探条件的关键因素。钻井与地震剖面资料显示,坳陷内震旦系灯影组三段与灯影组四段厚度远小于坳陷两侧,而麦地坪组与筇竹寺组厚度远大于坳陷两侧。目前对该隆坳构造格局的成因尚存在多种解释方案,汪泽成等(2014)认为震旦纪末期桐湾运动Ⅱ幕区域逆冲—褶皱隆升、剥蚀作用以及早寒武世拉张背景是形成隆坳格局的关键。李忠权等(2015)认为早寒武世地壳差异抬升运动,河流下切侵蚀和溶蚀作用是坳陷内灯三段与灯四段厚度薄的关键,随后坳陷内沉积充填了厚层的下寒武统麦地坪组和筇竹寺组。魏国齐等(2015)提出隆坳构造为震旦纪—早寒武世克拉通内裂陷,认为灯三段、灯四段沉积期,裂陷内呈现欠补偿沉积环境,仅沉积了薄层灯三段碎屑岩与灯四段含硅质白云岩。

明确隆坳构造格局的成因机制对研究四川盆地深部油气勘探方向具有十分重要的意义。普遍含火山碎屑岩的灯三段为四川盆地灯影组对比的重要标志层(邓胜徽等, 2015),亦是隆坳构造格局的关键层位。本文对四川乐山先锋剖面灯影组三段火山碎屑岩进行锆石 LA-ICP-MS U-Pb 定年,以期对隆坳构造格局增添新的认识。

1 区域地质背景

震旦纪至早寒武世,华南扬子地块具有自西北向东南水体总体加深的趋势(Zhu Maoyan et al., 2003; Steiner et al., 2007)。古地理可依次划分为内部台地带、过渡带和斜坡至深水盆地带,界线沿北东—南西展布。沉积环境差异引起区域沉积发生相变,晚震旦世浅水台地相区以沉积碳酸盐岩为主,而在水体加深的过渡带和斜坡至深水盆地带则普遍沉积碳质硅质岩。进入寒武纪,扬子地块普遍沉积了一套黑色页岩(陈南生等, 1982),上扬子地区该套

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作者简介:资金平,男,1991年生。硕士研究生,构造地质学专业。zijinping@qq.com。通讯作者:贾东,男,1960年生。博士,教授,主要从事构造地质学研究。Email: djia@nju.edu.cn。

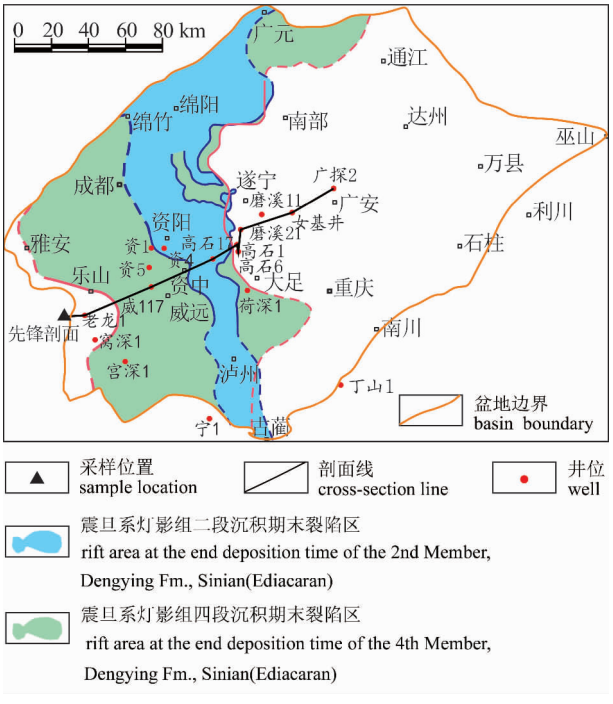


图 1 四川盆地震旦纪(埃迪卡拉纪)灯影组二段沉积期末和灯影组四段沉积期末裂陷分布范围图(据魏国齐等,2015 修改)

Fig. 1 The rift areas at the end deposition time of the Second and the Fourth Member of the Sinian (Ediacaran) Dengying Formation((modified after Wei Guoqi et al., 2015&)

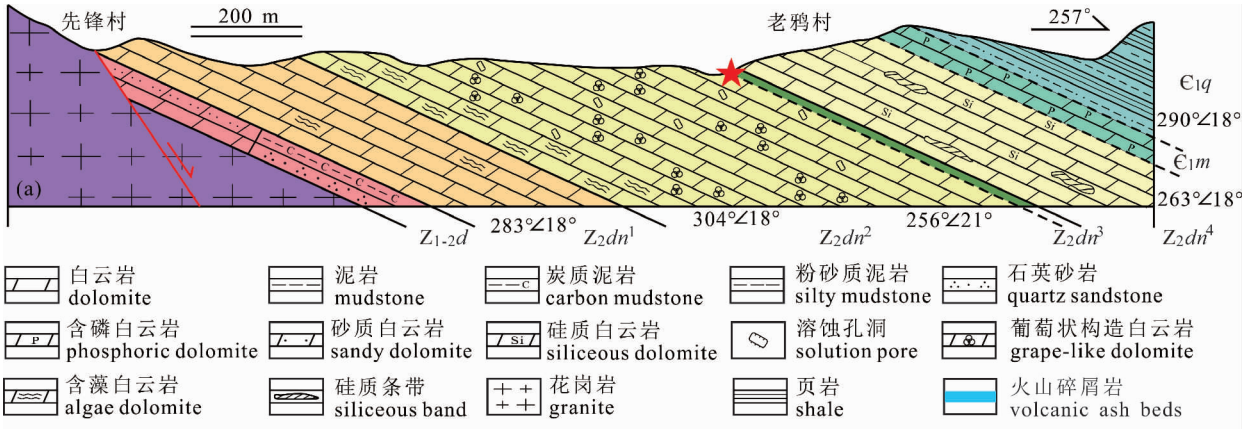
黑色页岩底部或之下为一套富磷地层(陈志明等,1987;牟南等,2005;毛铁等,2015)。四川盆地位于扬子地块西部的内部台地带,晚震旦世—早寒武世水体较浅,自下而上地层沉积了以白云岩为主的灯影组、以含磷白云岩为主的麦地坪组、以黑色碳质页岩为特征的筇竹寺组、下部碎屑岩段上部碳酸盐岩段的沧浪铺组以及龙王庙组海相碳酸盐岩。

