

# 南秦岭刘岭群砂岩碎屑锆石 LA-ICP-MS U-Pb 年龄及其构造意义

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**摘要:** 秦岭造山带的构造演化是理解华北与扬子陆块缝合过程的关键, 位于商丹断裂带以南的刘岭群是揭示秦岭造山带晚古生代构造演化历史的重要窗口。采用 LA-ICP-MS 对刘岭群 3 个变质砂岩样品中的碎屑锆石进行了 U-Th-Pb 同位素测定, 获得最年轻的一组年龄区间为 377~395Ma, 主要年龄峰值约为 442Ma、780~850Ma 和 900~970Ma, 表明刘岭群沉积时代可以持续到晚泥盆世, 物质来源于北秦岭构造带。结合刘岭群北侧武关杂岩的最新研究成果可以确定, 刘岭群和武关杂岩共同构成了华北陆块南缘中—晚泥盆世弧前盆地的沉积序列, 暗示古秦岭洋的最终闭合发生在泥盆纪之后, 而华北与扬子陆块碰撞的主缝合线应位于刘岭群的南侧。

**关键词:** 碎屑锆石; LA-ICP-MS U-Pb 年龄; 物质来源; 晚古生代; 古秦岭洋; 刘岭群; 秦岭造山带

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**Abstract:** The tectonic evolution of the Qinling orogen is the key to understanding the assembly of the North China and South China blocks. The Liuling Group in the south of the Shangdan fault can provide an important window for detecting the Late Paleozoic evolutionary process of the Qinling orogen. The LA-ICP-MS U-Pb ages of detrital zircons from three metasandstone samples from the Liuling Group show a age spectrum with major populations at ca. 442Ma and in the range of 780~850Ma and 900~970Ma, with the youngest population being ca. 377~395Ma. These data suggest that the deposition of the Liuling Group might have lasted to the Late Devonian, and sediments were probably derived from the North Qinling tectonic belt. In combination with the recent investigation of the Wuguan complex in the north of the Liuling Group, the authors infer that a Middle to Late Devonian turbidite sequence might have formed in a fore-arc basin on the southern margin of the North China block, and the closure of the Paleo-Qinling ocean might have occurred after Devonian. Hence, the collisional boundary of the North and South China blocks should be located in the south of the Liuling Group.

**Key words:** Detrital zircons; LA-ICP-MS U-Pb ages; material source; Late Paleozoic; Pale-Qinling Ocean; Liuling Group; Qinling orogen

秦岭—桐柏—大别—苏鲁造山带是中亚地区最重要的巨型碰撞造山带之一, 是标志华北与扬子

陆块缝合的区域<sup>[1-4]</sup>。这一巨型造山带自显生宙以来的演化历史可以清晰地划分为早古生代增生造

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山(北秦岭—北桐柏构造带)、中生代碰撞造山(南秦岭—南桐柏—大别—苏鲁构造带)及白垩纪以来的陆内造山过程<sup>[4-6]</sup>。相对于早古生代末的弧陆碰撞和中生代的陆陆碰撞造山事件,晚古生代的地质演化历史最不清晰。分布于商丹断裂带以南的武关杂岩和刘岭群代表早古生代北秦岭和中生代南秦岭之间的晚古生代构造带<sup>[7-8]</sup>,因此对这2个构造单元性质的研究成为解决秦岭造山带晚古生代构造演化历史的关键。最新的研究<sup>[9-10]</sup>表明,武关杂岩是秦岭大陆岛弧与弧前复理石沉积的混合物,时代为晚奥陶世—晚泥盆世。但是,在刘岭群沉积环境、构造归属等关键问题的认识上依然存在较大的分歧,主要有:①古秦岭洋闭合之后形成的前陆盆地沉积<sup>[7-8,10-14]</sup>;②扬子板块北缘被动大陆边缘沉积<sup>[15-19]</sup>;③秦岭古岛弧南侧弧前盆地沉积<sup>[2,20-24]</sup>;④秦岭微板块之上的残留(断陷)盆地沉积<sup>[1,25-26]</sup>。由此可以看出,刘岭群的物质来源是所有争论的关键所在。

研究表明,沉积岩中的副矿物碎屑锆石 U—Th—Pb 同位素体系具有较高的封闭温度,在低级变质作用和风化搬运过程中保持稳定,所以在漫长的地质演化历史中能较好地记录最初的构造热事件。随着锆石微区原位 U—Th—Pb 同位素测定技术的发展,碎屑锆石测年被广泛应用于秦岭造山带及其邻区的研究,例如:限定沉积地层的最大沉积年龄<sup>[6,27]</sup>、示踪沉积物源区<sup>[9,28]</sup>、揭示早期地壳演化<sup>[29-30]</sup>等方面。因此,从沉积盆地碎屑锆石角度来探讨造山作用过程和区域构造演化已成为当今大陆动力学研究的重要组成部分。刘岭群碎屑沉积岩中保存有完整的物源区信息和古生代构造演化的地质记录。本文基于造山作用沉积响应的事实,以出露于丹凤—商南一带的泥盆系刘岭群作为研究重点,采用 LA-ICP-MS 技术对其中的碎屑锆石进行了系统的 U—Pb 年龄研究,以限定其沉积时代,揭示物源区特征,并结合碎屑岩地球化学特征及区域可利用的资料,对其沉积环境和构造意义进行讨论。

## 1 区域地质概况

秦岭造山带西连祁连造山带,东接桐柏—大别造山带,延伸超过 1500 km。该造山带北以洛南—栾川断裂为界,南以勉略—巴山—襄广断裂带为界(图 1-a)。根据板块构造模式,一般以商丹断裂带为界将秦岭造山带的主体分为北秦岭和南秦岭 2 个

构造带<sup>[11-12,15-17]</sup>。北秦岭主要由前寒武纪基底(秦岭群)、新元古代变质沉积岩和变质火山岩(宽坪群)、早古生代变质火山岩系(二郎坪群和丹凤群)及古生代变质程度较低的沉积地层组成,此外还包含有新元古代早期(980~910 Ma)、早古生代(507~400 Ma)和中生代晚期(250~180 Ma)侵入的花岗岩<sup>[32-33]</sup>。南秦岭主要包括弧前增生杂岩(武关杂岩)、新元古代裂谷性质的火山岩系(武当群和耀岭河群)、震旦纪—志留纪被动大陆边缘沉积地层和东秦岭泥盆纪—三叠纪沉积地层。

刘岭群专指分布于马鞍桥—鲢鱼咀韧性剪切带与凤镇—山阳断裂之间的泥盆纪地层(图 1-b),向东可与桐柏山、大别山以北的南湾复理石和佛子岭群相对比。刘岭群主要岩石组合为遭受绿片岩相—角闪岩相变质的砂岩、粉砂岩、泥岩和少量泥质灰岩夹层。根据岩石组合和生物地层特征,自下而上可将刘岭群分为中泥盆世牛耳川组、池沟组、青石垭组和晚泥盆世桐峪寺组<sup>[34]</sup>。其中,池沟组和青石垭组构成了刘岭群的主体,桐峪寺组和牛耳川组仅出露于柞水—山阳地区。牛耳川组主要岩性为灰、灰绿色薄层至中层砂岩、粉砂质板岩及粉砂岩,夹少量白云质灰岩。水平层理发育,并见波状层理。池沟组岩石组合为灰色、深灰色中—薄层砂岩、粉砂岩、钙质粉砂岩、泥岩夹薄层灰岩。该组中下部发育大型交错层理及双向斜层理,与下伏地层牛耳川组整合接触。青石垭组岩石组合分为上、下 2 个岩性段,下部为灰色、深灰色砂岩、粉砂岩与泥岩互层产出,上部为泥岩、钙质粉砂岩与薄层灰岩互层。桐峪寺组主要岩石组合为互层状灰绿色砂岩、泥质粉砂岩和板岩,韵律层发育,其中夹多层薄层灰岩。

## 2 样品及测试方法

### 2.1 样品描述

本文研究的 3 个变质砂岩样品(DF04-4、TYP07-2、XP12-1)由西向东分别取自七里店、小花瓶子和鸡听河(图 1-b),其中样品 DF04-4 和 XP12-1 取自池沟组,样品 TYP07-2 取自青石垭组。这些样品的位置、矿物组合特征及年龄结果见表 1。

样品 DF04-4 为灰黑色二云母石英片岩,呈厚层状夹于变质长石石英砂岩中。主要由白云母、黑

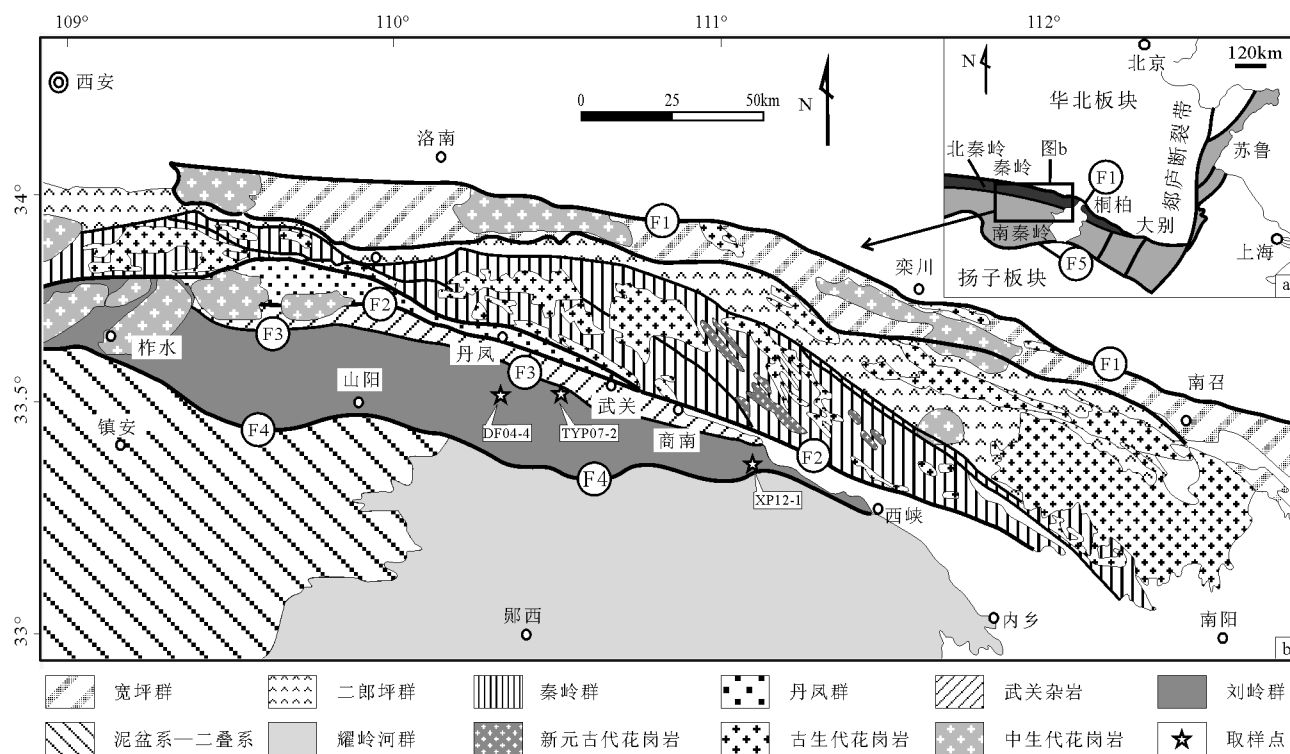


图 1 秦岭—桐柏—大别—苏鲁造山带区域构造简图(a)<sup>[31]</sup>与  
东秦岭造山带地质简图及取样位置(b)<sup>[7]</sup>

Fig. 1 Regional tectonic map of the Qinling-Tongbai-Dabie-Sulu orogenic belt (a) and  
simplified geological map of the eastern Qinling orogenic belt and sampling sites (b)

F1—洛南—栾川断裂带; F2—商丹断裂带; F3—马鞍桥—鲃鱼咀韧性剪切带; F4—丰镇—山阳断裂; F5—勉略—巴山—襄广断裂带

云母和石英组成。白云母和黑云母呈长叶片状均匀分布,强烈定向。原岩应为泥质粉砂岩。

样品 TYP07-2 为厚层状含石榴二云石英片岩,局部夹有条带状变质砂岩,并强烈褶皱。岩石细粒,主要矿物组成为石榴子石、黑云母、白云母、石英和电气石,含少量绿泥石和斜长石。石榴子石呈自形粒状,白云母和黑云母呈叶片状强烈定向。原

岩应是泥质粉砂岩。

样品 XP12-1 为紫灰色中厚层状变质石英砂岩,内发育小褶皱。主要组成矿物为白云母、黑云母和石英,含极少量斜长石,变形较强,白云母和黑云母呈长叶片状强烈定向。

## 2.2 测试方法

锆石的分选在河北省区域地质矿产调查研究

表 1 刘岭群中定年样品的位置、岩性、矿物组合和锆石 U-Pb 定年结果

Table 1 Sampling sites, lithology, mineral assemblages and U-Pb dating results of the rocks from the Liuling Group

| 样品      | 位置   | 经纬度                        | 岩性        | 矿物组合                          | 最年轻的年龄/Ma | 主要峰值年龄/Ma                    |
|---------|------|----------------------------|-----------|-------------------------------|-----------|------------------------------|
| DF04-4  | 七里店  | N33°33'29"<br>E110°19'44"  | 二云石英片岩    | Bt+Ms+Qtz                     | 425±5     | 440、826                      |
| TYP07-2 | 小花瓶子 | N 33°35'02"<br>E110°30'10" | 含石榴二云石英片岩 | Grt+Bt+Ms+Ep+<br>Pl + Qtz+Tur | 377±4     | 382、442、805、957、<br>2512     |
| XP12-1  | 鸡听河  | N 33°23'41"<br>E111°05'21" | 变质石英砂岩    | Bt+Ms+Qtz                     | 418±5     | 442、723、788、803、<br>968、2460 |

注: Bt—黑云母, Ep—绿帘石, Grt—石榴子石, Ms—白云母, Oq—不透明矿物, Pl—斜长石, Qtz—石英, Tur—电气石

所岩矿分析实验室完成。将待测锆石颗粒制成环氧树脂样品靶,抛光至锆石颗粒保留 2/3 部分。在 U-Th-Pb 同位素测定前,拍摄可见光和阴极发光 (CL) 照片,根据它们所反映的特征,选择合适的颗粒和部位进行测定。锆石微区 U-Pb 定年在中国地质调查局天津地质调查中心同位素实验室的激光烧蚀多接收器电感耦合等离子体质谱仪上 (LA-MC-ICPMS) 完成。仪器性能、分析方法、测试过程见参考文献 [35]。激光束斑孔径为  $35\mu\text{m}$ , 频率 8~10Hz, 激光器能量密度为  $13\sim 14\text{J}/\text{cm}^2$ 。采用 GJ-1 作为外部锆石年龄标准,同时利用 NIST612 玻璃标样作为外标计算锆石样品的 Pb、U 和 Th 含量。采用中国地质大学刘勇胜教授研发的 ICPMSDataCal 程序和 Isoplot 程序进行数据处理,采用  $^{208}\text{Pb}$  校正法进行普通 Pb 校正。锆石年龄加权平均值的计算及 U-Pb 谐和图的绘制采用 Isoplot3.23 程序 [36]。单个点的同位素比值及年龄误差均为  $1\sigma$ , 年龄加权平均值对应 95% 的置信度。

### 3 测试结果

对 3 个变质砂岩中每个样品的碎屑锆石按顺序排列分析了 120 个点,分析结果列于表 2。将谐和度大于等于 95% 的分析点作为有效数据来统计,其他数

据舍去。按照一般的原则,对于小于等于 1000Ma 的数据点取  $^{206}\text{Pb}/^{238}\text{U}$  年龄,大于 1000Ma 的数据点则取  $^{207}\text{Pb}/^{206}\text{Pb}$  年龄。