扬子地块震旦系上统与下统界线位于陡山沱组内部(Zhu Maoyan et al., 2007;刘鹏举等,2012;全国地层委员会《中国地层表》编委会,2014)。邓胜徽等(2015)将四川盆地震旦系上统灯影组自下而上划分为四个岩性段:以贫菌藻类白云岩为特征的灯一段;以下部富含菌藻类、上部贫菌藻类白云岩为特征的灯二段;岩性为碎屑岩,常夹火山碎屑岩层的灯三段;以硅质条带为特征的灯四段。罗贝维等(2013a,b)研究指出,四川盆地灯影组沉积期,海水温度介于 15 ~ 30℃,灯一段沉积期海平面逐渐上升;灯二段沉积期海平面明显降低且整体处于动荡的海退环境;灯三段沉积期,发生了一次范围大、时间短的海侵事件;灯四段沉积期,海平面逐渐降低,并在后期存在持续震荡的过程。

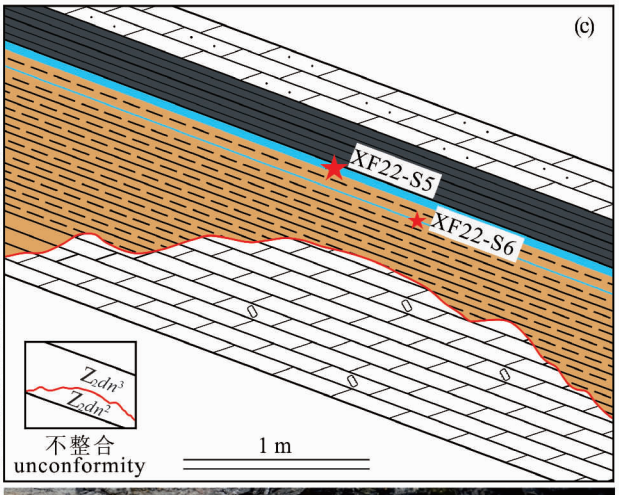
震旦纪末至早寒武世的桐湾运动与川中隆坳构造格局的形成关系紧密(汪泽成等,2014;武赛军等,2016)。三幕桐湾运动引起的区域抬升与剥蚀分别形成了四川盆地灯影组三段与二段之间、下寒武统麦地坪组与灯影组四段之间以及筇竹寺组与麦地坪组之间的普遍假整合,也使灯影组二段与四段发育大量溶蚀孔洞,成为优质储层(汪泽成等,2014)。而在区域上,同一幕运动在整体幕式隆升的背景下,局部地区存在差异升降(武赛军等,2016)。

川中隆坳构造格局呈南北向展布,东部边界陡,西部边界缓(图 1)。坳陷内震旦系—下寒武统沉积存在以下三个特点:①通过钻井标定后的地震解释预测坳陷内灯二段厚度略小于坳陷东西两侧灯二段厚度,位于坳陷东侧的高石 1 井灯二段厚度约为 486.8 m;②灯三段碎屑岩、灯四段白云岩厚度薄,以高石 17 井为例,灯三段厚度约 2.0 m,灯四段厚度约 15.0 m;坳陷东侧高石 1 井,灯四段厚 262.5 m;③坳陷内麦地坪组和筇竹寺组黑色页岩和浅灰色泥岩累计厚度介于 500 ~ 700 m,大于东西两侧约 300 ~ 500 m(魏国齐等,2015)。隆坳构造的成因目前尚有不同观点(汪泽成等,2014;李忠权等,2015;魏国齐等,2015),关键层位的年代学约束至关重要。

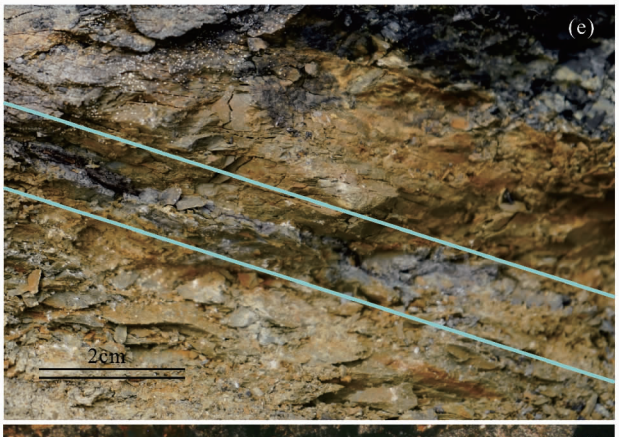
谷志东等(2015)获得四川盆地威远地区威 117 井基底花岗岩锆石 SHRIMP U-Pb 年龄为(794 ± 11) Ma,指示了区域基底结晶时间。Condon 等(2005)获得湖北宜昌峡东震旦系陡山沱组底部与顶部凝灰岩的高精度锆石 U-Pb 年龄分别为(635.2 ± 0.6) Ma 和(551.1 ± 0.7) Ma,以上两个年龄约束了扬子地块陡山沱组与灯影组的起始沉积时间。麦地坪组为四川盆地小壳化石的首现层位(陈孟羲,1982),朱日祥等(2009)获得云南梅树村剖面小壳化石首现层位附近凝灰岩(即第 5 层)年龄为(535.2 ± 1.7) Ma,该年龄亦可大致约束四川盆地麦地坪组的沉积时间。Compston 等(2008)获得四川乐山范店剖面筇竹寺组底部凝灰岩锆石 SHRIMP U-Pb 年龄(526.5 ± 1.1) Ma,该年龄约束了区域筇竹寺组的沉积时间。华南扬子地块下寒武统具一 Ni、Mo、PGE 和 Au 等多金属硫化物富集层,延伸长度可达 1600 km,Zhu Maoyan 等(2003)提出将其作为华南下寒武统划分与对比的地球化学标志层。在四川盆地,该富集层在四川盆地筇竹寺组(或郭家坝组)底

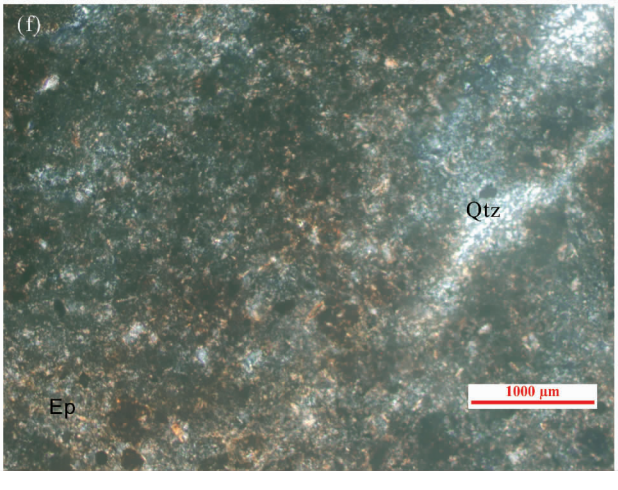

先锋村
200 m
老鸦村
257°
$\in_1 q$
290°∠18°
$\in_1 m$
263°∠18°
(a)
$Z_{1\text{-}2}d$
283°∠18°
Z_2dn^1
304°∠18°
Z_2dn^2
256°∠21°
Z_2dn^3
Z_2dn^4
白云岩 dolomite
泥岩 mudstone
炭质泥岩 carbon mudstone
粉砂质泥岩 silty mudstone
石英砂岩 quartz sandstone
含磷白云岩 phosphoric dolomite
砂质白云岩 sandy dolomite
硅质白云岩 siliceous dolomite
溶蚀孔洞 solution pore
葡萄状构造白云岩 grape-like dolomite
含藻白云岩 algae dolomite
硅质条带 siliceous band
花岗岩 granite
页岩 shale
火山碎屑岩 volcanic ash beds


(b)


(c)
XF22-S5
XF22-S6
Z_2dn^3
Z_2dn^3
不整合
unconformity
1 m


(d)


(e)
2cm


(f)
Qtz
Ep
1000 μm

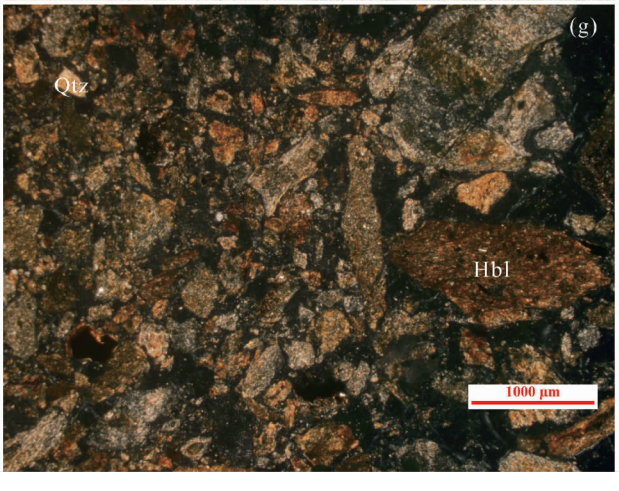

(g)
Qtz
Hbl
1000 μm

图 2 四川乐山先锋剖面图及部分野外露头照片

Fig. 2 Geological sketch map of the Xianfeng Section in Leshan, Sichuan and some photo of sampling layers

(a)四川乐山先锋剖面图;(b)采样位置示意图。左图为采样层位露头,右图为采样层位露头素描图;(c)样品 XF22-S5 采样露头照片;(d)样品 XF22-S6 采样露头照片;(e)样品 XF22-S5 显微镜下照片;矿物颗粒极细,能识别石英(Qtz)、绿帘石(Ep)等矿物。(f)样品 XF22-S6 显微镜下照片。火山碎屑结构,岩屑与晶屑含量超过 80%,矿物含角闪石(Hbl)、石英(Qtz)等