#### 3.1 二云母石英片岩 (样品 DF04-4)

二云母石英片岩 (DF04-4) 中锆石呈卵形到柱状,阴极发光 (CL) 下绝大多数颗粒具有韵律环带 (图 2-a), 属于岩浆成因,少数暗色颗粒无环带或具面状环带,可能属于变质成因。此外,仅个别颗粒发育有很窄的暗色或灰色生长边。120 个分析点基本都位于韵律环带部位,个别点位于面状环带部位。有效数据所获得的年龄范围从  $3519\text{Ma}\pm 12\text{Ma}$  变化到  $425\text{Ma}\pm 5\text{Ma}$ , 其中 1 个主要峰值约为 440Ma, 另 1 个次要峰值约为 826Ma (图 3)。

#### 3.2 含石榴二云石英片岩 (样品 TYP07-2)

含石榴二云石英片岩 (TYP07-2) 中锆石比较细小,多数呈卵形,少数呈柱状。绝大多数颗粒均具有韵律环带,可发育一条狭窄的暗色或灰色边 (图 2-b), 少数颗粒暗色,也可有灰色边。120 个分析点基本上都位于韵律环带部位,仅个别点位于暗色发光部位。有效数据所获得的年龄范围从  $2748\text{Ma}\pm 13\text{Ma}$  变化到  $377\text{Ma}\pm 4\text{Ma}$ , 其中 1 个主要峰值约在 442Ma, 另 4 个次要峰值约在 2512Ma、957Ma、805Ma 和 382Ma (图 3)。

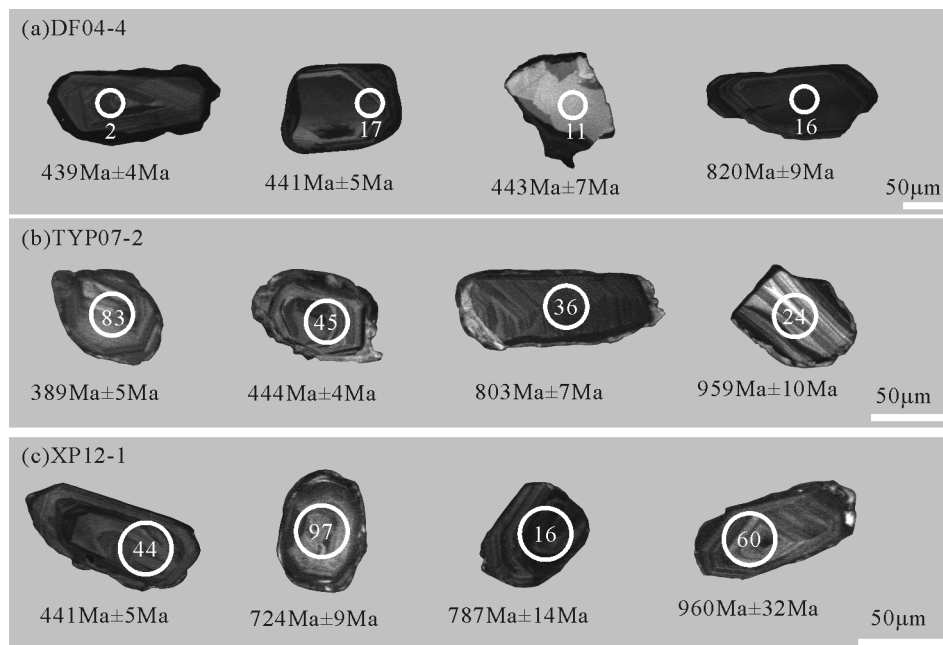


图 2 刘岭群变质砂岩中碎屑锆石的阴极发光图像 (年龄误差为  $1\sigma$ )

Fig. 2 Cathodoluminescence (CL) images of detrital zircons from metasandstones from the Liuling Group

表 2 刘岭群中变质砂岩碎屑锆石 LA-ICP-MS U-Th-Pb 分析结果

Table 2 LA-ICP-MS U-Th-Pb analyses of detrital zircons from metasediments of the Liuling Group

| 分析点       | Th/10 <sup>-6</sup> | U/10 <sup>-6</sup> | Th/U | 同 位 素 比 值                            |        |                                     |       |                                     |        | 年 龄 /Ma                              |     |                                     |    |                                     |    | 谐和度  |
|-----------|---------------------|--------------------|------|--------------------------------------|--------|-------------------------------------|-------|-------------------------------------|--------|--------------------------------------|-----|-------------------------------------|----|-------------------------------------|----|------|
|           |                     |                    |      | <sup>207</sup> Pb/ <sup>206</sup> Pb | ±σ     | <sup>207</sup> Pb/ <sup>235</sup> U | ±σ    | <sup>206</sup> Pb/ <sup>238</sup> U | ±σ     | <sup>207</sup> Pb/ <sup>206</sup> Pb | ±σ  | <sup>207</sup> Pb/ <sup>235</sup> U | ±σ | <sup>206</sup> Pb/ <sup>238</sup> U | ±σ |      |
| 样品 DF04-4 |                     |                    |      |                                      |        |                                     |       |                                     |        |                                      |     |                                     |    |                                     |    |      |
| 1         | 33                  | 82                 | 0.41 | 0.0562                               | 0.0044 | 0.554                               | 0.016 | 0.0714                              | 0.0010 | 462                                  | 175 | 447                                 | 13 | 445                                 | 7  | 99%  |
| 2         | 130                 | 295                | 0.44 | 0.0564                               | 0.0013 | 0.549                               | 0.009 | 0.0705                              | 0.0006 | 469                                  | 50  | 444                                 | 7  | 439                                 | 4  | 99%  |
| 3         | 54                  | 73                 | 0.74 | 0.0564                               | 0.0041 | 0.551                               | 0.014 | 0.0709                              | 0.0009 | 467                                  | 163 | 446                                 | 11 | 441                                 | 6  | 99%  |
| 4         | 43                  | 79                 | 0.54 | 0.0558                               | 0.0042 | 0.559                               | 0.014 | 0.0727                              | 0.0009 | 445                                  | 168 | 451                                 | 12 | 452                                 | 6  | 100% |
| 5         | 147                 | 268                | 0.55 | 0.0553                               | 0.0014 | 0.520                               | 0.008 | 0.0682                              | 0.0007 | 423                                  | 56  | 425                                 | 7  | 425                                 | 5  | 100% |
| 6         | 25                  | 87                 | 0.29 | 0.0734                               | 0.0017 | 1.654                               | 0.021 | 0.1634                              | 0.0014 | 1025                                 | 46  | 991                                 | 13 | 976                                 | 8  | 98%  |
| 7         | 78                  | 64                 | 1.22 | 0.0655                               | 0.0035 | 1.104                               | 0.021 | 0.1222                              | 0.0014 | 792                                  | 112 | 755                                 | 15 | 743                                 | 9  | 98%  |
| 8         | 256                 | 457                | 0.56 | 0.0635                               | 0.0006 | 1.047                               | 0.017 | 0.1196                              | 0.0011 | 724                                  | 22  | 727                                 | 12 | 728                                 | 7  | 100% |
| 9         | 69                  | 190                | 0.37 | 0.0562                               | 0.0020 | 0.539                               | 0.008 | 0.0696                              | 0.0005 | 459                                  | 80  | 438                                 | 6  | 434                                 | 3  | 99%  |
| 10        | 45                  | 1346               | 0.03 | 0.0716                               | 0.0005 | 1.546                               | 0.018 | 0.1566                              | 0.0012 | 975                                  | 15  | 949                                 | 11 | 938                                 | 7  | 99%  |
| 11        | 22                  | 55                 | 0.41 | 0.0562                               | 0.0062 | 0.551                               | 0.017 | 0.0711                              | 0.0011 | 461                                  | 243 | 446                                 | 14 | 443                                 | 7  | 99%  |
| 12        | 297                 | 421                | 0.71 | 0.0563                               | 0.0008 | 0.643                               | 0.011 | 0.0828                              | 0.0007 | 463                                  | 32  | 504                                 | 9  | 513                                 | 5  | 102% |
| 13        | 137                 | 307                | 0.45 | 0.0651                               | 0.0007 | 1.155                               | 0.016 | 0.1287                              | 0.0011 | 776                                  | 22  | 779                                 | 11 | 781                                 | 7  | 100% |
| 14        | 74                  | 138                | 0.54 | 0.0567                               | 0.0023 | 0.603                               | 0.012 | 0.0771                              | 0.0008 | 480                                  | 88  | 479                                 | 10 | 479                                 | 5  | 100% |
| 15        | 103                 | 254                | 0.40 | 0.0554                               | 0.0015 | 0.531                               | 0.013 | 0.0695                              | 0.0009 | 430                                  | 60  | 433                                 | 11 | 433                                 | 5  | 100% |
| 16        | 211                 | 421                | 0.50 | 0.0664                               | 0.0006 | 1.243                               | 0.023 | 0.1356                              | 0.0015 | 821                                  | 20  | 820                                 | 15 | 820                                 | 9  | 100% |
| 17        | 186                 | 542                | 0.34 | 0.0565                               | 0.0008 | 0.551                               | 0.013 | 0.0707                              | 0.0008 | 472                                  | 33  | 446                                 | 10 | 441                                 | 5  | 99%  |
| 18        | 58                  | 135                | 0.43 | 0.0541                               | 0.0027 | 0.518                               | 0.011 | 0.0694                              | 0.0007 | 374                                  | 110 | 424                                 | 9  | 433                                 | 4  | 102% |
| 19        | 105                 | 298                | 0.35 | 0.0600                               | 0.0026 | 0.585                               | 0.019 | 0.0708                              | 0.0012 | 602                                  | 93  | 468                                 | 15 | 441                                 | 8  | 94%  |
| 20        | 234                 | 393                | 0.60 | 0.0600                               | 0.0018 | 0.577                               | 0.011 | 0.0697                              | 0.0007 | 605                                  | 65  | 463                                 | 9  | 434                                 | 4  | 94%  |
| 21        | 359                 | 938                | 0.38 | 0.0675                               | 0.0004 | 1.286                               | 0.022 | 0.1383                              | 0.0014 | 852                                  | 14  | 840                                 | 14 | 835                                 | 9  | 99%  |
| 22        | 95                  | 347                | 0.27 | 0.1473                               | 0.0010 | 7.994                               | 0.042 | 0.3936                              | 0.0028 | 2315                                 | 12  | 2230                                | 12 | 2139                                | 15 | 96%  |
| 23        | 144                 | 271                | 0.53 | 0.0566                               | 0.0017 | 0.545                               | 0.009 | 0.0699                              | 0.0006 | 475                                  | 68  | 442                                 | 7  | 436                                 | 4  | 99%  |
| 24        | 139                 | 197                | 0.70 | 0.0553                               | 0.0018 | 0.537                               | 0.011 | 0.0704                              | 0.0007 | 425                                  | 72  | 436                                 | 9  | 439                                 | 5  | 101% |
| 25        | 196                 | 515                | 0.38 | 0.0579                               | 0.0015 | 0.563                               | 0.013 | 0.0705                              | 0.0009 | 525                                  | 58  | 453                                 | 10 | 439                                 | 5  | 97%  |
| 26        | 297                 | 677                | 0.44 | 0.0753                               | 0.0006 | 1.828                               | 0.024 | 0.1761                              | 0.0016 | 1076                                 | 15  | 1056                                | 14 | 1046                                | 9  | 99%  |
| 27        | 83                  | 334                | 0.25 | 0.0564                               | 0.0012 | 0.549                               | 0.013 | 0.0706                              | 0.0009 | 466                                  | 45  | 444                                 | 11 | 440                                 | 5  | 99%  |
| 28        | 281                 | 787                | 0.36 | 0.0582                               | 0.0005 | 0.659                               | 0.011 | 0.0821                              | 0.0007 | 536                                  | 20  | 514                                 | 8  | 509                                 | 4  | 99%  |
| 29        | 325                 | 625                | 0.52 | 0.0572                               | 0.0006 | 0.560                               | 0.011 | 0.0710                              | 0.0007 | 500                                  | 23  | 452                                 | 9  | 442                                 | 4  | 98%  |
| 30        | 28                  | 159                | 0.18 | 0.1618                               | 0.0010 | 10.476                              | 0.074 | 0.4697                              | 0.0049 | 2474                                 | 11  | 2478                                | 18 | 2482                                | 26 | 100% |
| 31        | 113                 | 130                | 0.87 | 0.0682                               | 0.0039 | 0.678                               | 0.025 | 0.0721                              | 0.0017 | 875                                  | 118 | 526                                 | 19 | 449                                 | 10 | 85%  |
| 32        | 140                 | 546                | 0.26 | 0.0900                               | 0.0007 | 2.820                               | 0.057 | 0.2272                              | 0.0037 | 1426                                 | 16  | 1361                                | 27 | 1320                                | 22 | 97%  |
| 33        | 117                 | 430                | 0.27 | 0.0571                               | 0.0009 | 0.579                               | 0.009 | 0.0736                              | 0.0006 | 495                                  | 35  | 464                                 | 7  | 458                                 | 4  | 99%  |
| 34        | 126                 | 146                | 0.87 | 0.0571                               | 0.0027 | 0.554                               | 0.011 | 0.0703                              | 0.0007 | 495                                  | 102 | 447                                 | 9  | 438                                 | 5  | 98%  |
| 35        | 46                  | 920                | 0.05 | 0.1175                               | 0.0016 | 3.976                               | 0.070 | 0.2454                              | 0.0046 | 1918                                 | 25  | 1629                                | 29 | 1415                                | 27 | 87%  |
| 36        | 260                 | 583                | 0.45 | 0.0554                               | 0.0007 | 0.540                               | 0.007 | 0.0706                              | 0.0005 | 429                                  | 29  | 438                                 | 6  | 440                                 | 3  | 100% |
| 37        | 15                  | 43                 | 0.36 | 0.0691                               | 0.0034 | 1.621                               | 0.028 | 0.1701                              | 0.0019 | 903                                  | 102 | 979                                 | 17 | 1013                                | 11 | 103% |
| 38        | 168                 | 291                | 0.58 | 0.0585                               | 0.0016 | 0.588                               | 0.009 | 0.0728                              | 0.0006 | 550                                  | 59  | 470                                 | 7  | 453                                 | 4  | 97%  |
| 39        | 69                  | 206                | 0.33 | 0.0575                               | 0.0019 | 0.566                               | 0.009 | 0.0715                              | 0.0006 | 510                                  | 74  | 456                                 | 7  | 445                                 | 4  | 98%  |
| 40        | 58                  | 213                | 0.27 | 0.0570                               | 0.0018 | 0.551                               | 0.010 | 0.0701                              | 0.0007 | 492                                  | 69  | 446                                 | 8  | 437                                 | 4  | 98%  |
| 41        | 103                 | 205                | 0.50 | 0.0584                               | 0.0017 | 0.581                               | 0.010 | 0.0721                              | 0.0007 | 545                                  | 64  | 465                                 | 8  | 449                                 | 4  | 97%  |
| 42        | 427                 | 962                | 0.44 | 0.1433                               | 0.0012 | 2.626                               | 0.051 | 0.1329                              | 0.0034 | 2267                                 | 14  | 1308                                | 26 | 805                                 | 21 | 62%  |
| 43        | 22                  | 645                | 0.03 | 0.0579                               | 0.0006 | 0.627                               | 0.008 | 0.0785                              | 0.0005 | 527                                  | 23  | 494                                 | 6  | 487                                 | 3  | 99%  |
| 44        | 90                  | 261                | 0.34 | 0.1139                               | 0.0007 | 5.216                               | 0.028 | 0.3321                              | 0.0019 | 1863                                 | 11  | 1855                                | 10 | 1849                                | 10 | 100% |
| 45        | 66                  | 434                | 0.15 | 0.0737                               | 0.0006 | 1.706                               | 0.014 | 0.1679                              | 0.0009 | 1033                                 | 16  | 1011                                | 8  | 1000                                | 5  | 99%  |
| 46        | 378                 | 443                | 0.85 | 0.1650                               | 0.0010 | 10.649                              | 0.053 | 0.4681                              | 0.0035 | 2508                                 | 10  | 2493                                | 13 | 2475                                | 19 | 99%  |
| 47        | 237                 | 984                | 0.24 | 0.0658                               | 0.0005 | 1.244                               | 0.017 | 0.1371                              | 0.0011 | 800                                  | 15  | 821                                 | 11 | 828                                 | 7  | 101% |
| 48        | 49                  | 97                 | 0.50 | 0.0567                               | 0.0042 | 0.558                               | 0.014 | 0.0714                              | 0.0009 | 478                                  | 164 | 450                                 | 11 | 445                                 | 6  | 99%  |