(a) Geological sketch map of the Xianfeng Section in Leshan, Sichuan province; (b) Photo showing the sampling site and the sketch map is in the right; (c) Photo showing the sampling layer of the Sample XF22-S5; (d) Photo showing the sampling layer of the Sample XF22-S6; (e) Photomicrograph of the Sample XF22-S5, the grains are small, the quartz and epidote are recognized; (f) Photomicrograph of the Sample XF22-S6, Hornblende, quartz and pyroclastic texture are recognized, debris weighted more than 80 percent

部亦有沉积记录(Guo Qingjun et al., 2007)。Xu Lingang 等(2011)获得该 Ni—Mo 多金属硫化物富集层年龄为(521 ±5) Ma。

先锋剖面位于四川省乐山市峨边县北东向约 20 km 的先锋村与老鸦村之间(图 1),是四川盆地灯影组的典型剖面,位于坳陷西侧。前人对先锋剖面进行了丰富的岩石地层学、同位素化学地层学和同位素年代学研究并应用于古环境恢复、四川盆地及周缘地区地层对比和古地理重建(罗贝维等, 2013b; 邓胜徽等, 2015; 刘静江等, 2015)。研究区陡山沱组($Z_{1-2}d$)直接覆盖于前震旦花岗岩基底之上,灯影组与陡山沱组碎屑岩整合接触,下寒武统麦地坪组($\epsilon_1 m$)与灯影组接触关系为平行不整合(图 2a)。剖面灯二段与灯三段之间见有起伏不平的不整合面(图 2b)。我们于先锋剖面靠近灯三段底部位置发现两层火山碎屑岩,前者厚度约 3 cm,后者厚度不足 1 cm,层位相距约 6 cm(图 2b、c、d)。分别取样标记为 XF22-S5 与 XF22-S6 以进行锆石 U-Pb 年代学研究,采样过程中严格避免围岩污染。

2　分析方法与实验结果

用常规的重液和磁选方法分选样品中的锆石,锆石挑选完成后在双目镜下将挑选的锆石粘在双面胶上,用环氧树脂与三乙醇胺(7 ∶ 1)的混合胶固结,在 60℃恒温状态下固化;并用 7000 目砂纸将锆石打磨直至大部分锆石暴露出内部晶面;对待测锆石做透射光、反射光和阴极发光(CL)图像分析(图 3),以确定锆石形态,揭示锆石内部结构并帮助选定最佳的锆石分析位置。锆石定年分析在南京大学内生金属矿床成矿机制研究国家重点实验室完成,仪器为美国 Agilent 公司的 7500a 型四极杆电感耦合等离子体质谱仪(ICP-MS)。激光剥蚀系统采用美国 New Wave 公司的 UP-213 Laser Ablation System 固体激光器,激光束斑直径为 24 μm。测试分析标样为 GJ-1(608.5 ±1.5 Ma)和 Mud Tank(732 ±5 Ma)(Jackson et al., 2004)。单点分析的同位素比值及年龄误差为 1σ,加权平均年龄误差为 95% 置信度。运用 GLITTER 4.4.1 软件包计算各测点的 U-Pb 年龄,测试原理、数据处理和铅校正方法详见 Griffin 等(2004)。数据处理采用 Isoplot/Ex v.4.15 软件(Ludwig, 2008)。

挑选样品 XF22-S5 中 31 颗与样品 XF22-S6 中 9 颗晶形完整、岩浆生长环带清晰的锆石进行 U-Pb 同位素年龄分析。所分析的锆石 Pb 含量介于 32 ~ 343μg/g,U 含量介于 51 ~ 1239 μg/g,Th 含量介于 62 ~ 1110 μg/g,Th/U 比值介于 0.59 ~ 2.79,平均值 1.28。

40 个分析点共获得 38 个谐和年龄(图 4),有

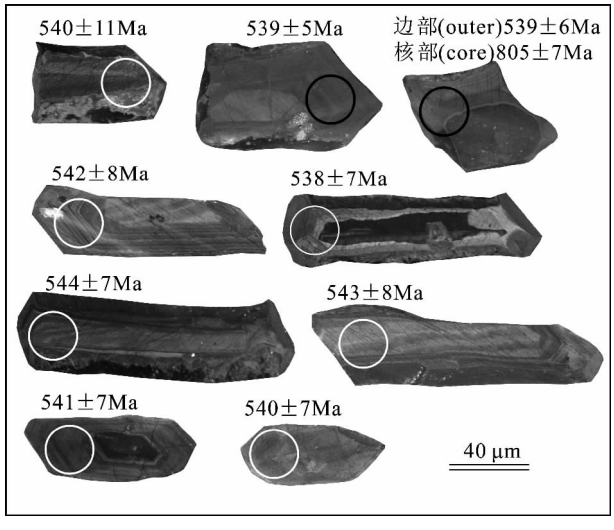


图 3 先锋剖面灯三段火山碎屑岩层的代表性锆石阴极发光(CL)图像

Fig. 3 CL image of typical zircons from volcanic ash beds in the Third Member of the Dengying Formation in the Xianfeng Section

图中白色圆圈表示样品 XF22-S5 锆石定年分析位置,黑色圆圈表示样品 XF22-S6 锆石定年分析位置

The white circles mean analysis locations of zircons from the Sample XF22-S5, the black circles mean analysis locations of zircons from the Sample XF22-S6