续表 2-1

| 分析点       | Th/10 <sup>-6</sup> | U/10 <sup>-6</sup> | Th/U | 同 位 素 比 值                            |        |                                     |       |                                     |        | 年 龄 /Ma                              |     |                                     |    |                                     |     | 谐和度  |
|-----------|---------------------|--------------------|------|--------------------------------------|--------|-------------------------------------|-------|-------------------------------------|--------|--------------------------------------|-----|-------------------------------------|----|-------------------------------------|-----|------|
|           |                     |                    |      | <sup>207</sup> Pb/ <sup>206</sup> Pb | ±σ     | <sup>207</sup> Pb/ <sup>235</sup> U | ±σ    | <sup>206</sup> Pb/ <sup>238</sup> U | ±σ     | <sup>207</sup> Pb/ <sup>206</sup> Pb | ±σ  | <sup>207</sup> Pb/ <sup>235</sup> U | ±σ | <sup>206</sup> Pb/ <sup>238</sup> U | ±σ  |      |
| 样品 DF04-4 |                     |                    |      |                                      |        |                                     |       |                                     |        |                                      |     |                                     |    |                                     |     |      |
| 49        | 11                  | 42                 | 0.26 | 0.1260                               | 0.0020 | 6.349                               | 0.059 | 0.3655                              | 0.0039 | 2043                                 | 28  | 2025                                | 19 | 2008                                | 22  | 99%  |
| 50        | 96                  | 246                | 0.39 | 0.0566                               | 0.0015 | 0.550                               | 0.011 | 0.0705                              | 0.0007 | 474                                  | 60  | 445                                 | 9  | 439                                 | 4   | 99%  |
| 51        | 137                 | 400                | 0.34 | 0.0554                               | 0.0011 | 0.545                               | 0.012 | 0.0713                              | 0.0008 | 428                                  | 42  | 442                                 | 9  | 444                                 | 5   | 101% |
| 52        | 123                 | 218                | 0.56 | 0.0546                               | 0.0014 | 0.532                               | 0.009 | 0.0707                              | 0.0006 | 395                                  | 58  | 433                                 | 8  | 440                                 | 4   | 102% |
| 53        | 319                 | 764                | 0.42 | 0.0675                               | 0.0005 | 1.316                               | 0.017 | 0.1414                              | 0.0011 | 854                                  | 15  | 853                                 | 11 | 853                                 | 7   | 100% |
| 54        | 72                  | 360                | 0.20 | 0.1620                               | 0.0012 | 6.558                               | 0.210 | 0.2936                              | 0.0079 | 2477                                 | 13  | 2054                                | 66 | 1660                                | 45  | 81%  |
| 55        | 148                 | 598                | 0.25 | 0.0698                               | 0.0006 | 1.506                               | 0.017 | 0.1564                              | 0.0011 | 924                                  | 19  | 933                                 | 11 | 936                                 | 7   | 100% |
| 56        | 74                  | 151                | 0.49 | 0.0579                               | 0.0025 | 0.560                               | 0.012 | 0.0702                              | 0.0008 | 525                                  | 96  | 451                                 | 10 | 437                                 | 5   | 97%  |
| 57        | 170                 | 322                | 0.53 | 0.0610                               | 0.0012 | 0.624                               | 0.008 | 0.0742                              | 0.0005 | 639                                  | 42  | 492                                 | 6  | 461                                 | 3   | 94%  |
| 58        | 3                   | 39                 | 0.07 | 0.4412                               | 0.0103 | 4.977                               | 0.097 | 0.0818                              | 0.0018 | 4056                                 | 35  | 1815                                | 36 | 507                                 | 11  | 28%  |
| 59        | 127                 | 303                | 0.42 | 0.0591                               | 0.0014 | 0.571                               | 0.009 | 0.0702                              | 0.0006 | 570                                  | 51  | 459                                 | 7  | 437                                 | 4   | 95%  |
| 60        | 1                   | 15                 | 0.07 | 0.6902                               | 0.0150 | 20.461                              | 0.343 | 0.2150                              | 0.0227 | 4710                                 | 31  | 3113                                | 52 | 1255                                | 133 | 40%  |
| 61        | 122                 | 175                | 0.70 | 0.0560                               | 0.0021 | 0.543                               | 0.010 | 0.0703                              | 0.0006 | 452                                  | 84  | 440                                 | 8  | 438                                 | 4   | 100% |
| 62        | 787                 | 1189               | 0.66 | 0.0608                               | 0.0010 | 0.708                               | 0.019 | 0.0845                              | 0.0012 | 632                                  | 36  | 544                                 | 14 | 523                                 | 8   | 96%  |
| 63        | 72                  | 112                | 0.64 | 0.0598                               | 0.0030 | 0.578                               | 0.013 | 0.0701                              | 0.0009 | 595                                  | 110 | 463                                 | 10 | 437                                 | 5   | 94%  |
| 64        | 42                  | 96                 | 0.44 | 0.0632                               | 0.0043 | 0.647                               | 0.013 | 0.0742                              | 0.0009 | 717                                  | 145 | 507                                 | 10 | 461                                 | 5   | 91%  |
| 65        | 16                  | 34                 | 0.46 | 0.1123                               | 0.0014 | 5.050                               | 0.052 | 0.3262                              | 0.0034 | 1837                                 | 23  | 1828                                | 19 | 1820                                | 19  | 100% |
| 66        | 20                  | 1069               | 0.02 | 0.1008                               | 0.0007 | 4.040                               | 0.044 | 0.2907                              | 0.0029 | 1639                                 | 13  | 1642                                | 18 | 1645                                | 17  | 100% |
| 67        | 262                 | 747                | 0.35 | 0.0562                               | 0.0008 | 0.558                               | 0.010 | 0.0720                              | 0.0007 | 462                                  | 31  | 450                                 | 8  | 448                                 | 4   | 99%  |
| 68        | 268                 | 626                | 0.43 | 0.0567                               | 0.0007 | 0.556                               | 0.010 | 0.0711                              | 0.0006 | 480                                  | 26  | 449                                 | 8  | 443                                 | 4   | 99%  |
| 69        | 4                   | 56                 | 0.08 | 0.4025                               | 0.0071 | 3.941                               | 0.018 | 0.0710                              | 0.0012 | 3918                                 | 26  | 1622                                | 8  | 442                                 | 8   | 27%  |
| 70        | 74                  | 217                | 0.34 | 0.0567                               | 0.0017 | 0.552                               | 0.011 | 0.0706                              | 0.0007 | 481                                  | 65  | 447                                 | 9  | 440                                 | 4   | 99%  |
| 71        | 148                 | 1114               | 0.13 | 0.0564                               | 0.0006 | 0.555                               | 0.010 | 0.0713                              | 0.0007 | 469                                  | 25  | 448                                 | 8  | 444                                 | 4   | 99%  |
| 72        | 234                 | 804                | 0.29 | 0.0578                               | 0.0006 | 0.671                               | 0.014 | 0.0842                              | 0.0009 | 521                                  | 22  | 521                                 | 11 | 521                                 | 6   | 100% |
| 73        | 118                 | 238                | 0.50 | 0.0572                               | 0.0016 | 0.554                               | 0.010 | 0.0702                              | 0.0007 | 498                                  | 63  | 447                                 | 8  | 437                                 | 4   | 98%  |
| 74        | 434                 | 1302               | 0.33 | 0.0567                               | 0.0010 | 0.553                               | 0.010 | 0.0707                              | 0.0006 | 480                                  | 38  | 447                                 | 8  | 440                                 | 4   | 99%  |
| 75        | 64                  | 160                | 0.40 | 0.0580                               | 0.0028 | 0.560                               | 0.011 | 0.0700                              | 0.0007 | 528                                  | 106 | 451                                 | 9  | 436                                 | 5   | 97%  |
| 76        | 187                 | 355                | 0.53 | 0.0573                               | 0.0011 | 0.597                               | 0.009 | 0.0756                              | 0.0006 | 503                                  | 42  | 475                                 | 7  | 470                                 | 4   | 99%  |
| 77        | 49                  | 276                | 0.18 | 0.0679                               | 0.0009 | 1.283                               | 0.018 | 0.1370                              | 0.0012 | 866                                  | 27  | 838                                 | 12 | 828                                 | 7   | 99%  |
| 78        | 104                 | 1182               | 0.09 | 0.0695                               | 0.0005 | 1.448                               | 0.016 | 0.1510                              | 0.0011 | 914                                  | 16  | 909                                 | 10 | 907                                 | 6   | 100% |
| 79        | 251                 | 720                | 0.35 | 0.0593                               | 0.0007 | 0.601                               | 0.010 | 0.0735                              | 0.0007 | 580                                  | 24  | 478                                 | 8  | 457                                 | 4   | 96%  |
| 80        | 113                 | 205                | 0.55 | 0.0574                               | 0.0019 | 0.587                               | 0.009 | 0.0741                              | 0.0006 | 508                                  | 75  | 469                                 | 7  | 461                                 | 4   | 98%  |
| 81        | 103                 | 90                 | 1.14 | 0.0738                               | 0.0026 | 1.263                               | 0.017 | 0.1242                              | 0.0012 | 1035                                 | 70  | 829                                 | 11 | 755                                 | 7   | 91%  |
| 82        | 221                 | 164                | 1.34 | 0.1865                               | 0.0014 | 13.189                              | 0.058 | 0.5128                              | 0.0038 | 2712                                 | 12  | 2693                                | 12 | 2669                                | 20  | 99%  |
| 83        | 480                 | 649                | 0.74 | 0.1435                               | 0.0010 | 8.429                               | 0.067 | 0.4259                              | 0.0045 | 2270                                 | 12  | 2278                                | 18 | 2287                                | 24  | 100% |
| 84        | 342                 | 865                | 0.39 | 0.0587                               | 0.0006 | 0.670                               | 0.013 | 0.0829                              | 0.0009 | 554                                  | 23  | 521                                 | 10 | 513                                 | 5   | 99%  |
| 85        | 78                  | 120                | 0.65 | 0.1297                               | 0.0011 | 6.797                               | 0.038 | 0.3800                              | 0.0025 | 2094                                 | 15  | 2085                                | 12 | 2077                                | 14  | 100% |
| 86        | 87                  | 194                | 0.45 | 0.1650                               | 0.0012 | 10.599                              | 0.060 | 0.4660                              | 0.0040 | 2507                                 | 13  | 2489                                | 14 | 2466                                | 21  | 99%  |
| 87        | 82                  | 294                | 0.28 | 0.3096                               | 0.0024 | 30.539                              | 0.089 | 0.7153                              | 0.0059 | 3519                                 | 12  | 3504                                | 10 | 3479                                | 29  | 99%  |
| 88        | 199                 | 241                | 0.83 | 0.0585                               | 0.0018 | 0.573                               | 0.008 | 0.0711                              | 0.0005 | 548                                  | 67  | 460                                 | 6  | 443                                 | 3   | 96%  |
| 89        | 249                 | 720                | 0.35 | 0.0573                               | 0.0012 | 0.603                               | 0.009 | 0.0763                              | 0.0006 | 505                                  | 47  | 479                                 | 7  | 474                                 | 4   | 99%  |
| 90        | 265                 | 446                | 0.59 | 0.0560                               | 0.0011 | 0.543                               | 0.008 | 0.0703                              | 0.0005 | 453                                  | 44  | 440                                 | 6  | 438                                 | 3   | 99%  |
| 91        | 68                  | 423                | 0.16 | 0.0689                               | 0.0007 | 1.249                               | 0.028 | 0.1315                              | 0.0018 | 896                                  | 21  | 823                                 | 18 | 796                                 | 11  | 97%  |
| 92        | 430                 | 376                | 1.14 | 0.0571                               | 0.0013 | 0.551                               | 0.009 | 0.0700                              | 0.0006 | 495                                  | 48  | 446                                 | 7  | 436                                 | 4   | 98%  |
| 93        | 144                 | 1051               | 0.14 | 0.0818                               | 0.0007 | 2.201                               | 0.100 | 0.1951                              | 0.0066 | 1241                                 | 17  | 1181                                | 54 | 1149                                | 39  | 97%  |
| 94        | 223                 | 313                | 0.71 | 0.0564                               | 0.0013 | 0.546                               | 0.015 | 0.0702                              | 0.0010 | 469                                  | 51  | 442                                 | 12 | 437                                 | 6   | 99%  |
| 95        | 317                 | 542                | 0.59 | 0.0580                               | 0.0010 | 0.570                               | 0.009 | 0.0713                              | 0.0006 | 529                                  | 38  | 458                                 | 8  | 444                                 | 4   | 97%  |
| 96        | 213                 | 474                | 0.45 | 0.0563                               | 0.0009 | 0.549                               | 0.008 | 0.0707                              | 0.0010 | 466                                  | 35  | 445                                 | 7  | 440                                 | 6   | 99%  |
| 97        | 423                 | 754                | 0.56 | 0.0585                               | 0.0009 | 0.579                               | 0.007 | 0.0718                              | 0.0005 | 548                                  | 32  | 464                                 | 6  | 447                                 | 3   | 96%  |

续表 2-2

| 分析点        | Th/ $10^{-6}$ | U/ $10^{-6}$ | Th/U | 同 位 素 比 值                         |             |                                  |             |                                  |             | 年 龄 /Ma                           |             |                                  |             |                                  |             | 谐和度  |
|------------|---------------|--------------|------|-----------------------------------|-------------|----------------------------------|-------------|----------------------------------|-------------|-----------------------------------|-------------|----------------------------------|-------------|----------------------------------|-------------|------|
|            |               |              |      | $^{207}\text{Pb}/^{206}\text{Pb}$ | $\pm\sigma$ | $^{207}\text{Pb}/^{235}\text{U}$ | $\pm\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $\pm\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $\pm\sigma$ | $^{207}\text{Pb}/^{235}\text{U}$ | $\pm\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $\pm\sigma$ |      |
| 样品 DF04-4  |               |              |      |                                   |             |                                  |             |                                  |             |                                   |             |                                  |             |                                  |             |      |
| 98         | 303           | 580          | 0.52 | 0.1420                            | 0.0013      | 1.374                            | 0.010       | 0.0702                           | 0.0007      | 2252                              | 16          | 878                              | 6           | 437                              | 4           | 50%  |
| 99         | 149           | 377          | 0.40 | 0.0603                            | 0.0015      | 0.591                            | 0.008       | 0.0710                           | 0.0005      | 615                               | 52          | 471                              | 6           | 442                              | 3           | 94%  |
| 100        | 131           | 436          | 0.30 | 0.0570                            | 0.0008      | 0.571                            | 0.009       | 0.0726                           | 0.0006      | 493                               | 31          | 459                              | 7           | 452                              | 4           | 99%  |
| 101        | 107           | 204          | 0.52 | 0.1296                            | 0.0009      | 6.658                            | 0.042       | 0.3725                           | 0.0028      | 2093                              | 12          | 2067                             | 13          | 2041                             | 15          | 99%  |
| 102        | 187           | 394          | 0.48 | 0.0610                            | 0.0011      | 0.593                            | 0.011       | 0.0706                           | 0.0007      | 639                               | 41          | 473                              | 8           | 440                              | 4           | 93%  |
| 103        | 160           | 226          | 0.71 | 0.0578                            | 0.0017      | 0.590                            | 0.011       | 0.0741                           | 0.0007      | 521                               | 66          | 471                              | 8           | 461                              | 4           | 98%  |
| 104        | 421           | 1104         | 0.38 | 0.0577                            | 0.0015      | 0.562                            | 0.012       | 0.0707                           | 0.0008      | 517                               | 58          | 453                              | 9           | 440                              | 5           | 97%  |
| 105        | 320           | 989          | 0.32 | 0.0580                            | 0.0005      | 0.648                            | 0.012       | 0.0811                           | 0.0008      | 529                               | 20          | 507                              | 9           | 503                              | 5           | 99%  |
| 106        | 367           | 580          | 0.63 | 0.0598                            | 0.0009      | 0.570                            | 0.009       | 0.0691                           | 0.0006      | 596                               | 33          | 458                              | 7           | 431                              | 4           | 94%  |
| 107        | 197           | 566          | 0.35 | 0.0813                            | 0.0013      | 1.724                            | 0.016       | 0.1538                           | 0.0011      | 1228                              | 30          | 1017                             | 9           | 923                              | 6           | 91%  |
| 108        | 258           | 790          | 0.33 | 0.0914                            | 0.0014      | 1.955                            | 0.017       | 0.1552                           | 0.0011      | 1454                              | 28          | 1100                             | 9           | 930                              | 7           | 85%  |
| 109        | 536           | 2348         | 0.23 | 0.0665                            | 0.0005      | 1.270                            | 0.020       | 0.1384                           | 0.0013      | 823                               | 15          | 832                              | 13          | 836                              | 8           | 100% |
| 110        | 192           | 408          | 0.47 | 0.0553                            | 0.0009      | 0.559                            | 0.012       | 0.0733                           | 0.0008      | 424                               | 36          | 451                              | 9           | 456                              | 5           | 101% |
| 111        | 319           | 505          | 0.63 | 0.0590                            | 0.0006      | 0.821                            | 0.015       | 0.1008                           | 0.0010      | 569                               | 23          | 608                              | 11          | 619                              | 6           | 102% |
| 112        | 573           | 1170         | 0.49 | 0.0560                            | 0.0006      | 0.591                            | 0.013       | 0.0765                           | 0.0009      | 452                               | 24          | 471                              | 11          | 475                              | 5           | 101% |
| 113        | 535           | 514          | 1.04 | 0.0556                            | 0.0008      | 0.566                            | 0.012       | 0.0738                           | 0.0008      | 438                               | 32          | 455                              | 9           | 459                              | 5           | 101% |
| 114        | 101           | 425          | 0.24 | 0.0572                            | 0.0011      | 0.560                            | 0.010       | 0.0710                           | 0.0007      | 498                               | 42          | 451                              | 8           | 442                              | 4           | 98%  |
| 115        | 68            | 357          | 0.19 | 0.0744                            | 0.0008      | 1.912                            | 0.026       | 0.1863                           | 0.0017      | 1054                              | 21          | 1085                             | 15          | 1101                             | 10          | 101% |
| 116        | 379           | 842          | 0.45 | 0.0588                            | 0.0007      | 0.567                            | 0.010       | 0.0700                           | 0.0006      | 560                               | 26          | 456                              | 8           | 436                              | 4           | 96%  |
| 117        | 48            | 193          | 0.25 | 0.0863                            | 0.0010      | 2.858                            | 0.025       | 0.2402                           | 0.0016      | 1345                              | 22          | 1371                             | 12          | 1388                             | 9           | 101% |
| 118        | 158           | 193          | 0.82 | 0.1567                            | 0.0018      | 9.587                            | 0.060       | 0.4437                           | 0.0040      | 2420                              | 19          | 2396                             | 15          | 2367                             | 21          | 99%  |
| 119        | 631           | 2037         | 0.31 | 0.0726                            | 0.0016      | 0.821                            | 0.023       | 0.0821                           | 0.0015      | 1003                              | 45          | 609                              | 17          | 508                              | 9           | 84%  |
| 120        | 86            | 225          | 0.38 | 0.0544                            | 0.0016      | 0.546                            | 0.010       | 0.0728                           | 0.0007      | 389                               | 67          | 442                              | 8           | 453                              | 4           | 102% |
| 样品 TYP07-2 |               |              |      |                                   |             |                                  |             |                                  |             |                                   |             |                                  |             |                                  |             |      |
| 1          | 110           | 301          | 0.36 | 0.0869                            | 0.0009      | 2.762                            | 0.029       | 0.2305                           | 0.0023      | 1358                              | 20          | 1345                             | 14          | 1337                             | 13          | 99%  |
| 2          | 22            | 61           | 0.36 | 0.0811                            | 0.0015      | 2.151                            | 0.043       | 0.1925                           | 0.0026      | 1223                              | 37          | 1165                             | 23          | 1135                             | 15          | 97%  |
| 3          | 85            | 649          | 0.13 | 0.0699                            | 0.0009      | 1.537                            | 0.021       | 0.1595                           | 0.0023      | 925                               | 28          | 945                              | 13          | 954                              | 14          | 101% |
| 4          | 112           | 142          | 0.79 | 0.0824                            | 0.0006      | 2.485                            | 0.029       | 0.2187                           | 0.0020      | 1256                              | 14          | 1268                             | 15          | 1275                             | 11          | 101% |
| 5          | 48            | 103          | 0.47 | 0.0675                            | 0.0012      | 1.316                            | 0.023       | 0.1414                           | 0.0014      | 854                               | 36          | 853                              | 15          | 853                              | 9           | 100% |
| 6          | 137           | 305          | 0.45 | 0.0596                            | 0.0007      | 0.707                            | 0.010       | 0.0861                           | 0.0012      | 588                               | 27          | 543                              | 8           | 533                              | 7           | 98%  |
| 7          | 37            | 475          | 0.08 | 0.0711                            | 0.0009      | 1.591                            | 0.011       | 0.1623                           | 0.0022      | 960                               | 26          | 967                              | 7           | 970                              | 13          | 100% |
| 8          | 316           | 280          | 1.13 | 0.1619                            | 0.0013      | 10.185                           | 0.075       | 0.4562                           | 0.0066      | 2476                              | 13          | 2452                             | 18          | 2423                             | 35          | 99%  |
| 9          | 97            | 135          | 0.72 | 0.1650                            | 0.0014      | 10.874                           | 0.112       | 0.4781                           | 0.0052      | 2507                              | 14          | 2512                             | 26          | 2519                             | 27          | 100% |
| 10         | 315           | 396          | 0.80 | 0.0658                            | 0.0005      | 1.202                            | 0.010       | 0.1324                           | 0.0013      | 801                               | 15          | 801                              | 6           | 802                              | 8           | 100% |
| 11         | 253           | 525          | 0.48 | 0.0569                            | 0.0005      | 0.599                            | 0.005       | 0.0764                           | 0.0009      | 486                               | 19          | 477                              | 4           | 474                              | 6           | 99%  |
| 12         | 40            | 79           | 0.51 | 0.0680                            | 0.0014      | 1.283                            | 0.027       | 0.1369                           | 0.0014      | 867                               | 44          | 838                              | 18          | 827                              | 8           | 99%  |
| 13         | 70            | 181          | 0.39 | 0.0759                            | 0.0005      | 1.976                            | 0.015       | 0.1888                           | 0.0016      | 1093                              | 14          | 1107                             | 8           | 1115                             | 9           | 101% |
| 14         | 30            | 1010         | 0.03 | 0.1054                            | 0.0005      | 4.283                            | 0.023       | 0.2949                           | 0.0022      | 1721                              | 8           | 1690                             | 9           | 1666                             | 12          | 99%  |
| 15         | 115           | 834          | 0.14 | 0.0620                            | 0.0004      | 0.880                            | 0.006       | 0.1028                           | 0.0007      | 676                               | 13          | 641                              | 4           | 631                              | 4           | 98%  |
| 16         | 86            | 315          | 0.27 | 0.0736                            | 0.0005      | 1.807                            | 0.013       | 0.1781                           | 0.0018      | 1030                              | 13          | 1048                             | 7           | 1057                             | 11          | 101% |
| 17         | 99            | 94           | 1.05 | 0.0703                            | 0.0013      | 1.437                            | 0.026       | 0.1483                           | 0.0014      | 936                               | 37          | 904                              | 16          | 891                              | 9           | 99%  |
| 18         | 58            | 206          | 0.28 | 0.0670                            | 0.0006      | 1.265                            | 0.014       | 0.1369                           | 0.0020      | 838                               | 20          | 830                              | 9           | 827                              | 12          | 100% |
| 19         | 147           | 323          | 0.45 | 0.0586                            | 0.0010      | 0.613                            | 0.010       | 0.0758                           | 0.0006      | 553                               | 37          | 485                              | 8           | 471                              | 4           | 97%  |
| 20         | 69            | 127          | 0.54 | 0.0575                            | 0.0017      | 0.616                            | 0.019       | 0.0777                           | 0.0009      | 510                               | 67          | 487                              | 15          | 482                              | 5           | 99%  |
| 21         | 114           | 450          | 0.25 | 0.1907                            | 0.0016      | 14.183                           | 0.094       | 0.5394                           | 0.0055      | 2748                              | 13          | 2762                             | 18          | 2781                             | 28          | 101% |
| 22         | 65            | 182          | 0.36 | 0.0670                            | 0.0017      | 1.299                            | 0.034       | 0.1407                           | 0.0014      | 836                               | 52          | 845                              | 22          | 849                              | 9           | 100% |
| 23         | 182           | 408          | 0.45 | 0.1581                            | 0.0013      | 7.944                            | 0.070       | 0.3644                           | 0.0066      | 2435                              | 14          | 2225                             | 19          | 2003                             | 36          | 90%  |
| 24         | 105           | 136          | 0.77 | 0.0707                            | 0.0009      | 1.565                            | 0.020       | 0.1604                           | 0.0017      | 950                               | 25          | 956                              | 12          | 959                              | 10          | 100% |
| 25         | 462           | 655          | 0.71 | 0.0588                            | 0.0017      | 0.577                            | 0.017       | 0.0712                           | 0.0004      | 559                               | 63          | 462                              | 14          | 443                              | 3           | 96%  |
| 26         | 430           | 709          | 0.61 | 0.0846                            | 0.0005      | 2.227                            | 0.015       | 0.1910                           | 0.0021      | 1306                              | 10          | 1190                             | 8           | 1127                             | 12          | 95%  |