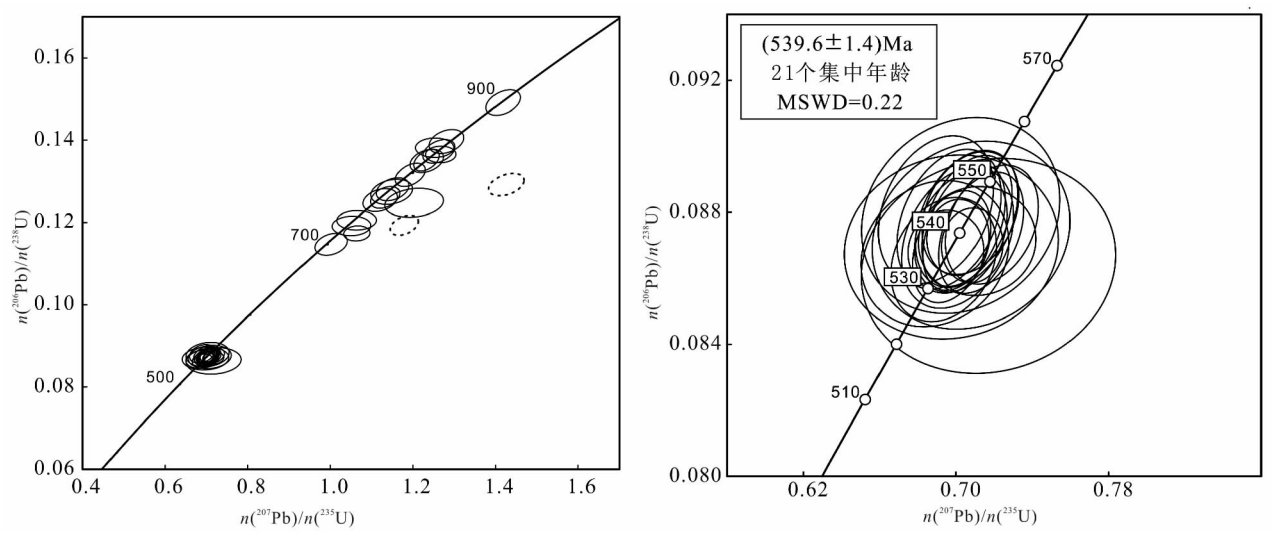


图 4 先锋剖面灯三段火山碎屑岩层的锆石 LA-ICP-MS U-Pb 年龄分析结果

Fig. 4 LA-ICP-MS U-Pb dating result of zircons from volcanic ash beds in the Third Member of the Dengying Formation in the Xianfeng Section

两个不谐和年龄,这可能是 Pb 丢失的结果,大部分锆石颗粒形成后 U-Pb 同位素体系保持封闭。样品 XF22-S5 中 17 个最年轻年龄与样品 XF22-S6 中 4 个最年轻年龄一致,本文对其进行合并分析(表 1)。21 个年龄集中分析点的谐和年龄为(539.6 ± 1.4) Ma(图 4),加权平均年龄为(539.4 ± 3.0) Ma(图 5)。根据锆石的形态、Th/U 比值和 CL 图像特征,我们将这 21 个分析点的 U-Pb 谐和年龄(539.6 ± 1.4) Ma 解释为灯三段火山碎屑岩层的锆石结晶年龄。

XF22-S6-5 具有核幔构造,边部年龄(539 ± 5) Ma,揭示了锆石结晶年龄,内部年龄为(805 ± 7) Ma。除 21 个集中年龄外,17 个谐和年龄分布在 700 ~ 900 Ma 之间,与扬子地块中广泛存在的 0.75 ~ 0.83 Ga 新元古代岩浆岩年龄基本一致(Li ZX et al., 2003),推测为捕获锆石。

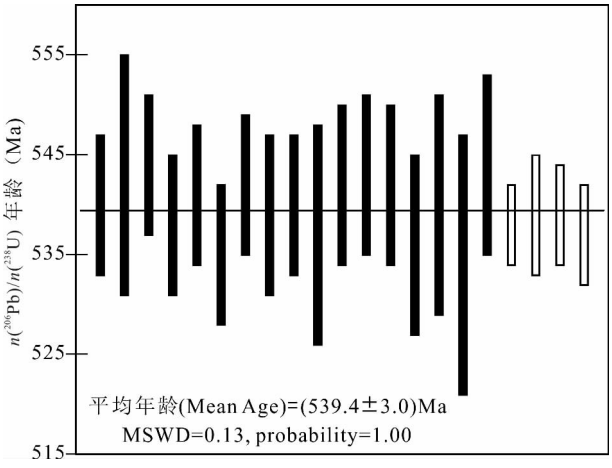


图 5 先锋剖面灯三段火山碎屑岩层的锆石 $^{206}Pb/^{238}U$ 年龄加权平均计算结果

Fig. 5 Weighted mean $^{206}Pb/^{238}U$ dating result of zircons from volcanic ash beds in the Third Member of the Dengying Formation in the Xianfeng Section

实心符号表示样品 XF22-S5,
空心符号表示样品 XF22-S6

The filled symbol means ages from the Sample XF22-S5, and the other means ages from the Sample XF22-S6

3 讨论

3.1 四川盆地灯三段火山碎屑岩层年龄及意义

本文获得四川盆地灯三段火山碎屑岩层的锆石 LA-ICP-MS U-Pb 年龄为(539.6 ± 1.4) Ma,接近全球寒武纪底界年龄(541 ± 1) Ma,指示了采样层位位于震旦纪—寒武纪界线附近。近期,Chen Daizhao 等(2015)获得贵州铜仁坝黄剖面、湖南张家界柑子坪剖面留茶坡组凝灰岩夹层的锆石 SHRIMP 年龄分别为(542.6 ± 3.7) Ma 和(542.1 ± 5.0) Ma,与本文所获年龄在误差范围内是一致的,指示着四川盆地灯三段的火山碎屑岩层在扬子地块分布广泛。