续表 2-3

| 分析点        | Th/10 <sup>-6</sup> | U/10 <sup>-6</sup> | Th/U | 同 位 素 比 值                            |        |                                     |       |                                     |        | 年 龄 /Ma                              |    |                                     |    |                                     |    | 谐和度  |
|------------|---------------------|--------------------|------|--------------------------------------|--------|-------------------------------------|-------|-------------------------------------|--------|--------------------------------------|----|-------------------------------------|----|-------------------------------------|----|------|
|            |                     |                    |      | <sup>207</sup> Pb/ <sup>206</sup> Pb | ±σ     | <sup>207</sup> Pb/ <sup>235</sup> U | ±σ    | <sup>206</sup> Pb/ <sup>238</sup> U | ±σ     | <sup>207</sup> Pb/ <sup>206</sup> Pb | ±σ | <sup>207</sup> Pb/ <sup>235</sup> U | ±σ | <sup>206</sup> Pb/ <sup>238</sup> U | ±σ |      |
| 样品 TYP07-2 |                     |                    |      |                                      |        |                                     |       |                                     |        |                                      |    |                                     |    |                                     |    |      |
| 27         | 209                 | 476                | 0.44 | 0.0568                               | 0.0005 | 0.615                               | 0.006 | 0.0785                              | 0.0009 | 484                                  | 21 | 487                                 | 5  | 487                                 | 5  | 100% |
| 28         | 106                 | 401                | 0.26 | 0.0585                               | 0.0010 | 0.599                               | 0.012 | 0.0744                              | 0.0009 | 547                                  | 36 | 477                                 | 10 | 462                                 | 6  | 97%  |
| 29         | 72                  | 85                 | 0.85 | 0.0594                               | 0.0023 | 0.694                               | 0.028 | 0.0848                              | 0.0008 | 581                                  | 85 | 535                                 | 21 | 525                                 | 5  | 98%  |
| 30         | 60                  | 281                | 0.21 | 0.0695                               | 0.0005 | 1.523                               | 0.011 | 0.1589                              | 0.0017 | 914                                  | 14 | 940                                 | 7  | 951                                 | 10 | 101% |
| 31         | 65                  | 228                | 0.28 | 0.0714                               | 0.0006 | 1.560                               | 0.013 | 0.1586                              | 0.0016 | 968                                  | 17 | 954                                 | 8  | 949                                 | 9  | 99%  |
| 32         | 75                  | 200                | 0.37 | 0.0602                               | 0.0012 | 0.683                               | 0.014 | 0.0823                              | 0.0009 | 611                                  | 42 | 529                                 | 11 | 510                                 | 6  | 96%  |
| 33         | 382                 | 617                | 0.62 | 0.0565                               | 0.0004 | 0.574                               | 0.005 | 0.0737                              | 0.0008 | 472                                  | 17 | 461                                 | 4  | 459                                 | 5  | 100% |
| 34         | 331                 | 714                | 0.46 | 0.0584                               | 0.0005 | 0.615                               | 0.005 | 0.0764                              | 0.0009 | 544                                  | 19 | 487                                 | 4  | 475                                 | 5  | 98%  |
| 35         | 59                  | 164                | 0.36 | 0.1142                               | 0.0005 | 5.285                               | 0.029 | 0.3355                              | 0.0029 | 1868                                 | 8  | 1866                                | 10 | 1865                                | 16 | 100% |
| 36         | 166                 | 366                | 0.45 | 0.0653                               | 0.0004 | 1.194                               | 0.008 | 0.1327                              | 0.0011 | 783                                  | 13 | 798                                 | 6  | 803                                 | 7  | 101% |
| 37         | 192                 | 300                | 0.64 | 0.0650                               | 0.0007 | 1.215                               | 0.011 | 0.1355                              | 0.0013 | 775                                  | 22 | 807                                 | 7  | 819                                 | 8  | 101% |
| 38         | 47                  | 868                | 0.05 | 0.0798                               | 0.0010 | 2.148                               | 0.012 | 0.1953                              | 0.0017 | 1191                                 | 24 | 1165                                | 6  | 1150                                | 10 | 99%  |
| 39         | 203                 | 1113               | 0.18 | 0.0716                               | 0.0009 | 1.588                               | 0.009 | 0.1608                              | 0.0015 | 975                                  | 27 | 965                                 | 5  | 961                                 | 9  | 100% |
| 40         | 269                 | 810                | 0.33 | 0.1001                               | 0.0010 | 4.018                               | 0.024 | 0.2911                              | 0.0029 | 1626                                 | 18 | 1638                                | 10 | 1647                                | 16 | 101% |
| 41         | 576                 | 743                | 0.78 | 0.0578                               | 0.0004 | 0.561                               | 0.006 | 0.0704                              | 0.0008 | 521                                  | 17 | 452                                 | 4  | 439                                 | 5  | 97%  |
| 42         | 224                 | 513                | 0.44 | 0.0563                               | 0.0006 | 0.558                               | 0.006 | 0.0719                              | 0.0007 | 464                                  | 23 | 450                                 | 5  | 448                                 | 5  | 100% |
| 43         | 204                 | 371                | 0.55 | 0.0560                               | 0.0007 | 0.542                               | 0.007 | 0.0702                              | 0.0006 | 451                                  | 27 | 440                                 | 6  | 438                                 | 4  | 100% |
| 44         | 118                 | 416                | 0.28 | 0.0683                               | 0.0005 | 1.244                               | 0.018 | 0.1320                              | 0.0032 | 879                                  | 15 | 820                                 | 12 | 799                                 | 20 | 97%  |
| 45         | 231                 | 327                | 0.71 | 0.0574                               | 0.0007 | 0.565                               | 0.007 | 0.0713                              | 0.0006 | 509                                  | 28 | 455                                 | 6  | 444                                 | 4  | 98%  |
| 46         | 58                  | 277                | 0.21 | 0.0769                               | 0.0008 | 1.957                               | 0.012 | 0.1846                              | 0.0014 | 1119                                 | 21 | 1101                                | 7  | 1092                                | 8  | 99%  |
| 47         | 391                 | 1074               | 0.36 | 0.0821                               | 0.0006 | 2.244                               | 0.012 | 0.1981                              | 0.0017 | 1249                                 | 15 | 1195                                | 6  | 1165                                | 10 | 97%  |
| 48         | 58                  | 111                | 0.53 | 0.0766                               | 0.0009 | 1.859                               | 0.023 | 0.1760                              | 0.0016 | 1111                                 | 25 | 1067                                | 13 | 1045                                | 9  | 98%  |
| 49         | 64                  | 180                | 0.36 | 0.0725                               | 0.0006 | 1.608                               | 0.014 | 0.1609                              | 0.0014 | 999                                  | 17 | 973                                 | 9  | 962                                 | 8  | 99%  |
| 50         | 213                 | 547                | 0.39 | 0.0585                               | 0.0006 | 0.605                               | 0.006 | 0.0750                              | 0.0006 | 548                                  | 21 | 480                                 | 4  | 466                                 | 4  | 97%  |
| 51         | 221                 | 457                | 0.48 | 0.1284                               | 0.0009 | 6.657                               | 0.051 | 0.3761                              | 0.0050 | 2076                                 | 13 | 2067                                | 16 | 2058                                | 28 | 100% |
| 52         | 70                  | 99                 | 0.71 | 0.1660                               | 0.0010 | 10.930                              | 0.086 | 0.4776                              | 0.0056 | 2518                                 | 10 | 2517                                | 20 | 2517                                | 29 | 100% |
| 53         | 155                 | 419                | 0.37 | 0.0731                               | 0.0004 | 1.638                               | 0.010 | 0.1624                              | 0.0013 | 1018                                 | 12 | 985                                 | 6  | 970                                 | 8  | 98%  |
| 54         | 226                 | 613                | 0.37 | 0.0575                               | 0.0005 | 0.591                               | 0.005 | 0.0745                              | 0.0007 | 511                                  | 18 | 471                                 | 4  | 463                                 | 5  | 98%  |
| 55         | 143                 | 1004               | 0.14 | 0.1398                               | 0.0011 | 5.029                               | 0.050 | 0.2610                              | 0.0053 | 2224                                 | 13 | 1824                                | 18 | 1495                                | 30 | 82%  |
| 56         | 289                 | 262                | 1.10 | 0.0552                               | 0.0009 | 0.511                               | 0.008 | 0.0671                              | 0.0006 | 420                                  | 35 | 419                                 | 7  | 419                                 | 4  | 100% |
| 57         | 102                 | 297                | 0.34 | 0.0985                               | 0.0010 | 3.834                               | 0.022 | 0.2823                              | 0.0026 | 1596                                 | 19 | 1600                                | 9  | 1603                                | 15 | 100% |
| 58         | 99                  | 409                | 0.24 | 0.0679                               | 0.0004 | 1.250                               | 0.008 | 0.1335                              | 0.0012 | 866                                  | 14 | 823                                 | 6  | 808                                 | 7  | 98%  |
| 59         | 266                 | 411                | 0.65 | 0.0579                               | 0.0008 | 0.551                               | 0.008 | 0.0690                              | 0.0005 | 527                                  | 30 | 446                                 | 6  | 430                                 | 3  | 96%  |
| 60         | 71                  | 217                | 0.33 | 0.0563                               | 0.0010 | 0.561                               | 0.010 | 0.0722                              | 0.0005 | 466                                  | 38 | 452                                 | 8  | 449                                 | 3  | 99%  |
| 61         | 399                 | 1746               | 0.23 | 0.0757                               | 0.0003 | 1.668                               | 0.010 | 0.1597                              | 0.0019 | 1088                                 | 9  | 996                                 | 6  | 955                                 | 11 | 96%  |
| 62         | 651                 | 865                | 0.75 | 0.0576                               | 0.0004 | 0.546                               | 0.006 | 0.0688                              | 0.0008 | 516                                  | 17 | 443                                 | 4  | 429                                 | 5  | 97%  |
| 63         | 110                 | 192                | 0.57 | 0.0663                               | 0.0008 | 1.216                               | 0.015 | 0.1329                              | 0.0012 | 817                                  | 25 | 808                                 | 10 | 804                                 | 7  | 100% |
| 64         | 78                  | 164                | 0.48 | 0.0729                               | 0.0009 | 1.685                               | 0.021 | 0.1677                              | 0.0013 | 1010                                 | 24 | 1003                                | 12 | 999                                 | 7  | 100% |
| 65         | 219                 | 307                | 0.71 | 0.0558                               | 0.0010 | 0.534                               | 0.009 | 0.0694                              | 0.0006 | 445                                  | 38 | 435                                 | 7  | 433                                 | 4  | 100% |
| 66         | 199                 | 615                | 0.32 | 0.1171                               | 0.0006 | 2.293                               | 0.024 | 0.1420                              | 0.0015 | 1912                                 | 10 | 1210                                | 12 | 856                                 | 9  | 71%  |
| 67         | 321                 | 702                | 0.46 | 0.1578                               | 0.0007 | 8.058                               | 0.070 | 0.3704                              | 0.0025 | 2432                                 | 8  | 2238                                | 20 | 2031                                | 14 | 91%  |
| 68         | 260                 | 619                | 0.42 | 0.0557                               | 0.0005 | 0.546                               | 0.005 | 0.0710                              | 0.0005 | 442                                  | 20 | 442                                 | 4  | 442                                 | 3  | 100% |
| 69         | 121                 | 598                | 0.20 | 0.0687                               | 0.0005 | 1.248                               | 0.008 | 0.1319                              | 0.0016 | 888                                  | 14 | 823                                 | 6  | 799                                 | 10 | 97%  |
| 70         | 361                 | 486                | 0.74 | 0.0578                               | 0.0005 | 0.583                               | 0.005 | 0.0732                              | 0.0009 | 521                                  | 19 | 467                                 | 4  | 456                                 | 6  | 98%  |
| 71         | 162                 | 648                | 0.25 | 0.0705                               | 0.0004 | 1.472                               | 0.009 | 0.1515                              | 0.0014 | 942                                  | 11 | 919                                 | 6  | 909                                 | 8  | 99%  |
| 72         | 754                 | 761                | 0.99 | 0.0553                               | 0.0005 | 0.511                               | 0.005 | 0.0669                              | 0.0008 | 426                                  | 20 | 419                                 | 4  | 418                                 | 5  | 100% |
| 73         | 40                  | 68                 | 0.58 | 0.0659                               | 0.0018 | 1.270                               | 0.036 | 0.1398                              | 0.0017 | 803                                  | 58 | 832                                 | 23 | 843                                 | 10 | 101% |
| 74         | 1791                | 1724               | 1.04 | 0.0588                               | 0.0005 | 0.641                               | 0.004 | 0.0791                              | 0.0008 | 559                                  | 19 | 503                                 | 3  | 491                                 | 5  | 98%  |
| 75         | 55                  | 124                | 0.44 | 0.0570                               | 0.0020 | 0.562                               | 0.021 | 0.0715                              | 0.0008 | 490                                  | 79 | 453                                 | 17 | 445                                 | 5  | 98%  |

续表 2-4

| 分析点        | Th/ $10^{-6}$ | U/ $10^{-6}$ | Th/U | 同 位 素 比 值                         |             |                                  |             |                                  |             | 年 龄 /Ma                           |             |                                  |             |                                  |             | 谐和度  |
|------------|---------------|--------------|------|-----------------------------------|-------------|----------------------------------|-------------|----------------------------------|-------------|-----------------------------------|-------------|----------------------------------|-------------|----------------------------------|-------------|------|
|            |               |              |      | $^{207}\text{Pb}/^{206}\text{Pb}$ | $\pm\sigma$ | $^{207}\text{Pb}/^{235}\text{U}$ | $\pm\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $\pm\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $\pm\sigma$ | $^{207}\text{Pb}/^{235}\text{U}$ | $\pm\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $\pm\sigma$ |      |
| 样品 TYP07-2 |               |              |      |                                   |             |                                  |             |                                  |             |                                   |             |                                  |             |                                  |             |      |
| 76         | 111           | 188          | 0.59 | 0.0687                            | 0.0008      | 1.259                            | 0.014       | 0.1329                           | 0.0014      | 891                               | 23          | 828                              | 9           | 804                              | 9           | 97%  |
| 77         | 17            | 1421         | 0.01 | 0.0718                            | 0.0005      | 1.567                            | 0.008       | 0.1583                           | 0.0015      | 980                               | 14          | 957                              | 5           | 948                              | 9           | 99%  |
| 78         | 185           | 262          | 0.71 | 0.1020                            | 0.0008      | 3.774                            | 0.030       | 0.2683                           | 0.0047      | 1661                              | 14          | 1587                             | 12          | 1532                             | 27          | 97%  |
| 79         | 270           | 318          | 0.85 | 0.0574                            | 0.0007      | 0.624                            | 0.008       | 0.0787                           | 0.0010      | 508                               | 27          | 492                              | 6           | 489                              | 6           | 99%  |
| 80         | 167           | 462          | 0.36 | 0.0595                            | 0.0006      | 0.642                            | 0.007       | 0.0782                           | 0.0010      | 585                               | 23          | 503                              | 5           | 486                              | 6           | 97%  |
| 81         | 298           | 929          | 0.32 | 0.0779                            | 0.0004      | 2.054                            | 0.013       | 0.1913                           | 0.0023      | 1144                              | 10          | 1134                             | 7           | 1128                             | 14          | 99%  |
| 82         | 124           | 268          | 0.46 | 0.0792                            | 0.0005      | 2.108                            | 0.015       | 0.1930                           | 0.0024      | 1177                              | 12          | 1151                             | 8           | 1138                             | 14          | 99%  |
| 83         | 129           | 191          | 0.67 | 0.0563                            | 0.0014      | 0.482                            | 0.012       | 0.0621                           | 0.0008      | 462                               | 56          | 399                              | 10          | 389                              | 5           | 97%  |
| 84         | 77            | 143          | 0.54 | 0.0668                            | 0.0011      | 1.241                            | 0.019       | 0.1347                           | 0.0016      | 832                               | 36          | 819                              | 13          | 814                              | 10          | 99%  |
| 85         | 1044          | 1335         | 0.78 | 0.0571                            | 0.0005      | 0.576                            | 0.007       | 0.0732                           | 0.0010      | 494                               | 19          | 462                              | 5           | 455                              | 6           | 98%  |
| 86         | 86            | 133          | 0.65 | 0.0552                            | 0.0019      | 0.501                            | 0.018       | 0.0658                           | 0.0008      | 422                               | 77          | 413                              | 14          | 411                              | 5           | 100% |
| 87         | 434           | 400          | 1.09 | 0.0568                            | 0.0007      | 0.550                            | 0.007       | 0.0703                           | 0.0011      | 483                               | 26          | 445                              | 6           | 438                              | 7           | 98%  |
| 88         | 289           | 561          | 0.52 | 0.0564                            | 0.0005      | 0.546                            | 0.006       | 0.0702                           | 0.0008      | 468                               | 21          | 442                              | 4           | 438                              | 5           | 99%  |
| 89         | 289           | 619          | 0.47 | 0.0580                            | 0.0005      | 0.551                            | 0.005       | 0.0689                           | 0.0006      | 529                               | 20          | 446                              | 4           | 430                              | 4           | 96%  |
| 90         | 289           | 420          | 0.69 | 0.0592                            | 0.0006      | 0.575                            | 0.006       | 0.0705                           | 0.0007      | 574                               | 24          | 461                              | 5           | 439                              | 5           | 95%  |
| 91         | 165           | 234          | 0.71 | 0.0990                            | 0.0008      | 3.650                            | 0.023       | 0.2675                           | 0.0027      | 1605                              | 16          | 1561                             | 10          | 1528                             | 16          | 98%  |
| 92         | 32            | 352          | 0.09 | 0.0831                            | 0.0006      | 2.366                            | 0.013       | 0.2066                           | 0.0016      | 1271                              | 14          | 1232                             | 7           | 1210                             | 9           | 98%  |
| 93         | 292           | 488          | 0.60 | 0.0552                            | 0.0006      | 0.528                            | 0.006       | 0.0694                           | 0.0008      | 419                               | 24          | 430                              | 5           | 432                              | 5           | 100% |
| 94         | 257           | 430          | 0.60 | 0.0721                            | 0.0007      | 1.572                            | 0.010       | 0.1580                           | 0.0017      | 990                               | 19          | 959                              | 6           | 946                              | 10          | 99%  |
| 95         | 92            | 168          | 0.55 | 0.0556                            | 0.0017      | 0.461                            | 0.014       | 0.0602                           | 0.0006      | 436                               | 67          | 385                              | 12          | 377                              | 4           | 98%  |
| 96         | 88            | 346          | 0.26 | 0.0700                            | 0.0005      | 1.433                            | 0.011       | 0.1485                           | 0.0015      | 927                               | 13          | 903                              | 7           | 893                              | 9           | 99%  |
| 97         | 61            | 487          | 0.12 | 0.0660                            | 0.0004      | 1.130                            | 0.009       | 0.1242                           | 0.0014      | 806                               | 14          | 768                              | 6           | 755                              | 9           | 98%  |
| 98         | 91            | 211          | 0.43 | 0.0695                            | 0.0006      | 1.435                            | 0.013       | 0.1497                           | 0.0013      | 915                               | 18          | 904                              | 8           | 899                              | 8           | 99%  |
| 99         | 305           | 1467         | 0.21 | 0.0553                            | 0.0005      | 0.527                            | 0.005       | 0.0691                           | 0.0010      | 426                               | 22          | 430                              | 4           | 431                              | 6           | 100% |
| 100        | 115           | 896          | 0.13 | 0.1486                            | 0.0011      | 6.680                            | 0.045       | 0.3260                           | 0.0044      | 2330                              | 13          | 2070                             | 14          | 1819                             | 25          | 88%  |
| 101        | 181           | 267          | 0.68 | 0.0550                            | 0.0009      | 0.546                            | 0.010       | 0.0720                           | 0.0007      | 414                               | 38          | 442                              | 8           | 448                              | 4           | 101% |
| 102        | 536           | 466          | 1.15 | 0.0594                            | 0.0009      | 0.558                            | 0.008       | 0.0681                           | 0.0007      | 583                               | 33          | 450                              | 6           | 424                              | 4           | 94%  |
| 103        | 524           | 841          | 0.62 | 0.0550                            | 0.0004      | 0.480                            | 0.004       | 0.0633                           | 0.0007      | 411                               | 16          | 398                              | 3           | 395                              | 4           | 99%  |
| 104        | 105           | 333          | 0.31 | 0.1609                            | 0.0012      | 9.319                            | 0.068       | 0.4200                           | 0.0052      | 2466                              | 12          | 2370                             | 17          | 2260                             | 28          | 95%  |
| 105        | 205           | 361          | 0.57 | 0.0539                            | 0.0007      | 0.530                            | 0.007       | 0.0713                           | 0.0007      | 369                               | 28          | 432                              | 6           | 444                              | 4           | 103% |
| 106        | 73            | 324          | 0.23 | 0.0739                            | 0.0005      | 1.646                            | 0.012       | 0.1616                           | 0.0019      | 1038                              | 13          | 988                              | 7           | 966                              | 11          | 98%  |
| 107        | 174           | 243          | 0.72 | 0.0724                            | 0.0005      | 1.603                            | 0.012       | 0.1606                           | 0.0010      | 996                               | 14          | 971                              | 7           | 960                              | 6           | 99%  |
| 108        | 151           | 537          | 0.28 | 0.1676                            | 0.0012      | 10.146                           | 0.088       | 0.4392                           | 0.0031      | 2533                              | 12          | 2448                             | 21          | 2347                             | 16          | 96%  |
| 109        | 59            | 486          | 0.12 | 0.0669                            | 0.0004      | 1.257                            | 0.013       | 0.1364                           | 0.0025      | 834                               | 13          | 827                              | 9           | 824                              | 15          | 100% |
| 110        | 89            | 193          | 0.46 | 0.0623                            | 0.0009      | 0.940                            | 0.015       | 0.1095                           | 0.0017      | 685                               | 31          | 673                              | 11          | 670                              | 10          | 100% |
| 111        | 33            | 32           | 1.04 | 0.1660                            | 0.0013      | 10.562                           | 0.095       | 0.4614                           | 0.0044      | 2518                              | 13          | 2485                             | 22          | 2446                             | 24          | 98%  |
| 112        | 60            | 284          | 0.21 | 0.0711                            | 0.0005      | 1.421                            | 0.011       | 0.1450                           | 0.0016      | 959                               | 16          | 898                              | 7           | 873                              | 10          | 97%  |
| 113        | 236           | 329          | 0.72 | 0.0590                            | 0.0006      | 0.838                            | 0.010       | 0.1030                           | 0.0014      | 568                               | 23          | 618                              | 7           | 632                              | 8           | 102% |
| 114        | 139           | 438          | 0.32 | 0.0680                            | 0.0006      | 1.172                            | 0.010       | 0.1249                           | 0.0012      | 870                               | 18          | 788                              | 7           | 759                              | 7           | 96%  |
| 115        | 144           | 244          | 0.59 | 0.0660                            | 0.0008      | 1.226                            | 0.016       | 0.1348                           | 0.0013      | 806                               | 26          | 813                              | 11          | 815                              | 8           | 100% |
| 116        | 189           | 184          | 1.03 | 0.0788                            | 0.0006      | 2.065                            | 0.015       | 0.1901                           | 0.0016      | 1167                              | 14          | 1137                             | 8           | 1122                             | 10          | 99%  |
| 117        | 671           | 1015         | 0.66 | 0.0506                            | 0.0004      | 0.426                            | 0.006       | 0.0610                           | 0.0009      | 224                               | 20          | 360                              | 5           | 382                              | 6           | 106% |
| 118        | 151           | 556          | 0.27 | 0.1206                            | 0.0006      | 4.244                            | 0.048       | 0.2551                           | 0.0053      | 1966                              | 9           | 1683                             | 19          | 1465                             | 31          | 87%  |
| 119        | 373           | 376          | 0.99 | 0.0571                            | 0.0008      | 0.556                            | 0.008       | 0.0705                           | 0.0006      | 497                               | 30          | 449                              | 7           | 439                              | 4           | 98%  |
| 120        | 168           | 1000         | 0.17 | 0.1148                            | 0.0006      | 5.404                            | 0.056       | 0.3415                           | 0.0044      | 1877                              | 9           | 1886                             | 20          | 1894                             | 24          | 100% |
| 样品 XP12-1  |               |              |      |                                   |             |                                  |             |                                  |             |                                   |             |                                  |             |                                  |             |      |
| 1          | 1             | 84           | 0.01 | 0.0734                            | 0.0017      | 1.730                            | 0.035       | 0.1709                           | 0.0013      | 1026                              | 48          | 1020                             | 21          | 1017                             | 8           | 100% |
| 2          | 220           | 510          | 0.43 | 0.1611                            | 0.0010      | 9.905                            | 0.057       | 0.4459                           | 0.0027      | 2467                              | 11          | 2426                             | 14          | 2377                             | 14          | 98%  |
| 3          | 64            | 103          | 0.63 | 0.1120                            | 0.0010      | 5.004                            | 0.045       | 0.3240                           | 0.0042      | 1832                              | 16          | 1820                             | 16          | 1809                             | 23          | 99%  |

续表 2-5

| 分析点       | Th/ $10^{-6}$ | U/ $10^{-6}$ | Th/U | 同 位 素 比 值                         |             |                                  |             |                                  |             | 年 龄 /Ma                           |             |                                  |             |                                  |             | 谐和度  |
|-----------|---------------|--------------|------|-----------------------------------|-------------|----------------------------------|-------------|----------------------------------|-------------|-----------------------------------|-------------|----------------------------------|-------------|----------------------------------|-------------|------|
|           |               |              |      | $^{207}\text{Pb}/^{206}\text{Pb}$ | $\pm\sigma$ | $^{207}\text{Pb}/^{235}\text{U}$ | $\pm\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $\pm\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $\pm\sigma$ | $^{207}\text{Pb}/^{235}\text{U}$ | $\pm\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $\pm\sigma$ |      |
| 样品 XP12-1 |               |              |      |                                   |             |                                  |             |                                  |             |                                   |             |                                  |             |                                  |             |      |
| 4         | 291           | 716          | 0.41 | 0.0552                            | 0.0006      | 0.524                            | 0.005       | 0.0688                           | 0.0012      | 419                               | 23          | 428                              | 4           | 429                              | 7           | 100% |
| 5         | 25            | 52           | 0.49 | 0.0903                            | 0.0017      | 3.044                            | 0.049       | 0.2445                           | 0.0037      | 1432                              | 35          | 1419                             | 23          | 1410                             | 21          | 99%  |
| 6         | 82            | 207          | 0.40 | 0.1686                            | 0.0010      | 11.265                           | 0.082       | 0.4846                           | 0.0069      | 2544                              | 10          | 2545                             | 19          | 2547                             | 36          | 100% |
| 7         | 60            | 67           | 0.90 | 0.0663                            | 0.0030      | 1.144                            | 0.044       | 0.1252                           | 0.0017      | 816                               | 93          | 774                              | 30          | 760                              | 10          | 98%  |
| 8         | 112           | 302          | 0.37 | 0.0559                            | 0.0014      | 0.516                            | 0.011       | 0.0670                           | 0.0008      | 447                               | 55          | 422                              | 9           | 418                              | 5           | 99%  |
| 9         | 65            | 132          | 0.49 | 0.0745                            | 0.0013      | 1.658                            | 0.024       | 0.1614                           | 0.0013      | 1056                              | 34          | 993                              | 14          | 965                              | 8           | 97%  |
| 10        | 114           | 515          | 0.22 | 0.0547                            | 0.0008      | 0.542                            | 0.006       | 0.0719                           | 0.0007      | 399                               | 32          | 440                              | 5           | 448                              | 5           | 102% |
| 11        | 268           | 825          | 0.33 | 0.0716                            | 0.0004      | 1.625                            | 0.010       | 0.1647                           | 0.0017      | 973                               | 13          | 980                              | 6           | 983                              | 10          | 100% |
| 12        | 377           | 611          | 0.62 | 0.0567                            | 0.0009      | 0.569                            | 0.007       | 0.0727                           | 0.0011      | 481                               | 34          | 457                              | 5           | 453                              | 7           | 99%  |
| 13        | 292           | 523          | 0.56 | 0.0614                            | 0.0006      | 0.847                            | 0.007       | 0.1000                           | 0.0006      | 654                               | 21          | 623                              | 5           | 614                              | 4           | 99%  |
| 14        | 49            | 37           | 1.30 | 0.0650                            | 0.0052      | 1.104                            | 0.076       | 0.1233                           | 0.0020      | 773                               | 169         | 756                              | 52          | 750                              | 12          | 99%  |
| 15        | 20            | 1103         | 0.02 | 0.0709                            | 0.0004      | 1.585                            | 0.012       | 0.1621                           | 0.0026      | 955                               | 13          | 964                              | 7           | 968                              | 16          | 100% |
| 16        | 295           | 673          | 0.44 | 0.0648                            | 0.0006      | 1.160                            | 0.009       | 0.1299                           | 0.0023      | 768                               | 18          | 782                              | 6           | 787                              | 14          | 101% |
| 17        | 167           | 228          | 0.73 | 0.0807                            | 0.0009      | 2.103                            | 0.028       | 0.1890                           | 0.0040      | 1215                              | 23          | 1150                             | 15          | 1116                             | 24          | 97%  |
| 18        | 12            | 50           | 0.24 | 0.0879                            | 0.0019      | 3.199                            | 0.061       | 0.2641                           | 0.0034      | 1379                              | 42          | 1457                             | 28          | 1511                             | 19          | 104% |
| 19        | 113           | 451          | 0.25 | 0.0703                            | 0.0005      | 1.591                            | 0.014       | 0.1642                           | 0.0031      | 937                               | 14          | 967                              | 9           | 980                              | 19          | 101% |
| 20        | 381           | 764          | 0.50 | 0.0568                            | 0.0006      | 0.578                            | 0.005       | 0.0737                           | 0.0008      | 485                               | 22          | 463                              | 4           | 459                              | 5           | 99%  |
| 21        | 101           | 157          | 0.64 | 0.0666                            | 0.0010      | 1.286                            | 0.017       | 0.1400                           | 0.0019      | 826                               | 32          | 840                              | 11          | 845                              | 11          | 101% |
| 22        | 110           | 346          | 0.32 | 0.0677                            | 0.0007      | 1.287                            | 0.011       | 0.1379                           | 0.0007      | 859                               | 21          | 840                              | 7           | 833                              | 4           | 99%  |
| 23        | 10            | 60           | 0.17 | 0.2285                            | 0.0016      | 16.297                           | 0.114       | 0.5172                           | 0.0055      | 3042                              | 11          | 2894                             | 20          | 2687                             | 28          | 93%  |
| 24        | 219           | 644          | 0.34 | 0.0673                            | 0.0005      | 1.242                            | 0.008       | 0.1338                           | 0.0008      | 848                               | 16          | 820                              | 5           | 809                              | 5           | 99%  |
| 25        | 226           | 428          | 0.53 | 0.1600                            | 0.0011      | 9.889                            | 0.068       | 0.4483                           | 0.0049      | 2455                              | 11          | 2425                             | 17          | 2388                             | 26          | 98%  |
| 26        | 84            | 639          | 0.13 | 0.1365                            | 0.0008      | 4.730                            | 0.038       | 0.2513                           | 0.0039      | 2183                              | 11          | 1773                             | 14          | 1445                             | 22          | 82%  |
| 27        | 282           | 1049         | 0.27 | 0.0690                            | 0.0004      | 1.377                            | 0.012       | 0.1447                           | 0.0026      | 900                               | 13          | 879                              | 8           | 871                              | 16          | 99%  |
| 28        | 128           | 335          | 0.38 | 0.0941                            | 0.0006      | 3.448                            | 0.021       | 0.2656                           | 0.0028      | 1511                              | 13          | 1515                             | 9           | 1518                             | 16          | 100% |
| 29        | 133           | 324          | 0.41 | 0.0560                            | 0.0012      | 0.548                            | 0.010       | 0.0710                           | 0.0007      | 453                               | 46          | 444                              | 8           | 442                              | 4           | 100% |
| 30        | 316           | 997          | 0.32 | 0.0877                            | 0.0010      | 2.721                            | 0.025       | 0.2250                           | 0.0021      | 1376                              | 21          | 1334                             | 12          | 1308                             | 12          | 98%  |
| 31        | 230           | 1097         | 0.21 | 0.0629                            | 0.0005      | 0.953                            | 0.008       | 0.1100                           | 0.0019      | 703                               | 19          | 680                              | 6           | 673                              | 12          | 99%  |
| 32        | 67            | 94           | 0.71 | 0.0786                            | 0.0023      | 1.820                            | 0.046       | 0.1679                           | 0.0021      | 1163                              | 58          | 1053                             | 26          | 1000                             | 12          | 95%  |
| 33        | 109           | 177          | 0.62 | 0.0569                            | 0.0021      | 0.550                            | 0.017       | 0.0701                           | 0.0009      | 488                               | 80          | 445                              | 13          | 437                              | 5           | 98%  |
| 34        | 165           | 158          | 1.05 | 0.0648                            | 0.0010      | 1.158                            | 0.016       | 0.1296                           | 0.0019      | 768                               | 34          | 781                              | 11          | 786                              | 11          | 101% |
| 35        | 670           | 697          | 0.96 | 0.0572                            | 0.0007      | 0.569                            | 0.006       | 0.0722                           | 0.0012      | 499                               | 26          | 457                              | 5           | 449                              | 7           | 98%  |
| 36        | 341           | 652          | 0.52 | 0.0763                            | 0.0005      | 2.023                            | 0.014       | 0.1923                           | 0.0024      | 1102                              | 13          | 1123                             | 8           | 1134                             | 14          | 101% |
| 37        | 52            | 109          | 0.48 | 0.0656                            | 0.0016      | 1.172                            | 0.024       | 0.1296                           | 0.0015      | 794                               | 51          | 788                              | 16          | 785                              | 9           | 100% |
| 38        | 295           | 569          | 0.52 | 0.0718                            | 0.0005      | 1.740                            | 0.014       | 0.1758                           | 0.0027      | 979                               | 14          | 1023                             | 8           | 1044                             | 16          | 102% |
| 39        | 247           | 1222         | 0.20 | 0.0827                            | 0.0007      | 2.039                            | 0.016       | 0.1787                           | 0.0015      | 1263                              | 16          | 1129                             | 9           | 1060                             | 9           | 94%  |
| 40        | 238           | 1367         | 0.17 | 0.0646                            | 0.0006      | 1.060                            | 0.009       | 0.1190                           | 0.0010      | 762                               | 19          | 734                              | 6           | 725                              | 6           | 99%  |
| 41        | 41            | 122          | 0.34 | 0.1858                            | 0.0015      | 13.369                           | 0.104       | 0.5218                           | 0.0061      | 2706                              | 13          | 2706                             | 21          | 2707                             | 32          | 100% |
| 42        | 95            | 119          | 0.79 | 0.0677                            | 0.0014      | 1.234                            | 0.022       | 0.1322                           | 0.0018      | 858                               | 44          | 816                              | 15          | 801                              | 11          | 98%  |
| 43        | 276           | 500          | 0.55 | 0.0578                            | 0.0007      | 0.597                            | 0.006       | 0.0749                           | 0.0009      | 522                               | 26          | 475                              | 5           | 466                              | 5           | 98%  |
| 44        | 93            | 188          | 0.49 | 0.0578                            | 0.0019      | 0.564                            | 0.016       | 0.0708                           | 0.0007      | 521                               | 73          | 454                              | 13          | 441                              | 5           | 97%  |
| 45        | 33            | 161          | 0.21 | 0.0668                            | 0.0011      | 1.235                            | 0.018       | 0.1341                           | 0.0013      | 832                               | 35          | 816                              | 12          | 811                              | 8           | 99%  |
| 46        | 185           | 174          | 1.06 | 0.0643                            | 0.0013      | 1.067                            | 0.017       | 0.1205                           | 0.0012      | 750                               | 42          | 737                              | 12          | 733                              | 7           | 99%  |
| 47        | 98            | 167          | 0.58 | 0.0589                            | 0.0018      | 0.619                            | 0.015       | 0.0763                           | 0.0011      | 562                               | 66          | 489                              | 12          | 474                              | 7           | 97%  |
| 48        | 41            | 67           | 0.61 | 0.1995                            | 0.0023      | 14.647                           | 0.155       | 0.5325                           | 0.0067      | 2822                              | 19          | 2793                             | 30          | 2752                             | 34          | 99%  |
| 49        | 118           | 82           | 1.44 | 0.0623                            | 0.0029      | 1.018                            | 0.041       | 0.1186                           | 0.0016      | 683                               | 100         | 713                              | 29          | 722                              | 10          | 101% |
| 50        | 63            | 104          | 0.61 | 0.1118                            | 0.0013      | 4.736                            | 0.050       | 0.3073                           | 0.0036      | 1828                              | 21          | 1774                             | 19          | 1728                             | 20          | 97%  |
| 51        | 108           | 634          | 0.17 | 0.0718                            | 0.0007      | 1.563                            | 0.014       | 0.1580                           | 0.0015      | 979                               | 19          | 956                              | 8           | 946                              | 9           | 99%  |
| 52        | 104           | 250          | 0.42 | 0.0699                            | 0.0011      | 1.563                            | 0.022       | 0.1623                           | 0.0012      | 925                               | 34          | 956                              | 14          | 969                              | 7           | 101% |
| 53        | 239           | 397          | 0.60 | 0.0713                            | 0.0008      | 1.635                            | 0.017       | 0.1663                           | 0.0025      | 966                               | 22          | 984                              | 10          | 992                              | 15          | 101% |