年代学研究成果表明灯三段火山碎屑岩层的锆石 U-Pb 年龄将四川盆地震旦系—寒武系界线约束在灯三段附近。灯三段层位低于小壳化石首现层位麦地坪组约 200 m,与寒武系全球界线层型纽芬兰

剖面相类似。全球前寒武系—寒武系界线定义于纽芬兰剖面遗迹化石 *T. pedum* 首现层位(Brasier et al., 1994),该位置距小壳化石首现点亦有约 150 m 的寒武纪地层。

3.2　对四川盆地震旦纪—早寒武世克拉通内裂陷的新认识

前人对四川盆地震旦纪—早寒武世隆坳构造格局形成机制存在的分歧在于解释坳陷内与坳陷两侧灯三段与灯四段、麦地坪组与筇竹寺组的分布特征。李忠权等(2015)将隆坳构造定义为拉张侵蚀槽;魏国齐等(2015)提出隆坳构造为震旦纪—早寒武世克拉通内裂陷,认为灯三段和灯四段沉积期,裂陷内水体较深,欠补偿沉积环境使得裂陷内仅沉积了少量灯三段与灯四段,并绘制了灯二段沉积期末与灯四段沉积期末的裂陷范围(图 1)。杜金虎等(2016)基于深层地震资料发现,裂陷分布受断裂控制,裂陷内部及两侧发育 NW 向为主的张性断层,其中灯影组三段底界断距最大在 400 ~ 500 m,向上至沧浪铺组断距减小,多数断层消失在龙王庙组。以上资料表明,断层的主要活动时间在灯影组沉积期至沧浪铺组沉积期。

基于本文年代学结果我们将研究区震旦系—寒武系界线置于灯影组三段,并以灯影组底界(551.1 ±0.7 Ma)(Condon et al., 2005)、含火山碎屑岩的灯三段(539.6 ±1.4 Ma)(本文)、小壳化石首现层位麦地坪组(535.2 ±1.7 Ma)(朱日祥等, 2009)和扬子地块下寒武统 Ni—Mo 多金属硫化物富集层(521 ±5 Ma)(Xu Lingang et al., 2011)构建了四个等时面以对裂陷进行系统的分析(图 6)。我们认为受边界断裂活动影响,裂陷内水体加深,同期异相沉积是裂陷内与裂陷两侧下寒武统分布差异的关键所在。桐湾运动Ⅰ幕结束后,研究区继续接受灯影组沉积,在边界断裂活动的影响下,裂陷内沉积了约 17 m 厚灯三段与灯四段后即开始沉积深水陆棚相的麦地坪组泥页岩,此时裂陷两侧台缘地区尚还在沉积灯四段含硅质白云岩,我们推测含小壳化石的

表 1 四川乐山先锋剖面灯影组三段火山碎屑岩层的岩浆锆石 U-Pb 同位素年龄分析结果

Table 1 U-Pb isotopic data of the zircons from the volcaniclastic beds of the Third Member, Dengying Formation, in the Xianfeng section, Leshan, Sichuan