续表 2-6

| 分析点       | Th/ $10^{-6}$ | U/ $10^{-6}$ | Th/U | 同 位 素 比 值                         |             |                                  |             |                                  |             | 年 龄 /Ma                           |             |                                  |             |                                  |             | 谐和度  |
|-----------|---------------|--------------|------|-----------------------------------|-------------|----------------------------------|-------------|----------------------------------|-------------|-----------------------------------|-------------|----------------------------------|-------------|----------------------------------|-------------|------|
|           |               |              |      | $^{207}\text{Pb}/^{206}\text{Pb}$ | $\pm\sigma$ | $^{207}\text{Pb}/^{235}\text{U}$ | $\pm\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $\pm\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $\pm\sigma$ | $^{207}\text{Pb}/^{235}\text{U}$ | $\pm\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $\pm\sigma$ |      |
| 样品 XP12-1 |               |              |      |                                   |             |                                  |             |                                  |             |                                   |             |                                  |             |                                  |             |      |
| 54        | 111           | 185          | 0.60 | 0.0724                            | 0.0014      | 1.403                            | 0.023       | 0.1404                           | 0.0010      | 998                               | 39          | 890                              | 15          | 847                              | 6           | 95%  |
| 55        | 74            | 231          | 0.32 | 0.0572                            | 0.0014      | 0.544                            | 0.012       | 0.0689                           | 0.0006      | 501                               | 55          | 441                              | 10          | 430                              | 3           | 97%  |
| 56        | 169           | 281          | 0.60 | 0.0769                            | 0.0009      | 1.785                            | 0.016       | 0.1684                           | 0.0019      | 1118                              | 22          | 1040                             | 10          | 1003                             | 11          | 96%  |
| 57        | 227           | 370          | 0.61 | 0.0597                            | 0.0011      | 0.573                            | 0.009       | 0.0696                           | 0.0008      | 592                               | 40          | 460                              | 7           | 434                              | 5           | 94%  |
| 58        | 151           | 810          | 0.19 | 0.1607                            | 0.0011      | 10.206                           | 0.063       | 0.4607                           | 0.0032      | 2463                              | 12          | 2454                             | 15          | 2442                             | 17          | 100% |
| 59        | 74            | 161          | 0.46 | 0.0801                            | 0.0008      | 2.381                            | 0.020       | 0.2155                           | 0.0024      | 1200                              | 19          | 1237                             | 11          | 1258                             | 14          | 102% |
| 60        | 131           | 376          | 0.35 | 0.0754                            | 0.0008      | 1.669                            | 0.034       | 0.1605                           | 0.0053      | 1080                              | 22          | 997                              | 20          | 960                              | 32          | 96%  |
| 61        | 224           | 358          | 0.63 | 0.1212                            | 0.0007      | 4.367                            | 0.029       | 0.2614                           | 0.0025      | 1974                              | 11          | 1706                             | 12          | 1497                             | 14          | 88%  |
| 62        | 87            | 219          | 0.40 | 0.0726                            | 0.0008      | 1.489                            | 0.014       | 0.1487                           | 0.0010      | 1004                              | 22          | 926                              | 9           | 893                              | 6           | 96%  |
| 63        | 23            | 129          | 0.18 | 0.1159                            | 0.0013      | 4.652                            | 0.046       | 0.2911                           | 0.0020      | 1894                              | 20          | 1759                             | 18          | 1647                             | 12          | 94%  |
| 64        | 94            | 206          | 0.46 | 0.0918                            | 0.0008      | 3.082                            | 0.024       | 0.2436                           | 0.0022      | 1463                              | 16          | 1428                             | 11          | 1405                             | 13          | 98%  |
| 65        | 277           | 631          | 0.44 | 0.0592                            | 0.0007      | 0.563                            | 0.006       | 0.0691                           | 0.0005      | 573                               | 27          | 454                              | 5           | 430                              | 3           | 95%  |
| 66        | 300           | 463          | 0.65 | 0.0624                            | 0.0006      | 1.005                            | 0.008       | 0.1169                           | 0.0010      | 687                               | 21          | 706                              | 6           | 712                              | 6           | 101% |
| 67        | 99            | 302          | 0.33 | 0.0925                            | 0.0006      | 3.087                            | 0.019       | 0.2421                           | 0.0023      | 1477                              | 13          | 1429                             | 9           | 1398                             | 13          | 98%  |
| 68        | 59            | 702          | 0.08 | 0.1135                            | 0.0007      | 4.907                            | 0.029       | 0.3134                           | 0.0027      | 1857                              | 11          | 1803                             | 10          | 1758                             | 15          | 97%  |
| 69        | 163           | 353          | 0.46 | 0.0904                            | 0.0006      | 2.885                            | 0.022       | 0.2315                           | 0.0032      | 1434                              | 13          | 1378                             | 11          | 1342                             | 18          | 97%  |
| 70        | 253           | 698          | 0.36 | 0.1757                            | 0.0012      | 11.347                           | 0.080       | 0.4685                           | 0.0052      | 2612                              | 11          | 2552                             | 18          | 2477                             | 27          | 97%  |
| 71        | 154           | 490          | 0.31 | 0.0737                            | 0.0006      | 1.680                            | 0.014       | 0.1655                           | 0.0016      | 1032                              | 18          | 1001                             | 8           | 987                              | 10          | 99%  |
| 72        | 221           | 667          | 0.33 | 0.0876                            | 0.0008      | 2.581                            | 0.026       | 0.2137                           | 0.0040      | 1374                              | 17          | 1295                             | 13          | 1249                             | 23          | 96%  |
| 73        | 217           | 215          | 1.01 | 0.0588                            | 0.0020      | 0.561                            | 0.016       | 0.0692                           | 0.0008      | 560                               | 73          | 452                              | 13          | 431                              | 5           | 95%  |
| 74        | 247           | 418          | 0.59 | 0.0671                            | 0.0007      | 1.207                            | 0.010       | 0.1305                           | 0.0018      | 840                               | 20          | 804                              | 7           | 791                              | 11          | 98%  |
| 75        | 138           | 295          | 0.47 | 0.0838                            | 0.0011      | 1.958                            | 0.027       | 0.1695                           | 0.0023      | 1288                              | 24          | 1101                             | 15          | 1009                             | 14          | 92%  |
| 76        | 254           | 381          | 0.67 | 0.0564                            | 0.0011      | 0.545                            | 0.008       | 0.0700                           | 0.0010      | 470                               | 42          | 442                              | 7           | 436                              | 6           | 99%  |
| 77        | 135           | 339          | 0.40 | 0.1917                            | 0.0011      | 13.711                           | 0.075       | 0.5187                           | 0.0041      | 2757                              | 10          | 2730                             | 15          | 2694                             | 21          | 99%  |
| 78        | 99            | 214          | 0.47 | 0.0572                            | 0.0017      | 0.546                            | 0.014       | 0.0692                           | 0.0005      | 500                               | 67          | 442                              | 11          | 431                              | 3           | 98%  |
| 79        | 223           | 998          | 0.22 | 0.1572                            | 0.0010      | 5.851                            | 0.067       | 0.2699                           | 0.0064      | 2426                              | 10          | 1954                             | 22          | 1540                             | 37          | 79%  |
| 80        | 224           | 474          | 0.47 | 0.1614                            | 0.0010      | 10.087                           | 0.071       | 0.4533                           | 0.0052      | 2470                              | 11          | 2443                             | 17          | 2410                             | 28          | 99%  |
| 81        | 475           | 833          | 0.57 | 0.0677                            | 0.0006      | 1.215                            | 0.009       | 0.1301                           | 0.0015      | 860                               | 17          | 807                              | 6           | 789                              | 9           | 98%  |
| 82        | 240           | 706          | 0.34 | 0.0631                            | 0.0004      | 0.964                            | 0.007       | 0.1107                           | 0.0012      | 713                               | 15          | 685                              | 5           | 677                              | 7           | 99%  |
| 83        | 382           | 2297         | 0.17 | 0.0660                            | 0.0004      | 1.185                            | 0.007       | 0.1301                           | 0.0014      | 808                               | 11          | 793                              | 5           | 788                              | 8           | 99%  |
| 84        | 62            | 63           | 0.98 | 0.1133                            | 0.0013      | 4.877                            | 0.051       | 0.3123                           | 0.0028      | 1852                              | 21          | 1798                             | 19          | 1752                             | 16          | 97%  |
| 85        | 198           | 281          | 0.71 | 0.0836                            | 0.0006      | 2.499                            | 0.016       | 0.2169                           | 0.0017      | 1282                              | 13          | 1272                             | 8           | 1265                             | 10          | 100% |
| 86        | 43            | 60           | 0.72 | 0.0678                            | 0.0030      | 1.160                            | 0.044       | 0.1241                           | 0.0016      | 861                               | 91          | 782                              | 30          | 754                              | 10          | 96%  |
| 87        | 59            | 39           | 1.51 | 0.1195                            | 0.0016      | 5.815                            | 0.069       | 0.3530                           | 0.0034      | 1949                              | 25          | 1949                             | 23          | 1949                             | 19          | 100% |
| 88        | 116           | 227          | 0.51 | 0.0556                            | 0.0013      | 0.538                            | 0.011       | 0.0701                           | 0.0006      | 437                               | 51          | 437                              | 9           | 437                              | 4           | 100% |
| 89        | 111           | 305          | 0.36 | 0.0602                            | 0.0009      | 0.744                            | 0.009       | 0.0895                           | 0.0008      | 612                               | 31          | 564                              | 7           | 553                              | 5           | 98%  |
| 90        | 199           | 369          | 0.54 | 0.0553                            | 0.0009      | 0.544                            | 0.007       | 0.0714                           | 0.0006      | 424                               | 37          | 441                              | 6           | 445                              | 4           | 101% |
| 91        | 329           | 610          | 0.54 | 0.0564                            | 0.0006      | 0.552                            | 0.005       | 0.0709                           | 0.0007      | 470                               | 24          | 446                              | 4           | 441                              | 4           | 99%  |
| 92        | 120           | 114          | 1.06 | 0.0685                            | 0.0013      | 1.533                            | 0.024       | 0.1623                           | 0.0021      | 884                               | 38          | 944                              | 15          | 969                              | 13          | 103% |
| 93        | 40            | 118          | 0.34 | 0.0676                            | 0.0015      | 1.208                            | 0.022       | 0.1295                           | 0.0012      | 857                               | 45          | 804                              | 15          | 785                              | 7           | 98%  |
| 94        | 430           | 591          | 0.73 | 0.0562                            | 0.0006      | 0.553                            | 0.005       | 0.0714                           | 0.0008      | 460                               | 24          | 447                              | 4           | 445                              | 5           | 99%  |
| 95        | 249           | 345          | 0.72 | 0.0980                            | 0.0008      | 3.623                            | 0.028       | 0.2682                           | 0.0038      | 1586                              | 14          | 1555                             | 12          | 1532                             | 22          | 99%  |
| 96        | 73            | 2172         | 0.03 | 0.0572                            | 0.0005      | 0.639                            | 0.005       | 0.0811                           | 0.0010      | 498                               | 19          | 502                              | 4           | 502                              | 6           | 100% |
| 97        | 109           | 287          | 0.38 | 0.0653                            | 0.0009      | 1.071                            | 0.011       | 0.1188                           | 0.0015      | 785                               | 27          | 739                              | 8           | 724                              | 9           | 98%  |
| 98        | 174           | 277          | 0.63 | 0.1052                            | 0.0008      | 4.415                            | 0.031       | 0.3043                           | 0.0033      | 1718                              | 14          | 1715                             | 12          | 1713                             | 18          | 100% |
| 99        | 31            | 30           | 1.01 | 0.0933                            | 0.0069      | 1.706                            | 0.107       | 0.1326                           | 0.0031      | 1493                              | 140         | 1011                             | 63          | 803                              | 19          | 79%  |
| 100       | 86            | 144          | 0.60 | 0.0654                            | 0.0013      | 1.111                            | 0.019       | 0.1232                           | 0.0011      | 788                               | 43          | 759                              | 13          | 749                              | 7           | 99%  |
| 101       | 368           | 1073         | 0.34 | 0.0557                            | 0.0005      | 0.538                            | 0.004       | 0.0701                           | 0.0006      | 440                               | 18          | 437                              | 3           | 437                              | 4           | 100% |
| 102       | 238           | 615          | 0.39 | 0.0671                            | 0.0005      | 1.210                            | 0.009       | 0.1307                           | 0.0013      | 842                               | 15          | 805                              | 6           | 792                              | 8           | 98%  |
| 103       | 197           | 184          | 1.07 | 0.0668                            | 0.0011      | 1.214                            | 0.017       | 0.1318                           | 0.0012      | 832                               | 34          | 807                              | 11          | 798                              | 7           | 99%  |

续表 2-7

| 分析点       | Th/10 <sup>-6</sup> | U/10 <sup>-6</sup> | Th/U | 同 位 素 比 值                            |        |                                     |       |                                     |        | 年 龄 /Ma                              |    |                                     |    |                                     |    | 谐和度  |
|-----------|---------------------|--------------------|------|--------------------------------------|--------|-------------------------------------|-------|-------------------------------------|--------|--------------------------------------|----|-------------------------------------|----|-------------------------------------|----|------|
|           |                     |                    |      | <sup>207</sup> Pb/ <sup>206</sup> Pb | ±σ     | <sup>207</sup> Pb/ <sup>235</sup> U | ±σ    | <sup>206</sup> Pb/ <sup>238</sup> U | ±σ     | <sup>207</sup> Pb/ <sup>206</sup> Pb | ±σ | <sup>207</sup> Pb/ <sup>235</sup> U | ±σ | <sup>206</sup> Pb/ <sup>238</sup> U | ±σ |      |
| 样品 XP12-1 |                     |                    |      |                                      |        |                                     |       |                                     |        |                                      |    |                                     |    |                                     |    |      |
| 104       | 273                 | 491                | 0.56 | 0.0573                               | 0.0008 | 0.565                               | 0.007 | 0.0715                              | 0.0009 | 503                                  | 29 | 455                                 | 5  | 445                                 | 5  | 98%  |
| 105       | 156                 | 756                | 0.21 | 0.0704                               | 0.0005 | 1.529                               | 0.011 | 0.1576                              | 0.0014 | 939                                  | 16 | 942                                 | 7  | 943                                 | 8  | 100% |
| 106       | 214                 | 388                | 0.55 | 0.1000                               | 0.0007 | 3.944                               | 0.026 | 0.2860                              | 0.0028 | 1625                                 | 13 | 1623                                | 11 | 1621                                | 16 | 100% |
| 107       | 109                 | 267                | 0.41 | 0.0668                               | 0.0007 | 1.274                               | 0.012 | 0.1384                              | 0.0010 | 830                                  | 23 | 834                                 | 8  | 835                                 | 6  | 100% |
| 108       | 30                  | 313                | 0.10 | 0.1553                               | 0.0009 | 8.949                               | 0.047 | 0.4180                              | 0.0026 | 2405                                 | 10 | 2333                                | 12 | 2252                                | 14 | 97%  |
| 109       | 86                  | 201                | 0.43 | 0.0561                               | 0.0015 | 0.547                               | 0.012 | 0.0707                              | 0.0006 | 457                                  | 58 | 443                                 | 10 | 440                                 | 4  | 99%  |
| 110       | 190                 | 417                | 0.45 | 0.0818                               | 0.0005 | 2.253                               | 0.018 | 0.1998                              | 0.0029 | 1240                                 | 13 | 1198                                | 9  | 1174                                | 17 | 98%  |
| 111       | 148                 | 304                | 0.49 | 0.0550                               | 0.0011 | 0.568                               | 0.010 | 0.0749                              | 0.0010 | 411                                  | 44 | 456                                 | 8  | 466                                 | 6  | 102% |
| 112       | 239                 | 452                | 0.53 | 0.0560                               | 0.0008 | 0.567                               | 0.007 | 0.0734                              | 0.0011 | 452                                  | 31 | 456                                 | 6  | 457                                 | 7  | 100% |
| 113       | 221                 | 454                | 0.49 | 0.0666                               | 0.0006 | 1.316                               | 0.011 | 0.1433                              | 0.0022 | 826                                  | 18 | 853                                 | 7  | 863                                 | 14 | 101% |
| 114       | 584                 | 504                | 1.16 | 0.0660                               | 0.0005 | 1.253                               | 0.009 | 0.1378                              | 0.0012 | 805                                  | 16 | 825                                 | 6  | 832                                 | 7  | 101% |
| 115       | 107                 | 1162               | 0.09 | 0.0696                               | 0.0004 | 1.480                               | 0.011 | 0.1541                              | 0.0022 | 917                                  | 12 | 922                                 | 7  | 924                                 | 13 | 100% |
| 116       | 87                  | 577                | 0.15 | 0.1024                               | 0.0006 | 4.258                               | 0.030 | 0.3017                              | 0.0045 | 1668                                 | 10 | 1685                                | 12 | 1700                                | 25 | 101% |
| 117       | 610                 | 708                | 0.86 | 0.0575                               | 0.0006 | 0.570                               | 0.005 | 0.0718                              | 0.0008 | 511                                  | 21 | 458                                 | 4  | 447                                 | 5  | 98%  |
| 118       | 27                  | 1039               | 0.03 | 0.1996                               | 0.0012 | 14.444                              | 0.125 | 0.5247                              | 0.0081 | 2823                                 | 10 | 2779                                | 24 | 2719                                | 42 | 98%  |
| 119       | 27                  | 669                | 0.04 | 0.0703                               | 0.0005 | 1.555                               | 0.013 | 0.1604                              | 0.0026 | 938                                  | 14 | 953                                 | 8  | 959                                 | 16 | 101% |
| 120       | 115                 | 1272               | 0.09 | 0.1436                               | 0.0010 | 7.330                               | 0.050 | 0.3701                              | 0.0035 | 2271                                 | 12 | 2152                                | 15 | 2030                                | 19 | 94%  |