测点号	元素含量(×10⁻⁶)			Th/U	同位素比值						同位素年龄(Ma)			谐和度(%)
	Pb	Th	U		$\frac{n(^{207}Pb)}{n(^{206}Pb)}$		$\frac{n(^{207}Pb)}{n(^{235}U)}$		$\frac{n(^{206}Pb)}{n(^{238}U)}$		$\frac{n(^{207}Pb)}{n(^{206}Pb)}$	$\frac{n(^{207}Pb)}{n(^{235}U)}$	$\frac{n(^{206}Pb)}{n(^{238}U)}$	
					测值	±%	测值	±%	测值	±%	测值 ±1σ	测值 ±1σ	测值 ±1σ	
XF22-S5-1	338	845	726	1.16	0.0592	2.0	0.7132	2.1	0.0874	1.4	575 ±44	547 ±9	540 ±7	101
XF22-S5-2	104	302	236	1.28	0.0581	5.0	0.7025	4.9	0.0879	2.2	532 ±113	540 ±20	543 ±12	99
XF22-S5-3	184	368	376	0.98	0.0584	2.4	0.7076	2.4	0.0880	1.4	545 ±53	543 ±10	544 ±7	100
XF22-S5-4	202	328	416	0.79	0.0582	1.9	0.6977	1.9	0.0870	1.3	538 ±43	537 ±8	538 ±7	100
XF22-S5-5	285	563	658	0.86	0.0584	1.9	0.7043	2.0	0.0875	1.4	543 ±47	541 ±8	541 ±7	100
XF22-S5-6	151	376	293	1.28	0.0581	2.7	0.6935	2.6	0.0866	1.4	534 ±60	535 ±11	535 ±7	100
XF22-S5-7	80	133	165	0.81	0.0595	2.2	0.7188	2.2	0.0876	1.4	586 ±50	550 ±9	542 ±7	101
XF22-S5-8	321	636	767	0.83	0.0583	2.7	0.7008	2.8	0.0872	1.6	540 ±61	539 ±12	539 ±8	100
XF22-S5-9	131	199	277	0.72	0.0583	2.3	0.7026	2.3	0.0874	1.4	541 ±51	540 ±10	540 ±7	100
XF22-S5-10	32	64	63	1.01	0.0582	5.5	0.6977	5.3	0.0870	2.1	538 ±125	537 ±22	537 ±11	100
XF22-S5-11	95	156	224	0.70	0.0602	6.4	0.7171	6.1	0.0864	2.5	611 ±142	549 ±26	534 ±13	103
XF22-S5-12	249	637	576	1.11	0.0584	2.1	0.7058	2.2	0.0877	1.5	543 ±47	542 ±9	542 ±8	100
XF22-S5-13	170	297	419	0.71	0.0583	2.4	0.7056	2.5	0.0878	1.6	541 ±55	542 ±11	543 ±8	100
XF22-S5-14	250	647	600	1.08	0.0575	2.5	0.6963	2.6	0.0878	1.6	512 ±57	537 ±11	542 ±8	99
XF22-S5-15	65	143	129	1.11	0.0576	3.8	0.6890	3.7	0.0868	1.7	515 ±86	532 ±15	536 ±9	99
XF22-S5-16	270	520	621	0.84	0.0588	5.0	0.7080	4.8	0.0873	2.2	561 ±111	544 ±20	540 ±11	101
XF22-S5-17	328	1017	732	1.39	0.0568	2.9	0.6895	2.9	0.0881	1.7	483 ±65	533 ±12	544 ±9	98
XF22-S6-1	343	961	773	1.24	0.0591	1.8	0.7085	1.5	0.0870	0.9	570 ±39	544 ±6	538 ±4	101
XF22-S6-2	129	237	335	0.71	0.0592	3.1	0.7111	2.9	0.0871	1.3	575 ±68	545 ±12	539 ±6	101
XF22-S6-3	319	834	737	1.13	0.0583	1.8	0.7010	1.5	0.0872	0.9	540 ±40	539 ±6	539 ±5	100
XF22-S6-4	145	417	334	1.25	0.0581	2.1	0.6947	1.9	0.0868	1.0	532 ±48	536 ±8	537 ±5	100

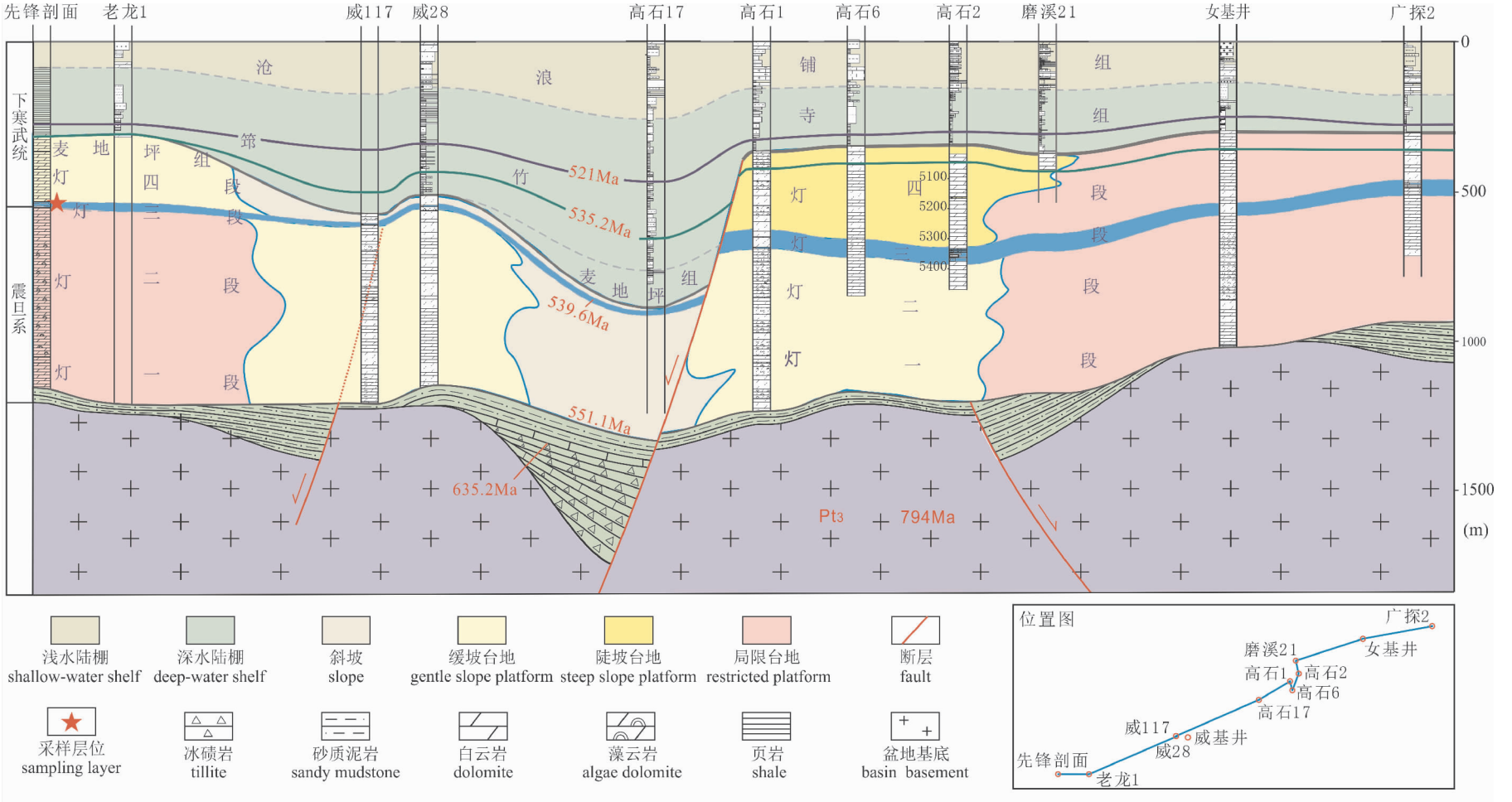


图6 过四川盆地中部克拉通内裂陷连井剖面图（龙王庙组底界拉平，剖面位置见图1，修改自魏国齐等，2015）

Fig. 6 Well-tie Section across the intracratonic rift in the Middle Sichuan Basin (the bottom of the Longwangmiao Formation is leveled, the position of this section is shown in Fig. 1, modified after Weiguoqi et al., 2015&)

麦地坪组沉积等时面在裂陷内位于筇竹寺组内部,表征裂陷内麦地坪组、筇竹寺组与裂陷两侧灯四段为同期异相沉积(图 6)。Ni—Mo 硫化物富集层位于四川盆地筇竹寺组(或郭家坝组)底部,在裂陷内该界线位于筇竹寺组中部。等时面之间的地层厚度变化表现出同构造沉积特征。

4　结论

(1)对来自四川乐山先锋剖面灯影组三段的火山碎屑岩进行锆石 LA-ICP-MS U-Pb 定年,获得谐和年龄为(539.6 ± 1.4) Ma,年代学结果表明四川盆地灯影组三段和灯影组四段属于寒武系。

(2)基于灯影组底界、含火山碎屑岩的灯影组三段、含小壳化石的麦地坪组和下寒武统 Ni—Mo 多金属硫化物富集层四个等时面构建了克拉通内裂陷的时间框架。在此基础上认为四川盆地中部晚震旦(埃迪卡拉)世—早寒武世隆坳构造的形成主要受边界断裂控制,断层活动使裂陷内水体加深,少量灯影组四段含硅质白云岩沉积后,麦地坪组与筇竹寺组开始沉积,麦地坪组与灯影组四段的界线在裂陷内与裂陷两侧并不等时,裂陷内麦地坪组、筇竹寺组与裂陷两侧灯影组四段为同期异相沉积。

致谢:衷心感谢西南油气田杨西南工程师在野外工作中给予的指导,感谢南京大学王孝磊教授、武兵工程师在锆石测年实验中给予的热情帮助。

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LA-ICP-MS U-Pb Zircon Ages of Volcaniclastic Beds of the Third Member of the Sinian(Ediacaran) Dengying Formation in Leshan, Sichuan, and a Discussion on the Rift Evolution in the Basin

ZI Jinping[1)], JIA Dong[1)], WEI Guoqi[2)], YANG Zhenyu[3)], ZHANG Yong[1)], HU Jing[1)], SHEN Shuxin[1)]

1) *State Key Laboratory for Mineral Deposit Research*, *Nanjing University*, *Nanjing*, 210023;

2) *Research Institute of Petroleum Exploration and Development*, *Langfang Branch*, *PetroChina*, *Langfang*, *Hebei*, 065007;

3) *College of Resources*, *Environment and Tourism*, *Capital Normal University*, *Beijing*, 100048

Abstract: The late-Sinian(Ediacaran) to early-Cambrian intracratonic rift in central Sichuan basin has a close relationship with the formation of Anyue Sinian(Ediacaran)—Cambrian giant gas field. geochronology study of the Dengying Formation is significant in understanding the evolution of the intracratonic rift. LA-ICP-MS U-Pb analysis of volcanic ash beds in the Third Member of the Dengying Formation at the Xianfeng Section, Sichuan, Southwest China yield a highly reliable Concordia age of 539.6 ± 1.4 Ma(MSWD = 0.22), suggesting a lower placement of the Precambrian—Cambrian boundary in the Sichuan Basin. We eatablished a evolution time frame of this intracratonic rift based on four isochronous strata, the bottom of the Dengying Formation(551.1 Ma), the Third Member of Dengying Formation(539.6 Ma), the Maidiping Formation(535.2 Ma) and the Ni—Mo sulfide enriched layer in the lower Cambrian(521 Ma). The boundary of the Maidiping Formation and the Dengying Formation inside and outside the rift is not synchronous. According to those, we propose that the formation of the late-Sinian(Ediacaran) to early-Cambrian intracratonic rift in central Sichuan Basin was mainly controlled by the boundary fault. Due to the deep-water depositional environment in the rift, the Maidiping Formation began to deposit rapidly after the deposition of the thin Third and Fourth Member of the Dengying Formation, the Maidiping Formation and the Qiongzusi Formation inside the rift and the Fourth Member of the Dengying Formation outside the rift are contemporary heteropical sediments.

Keywords: Sichuan Basin; Cambrian; Sinian(Ediacaran); the Dengying Formation; U-Pb geochronology; intracratonic rift

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First author: ZI Jinping, Male, Born in Hengyang city, Hunan Province. Now studying at School of Earth Sciences and Engineering, Nanjing University for a postgraduate degree, Major is structural geology. Email: zijinping@ qq. com

Corresponding author: JIA Dong, Professor of School of Earth Sciences and Engineering, Nanjing University, Email: djia@ nju. edu. cn

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