3.3 变质石英砂岩(样品 XP12-1)

变质石英砂岩(XP12-1)中的锆石呈卵形—柱状,所有颗粒均发育韵律环带,个别颗粒发育狭窄的暗色或灰色生长边(图 2-c)。120 个分析点全部位于韵律环带部位。有效数据所获得的年龄从 2823Ma±10Ma 变化到 418Ma±5Ma,其中 1 个主要峰值约为 442Ma,另 5 个次要峰值约为 2460Ma、968Ma、803Ma、788Ma 和 723Ma(图 3)。

4 讨 论

4.1 刘岭群的时代

前人<sup>[34]</sup>对于刘岭群沉积时代的确定主要依据古生物化石,自下而上将刘岭群分为中泥盆世牛耳川组、池沟组、青石垭组和晚泥盆世桐峪寺组。青石垭组产腕足类化石(*Stringocephalus*, *Ilmenia sinensis*, *Emanuella*)和珊瑚化石(*Thamnopora mcholsom Frech*, *Pseudomicroplasma* sp., *Alveolitella* sp.),其中 *Stringocephalus* 是中泥盆世晚期的标准分子。桐峪寺组产腕足类(*Chonetes*)、孢子化石(*Ara-chaeozonotrites varibilis*, *Discerussporites muromafestus*, *Samarisporites comcinnus* 等)、疑源类(*Micrystrid-*

*ium* sp.)、几丁虫(*Aangochitina* sp.)、虫颚(*Scolec-odonts*)等,时代属晚泥盆世。然而,牛耳川组和池沟组泥质灰岩中缺乏珊瑚和腕足类化石,其精确的地层年龄仍然不确定,仅根据层序关系也可将牛耳川组和池沟组一同定为中泥盆世。由于地层的沉积时代比碎屑形成的时代年轻,因此碎屑锆石的年龄常常被用来约束地层沉积时代的上限。最近, Dong 等<sup>[9]</sup>在刘岭群 3 个变质砂岩样品中获得的最年轻的碎屑锆石年龄为 401Ma±6Ma,最小的峰值年龄为 429~482Ma,由此推断刘岭群的沉积时代不早于中泥盆世。本次取自池沟组的 2 个变质砂岩样品 DF04-4 和 XP12-1 也给出了相似的最小年龄峰值,分别为 440Ma 和 442Ma。然而,从青石垭组含石榴二云石英片岩(样品 TYP07-2)中获得最年轻的一组年龄区间为 377~395Ma,峰值年龄为 392Ma。因此,从碎屑锆石年代学的角度可以证实沉积作用持续到晚泥盆世。

位于刘岭群北侧的武关杂岩是紧邻商丹断裂带的一套变质火山—沉积岩系(图 1-b)。主要由变质碎屑岩、变泥质岩及少量斜长角闪岩、大理岩和石英岩夹层组成。武关杂岩中同沉积变质安山

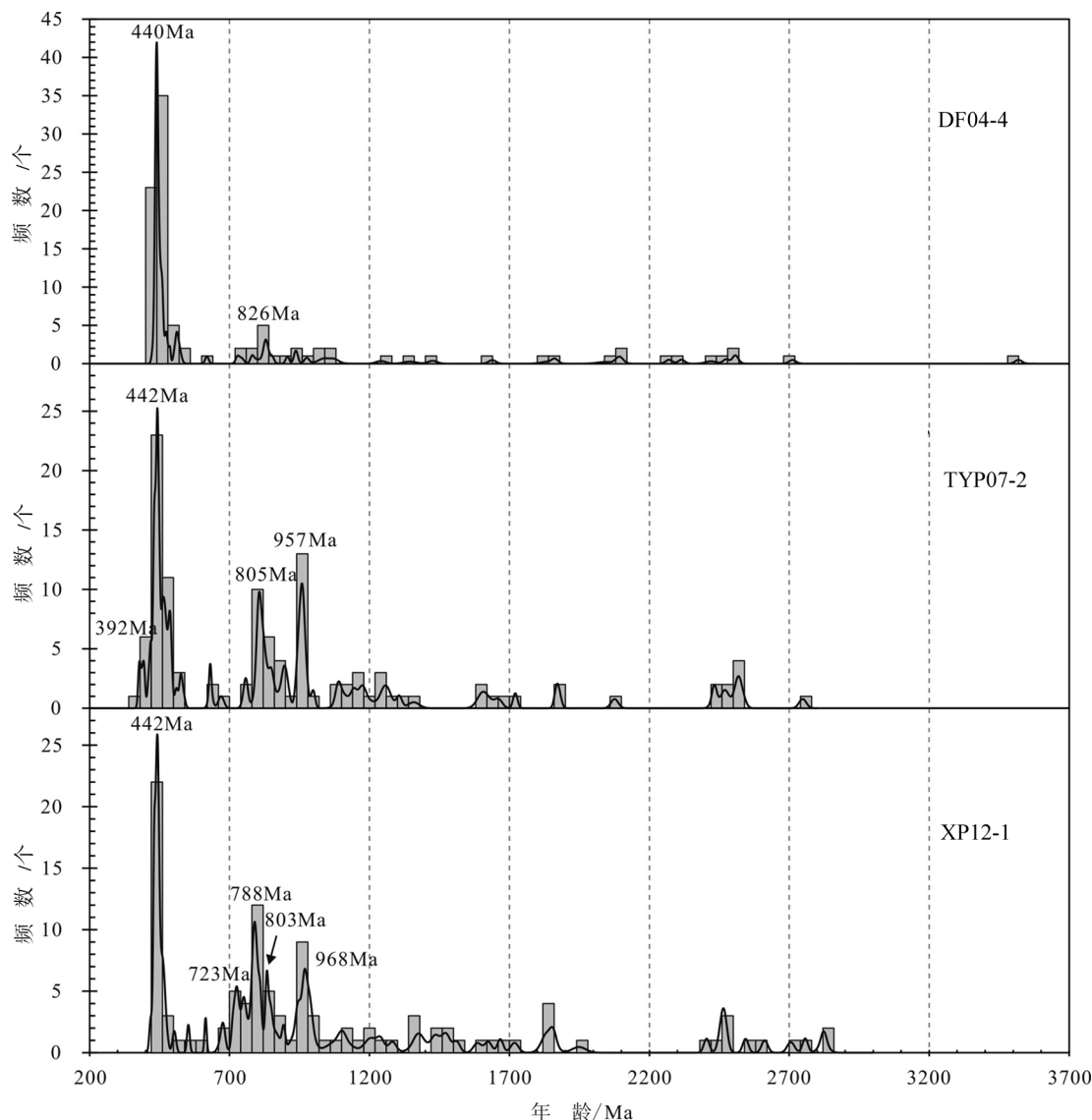


图3 刘岭群变质砂岩中碎屑锆石 U-Pb 年龄频率分布

Fig. 3 Relative probability plots of U-Pb ages for concordant detrital zircons from metasandstones of the Liuling Group

岩的形成时代为  $368\text{Ma} \pm 3\text{Ma}$ , 因此可将沉积时代限定为晚泥盆世<sup>[10]</sup>。构成武关杂岩主体的变质沉积岩在沉积时代和物质来源上与刘岭群具有可比性(见下文详细讨论)。由此说明, 武关杂岩的变质沉积岩与南侧刘岭群可能同为晚泥盆世盆地的沉积地层。二者在岩石组合、原岩建造及变性特征上的差异<sup>[37-38]</sup>, 可能是由于二者在盆地中的位置不同所致。

#### 4.2 刘岭群的物质来源

刘岭群的物质来源一直是个悬而未决的问

题。基于刘岭群砂岩的地球化学特征, Gao 等<sup>[39]</sup>认为, 碎屑物质既来源于北秦岭, 也来源于南秦岭。和政军等<sup>[19]</sup>对刘岭群砂岩的地球化学研究表明, 其具有较高的化学成熟度, 碎屑物质可能来源于相对稳定的陆源区或者是更老的沉积岩再旋回的产物, 属于扬子板块被动大陆边缘盆地沉积。Yan 等<sup>[23-24]</sup>对刘岭群各个岩性组的碎屑岩进行了详细的岩石地球化学研究, 认为刘岭群主要由成熟度低的硬砂岩组成, 物质来源为北秦岭大陆岛弧大量不成熟的长英质碎屑和少量弧基底的成熟性碎屑, 属于北秦

岭岛弧南缘弧前盆地沉积。Dong 等<sup>[9]</sup>对黑河和武关地区的刘岭群中 3 个变质砂岩样品进行了碎屑锆石 LA-ICP-MS U-Pb 测年分析, 获得碎屑锆石年龄频率的主要峰值为 400~600Ma, 次要峰值为 800~1100Ma, 其他样品年龄散布在 700~800Ma 之间。由此推断, 北秦岭和南秦岭共同为其提供物源, 其中北秦岭为主要物源供给, 刘岭群形成于前陆盆地环境。

本文的 3 个变质砂岩样品 (DF04-4、TYP07-2 和 XP12-1) 给出的碎屑锆石年龄谱图相差不大, 主要峰值约为 442Ma, 次要峰值约为 2.5Ga、900~970Ma 和 780~850Ma, 仅样品 XP12-1 给出了 1 组 723Ma 的次要峰值年龄。这一年龄图谱与刘岭群北侧武关杂岩 (780~920Ma 和 440~480Ma)<sup>[9-10]</sup>、桐柏南湾复理石 (970Ma、810~840Ma、480~490Ma 和 435~440Ma)<sup>[6]</sup> 和佛子岭岩群 (2.5Ga、1.8~1.9Ga、0.7~1.0Ga 和 0.4~0.5Ga)<sup>[40]</sup> 的年代学图谱基本相当, 因此将刘岭群归属于泥盆纪浊积岩建造应没有异议。442Ma、780~850Ma 和 900~970Ma 三个主要的年龄峰值 (约占) 说明, 北秦岭志留纪—泥盆纪岩浆岩及其前寒武纪基底可能是刘岭群碎屑沉积岩的重要物源, 这一假设得到了刘岭群碎屑沉积物地球化学研究<sup>[24]</sup> 的证实。同时, 通过对刘岭群和秦岭岩群沉积岩中碎屑锆石年龄图谱<sup>[4,28]</sup> 对比可以看出, 刘岭群中的所有峰值年龄在北秦岭中都能发现。因此, 刘岭群的碎屑物质可能仅来源于北秦岭。由此可见, 刘岭群及其对应的南湾复理石和佛子岭群应属于弧前盆地复理石建造, 而非扬子板块北缘被动边缘沉积或者前陆盆地沉积。

#### 4.3 构造意义

华北与扬子陆块的缝合经历了显生宙以来从增生到碰撞的多阶段构造演化。虽然多数学者<sup>[2-3,5-6,22,41]</sup> 认为秦岭大陆岛弧与华北陆块之间的弧陆碰撞结束于志留纪末, 同时在华北陆块南缘形成了一个安第斯型的大陆边缘, 但是, 随后关于大陆边缘增生和古秦岭洋 (Dong 等<sup>[3]</sup> 称其为商丹洋) 关闭的构造演化过程则存在很大的争议。基于刘岭群的地球化学特征和碎屑锆石的研究, 一些学者<sup>[9,39]</sup> 提出古秦岭洋的关闭发生在泥盆纪早期。同时, 秦岭造山带大规模的岛弧岩浆作用结束于泥盆纪这一事实<sup>[3,32-33]</sup> 似乎印证了这一推断。然而, 桐柏、大别和苏鲁地区高压/超高压变质作用的年龄<sup>[41-46]</sup> 和古地磁数据<sup>[47-48]</sup>

则表明华北与扬子陆块最终碰撞发生于晚二叠世—三叠纪<sup>[41-43,45-46]</sup>。

最近的研究证实, 刘岭群北侧的武关杂岩形成于秦岭大陆岛弧南缘的弧前盆地环境<sup>[9-10]</sup>。值得注意的是, 武关杂岩主体的变质沉积岩中碎屑锆石的年龄图谱和刘岭群年代学图谱基本相当。因此, 构成武关杂岩主体的变质沉积岩应属于泥盆纪刘岭群浊积岩的一部分<sup>[10]</sup>。本文研究证实, 刘岭群的碎屑物质来源于北秦岭大陆岛弧, 同时刘岭群最新的地球化学研究也证实其碎屑物质没有南秦岭的贡献<sup>[24]</sup>。因此, 刘岭群和武关杂岩同属于华北板块南缘弧前盆地的产物。此外, 武关杂岩中与岛弧相关的 350~370Ma 的火成岩也暗示了存在同期的洋壳俯冲<sup>[10]</sup>。由此可见, 古秦岭洋的最终关闭应在泥盆纪之后, 华北与扬子陆块碰撞的主缝合线可能位于刘岭群的南侧。

## 5 结 论

(1) 刘岭群碎屑锆石中最年轻的一组年龄区间 (377~392Ma) 表明其沉积时代可以持续到晚泥盆世。

(2) 刘岭群 3 个主要的峰值年龄 (442Ma、780~850Ma 和 900~970Ma) 说明, 北秦岭志留纪—泥盆纪岩浆岩及其前寒武纪基底可能是刘岭群碎屑沉积岩的主要物源。

(3) 刘岭群和武关杂岩具有相似的沉积年龄和物质来源, 它们共同构成了华北陆块南缘中一晚泥盆世弧前盆地, 暗示古秦岭洋的最终闭合发生在泥盆纪之后, 华北与扬子陆块碰撞的主缝合线应位于刘岭群的南侧。

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