# 内蒙古巴林左旗谭家湾剖面中三叠统幸福之路组厘定及其物源分析

## ——来自碎屑锆石LA-ICP-MS U-Pb测年的证据

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**内容提要**:内蒙古巴林左旗谭家湾剖面位于大兴安岭南部,岩性上表现为一套复成分砾岩及其上覆的以紫灰、灰紫色砂岩为主的红层沉积。通过区域地层对比认为,该剖面地层相当于幸福之路组建组剖面的中、下段。本文对采自该剖面幸福之路组中段下部的砂岩样品开展碎屑锆石LA-ICP-MS U-Pb测年分析,测年结果显示出最年轻的锆石年龄为244 Ma,最年轻的峰值年龄为268 Ma,可知该剖面幸福之路组中段沉积时代应晚于244 Ma;结合同层位粉砂岩中孢粉化石鉴定结果,推测该剖面幸福之路组中段沉积时代为中三叠世中期。砂岩样品碎屑锆石谐和年龄的组成和分布特征说明该剖面幸福之路组沉积物来源多样,结合相关区域构造和前人锆石U-Pb测年资料,推测主要物源为苏尼特左旗—锡林浩特—西乌旗一带古生代岩浆岩、林西地区中二叠世—中三叠世花岗岩(花岗质片麻岩)、华北板块北缘早古生代岩浆岩。

**关键词**:中三叠统;幸福之路组;碎屑锆石LA-ICP-MS U-Pb测年;物源分析;谭家湾剖面

大兴安岭南部地区在上二叠统林西组之上广泛分布了一套以红层为主要特征的杂色碎屑岩组合沉积。关于这套地层,前人主要围绕其沉积时限开展过相关研究。其中,朱儒峰等(1992)将幸福之路地区查干布拉格剖面和哈拉山东剖面的该套沉积确立为幸福之路组,并认为该套地层在岩性和构造特征上与晚二叠世地层存在明显差异,将其时代划为早三叠世;和政军等(1997,1998)通过研究巴林右旗幸福之路苏木查干布拉格剖面幸福之路组中采集到的叶肢介化石,认为中段下部沉积时代为早三叠世早期,上段下部沉积时代为中三叠世早期;郑月娟等(2014,2015)通过凝灰岩和侵入岩脉LA-ICP-MS锆石U-Pb年龄测试结果分析,认为幸福之路地区查干布拉格剖面幸福之路组二段沉积时代为晚二叠世—早三叠世,哈拉山东剖面幸福之路组三段的沉积时代为早三叠世早期。可见目前关于大兴安岭南部幸福之路组地层沉积时代的认识不尽相同;同时,前人针对这套地层物源特征的研究也相对较少,朱俊宾等(2017)研究认为内蒙古东南部幸福之路组砂岩物源主要来自林西周边岩浆岩。

碎屑锆石是沉积岩中常见的副矿物,具有较强的抗风化能力。沉积物中碎屑锆石的U-Pb年龄谱可以用来限定沉积岩形成时代下限(Fedo et al.,2003;Griffin et al.,2004)以及判别沉积物来源等,因此碎屑锆石LA-ICP-MS U-Pb测年是揭示沉积地层年代学信息及分析物源的一种有效的手段。因此本文以巴林左旗谭家湾剖面为研究对象,在大比例尺剖面实测资料的基础上,对采自剖面下部的砂岩样品开展碎屑锆石LA-ICP-MS U-Pb测年分析,并结合同一层位粉砂岩中孢粉化石鉴定结果及前人相关研究成果,对该剖面地层时代归属、沉积物来源等进行研究探讨,对重新厘定大兴安岭南部幸福之路组地层时代、明确其物源特征和进一步完善该地区基础地质认识具有重要意义。

## 1 地质概况及采样剖面

地理位置上,研究区位于大兴安岭中南部、内蒙古自治区巴林左旗一带;大地构造上,研究区位于额尔齐斯—西拉木伦构造—地层大区,该大区是古亚洲洋北支最终闭合消失的对接带(潘桂棠等,2009;

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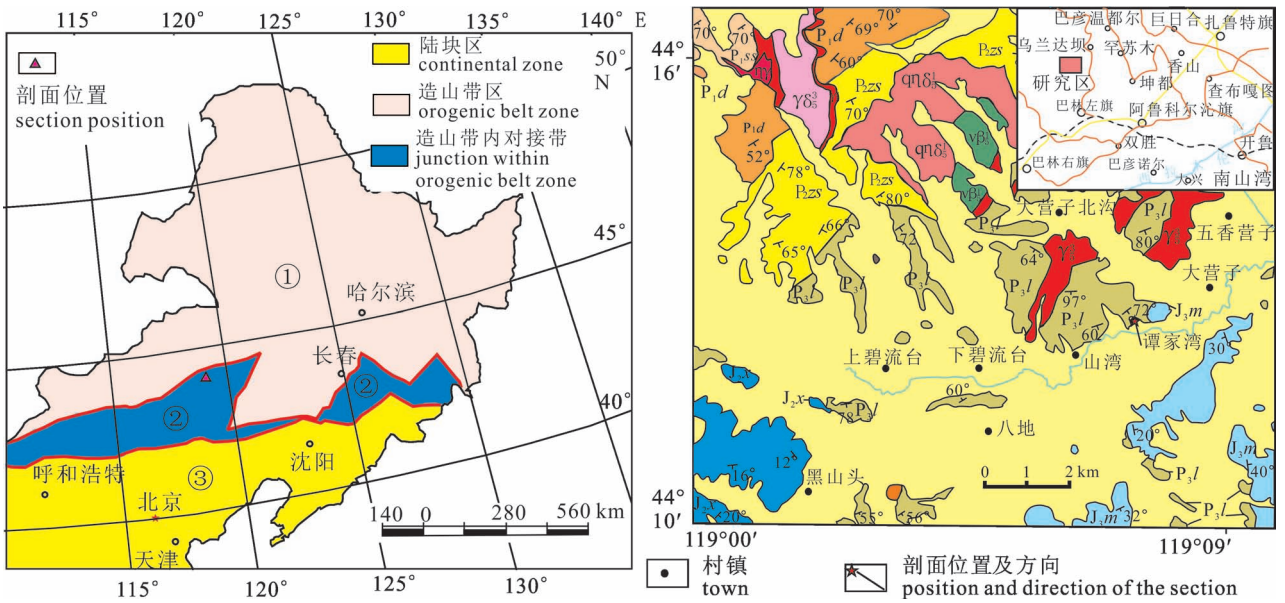



图 1 内蒙古巴林左旗谭家湾剖面构造位置及研究区地质简图(张克信等,2015,2016;张海华等,2015)

Fig. 1 Map of geological structure position of Tanjiawan section in Bairin Left Banner, Inner Mongolia and sketch geological map of the study area(After Zhang Kexin et al.,2015&,2016&;Zhang Haihua et al.,2015&)

构造—地层大区:①—阿尔泰—兴蒙;②—额尔齐斯—西拉木伦;③—华北;$J_3m$—满克头鄂博组;$J_2x$—新民组;$P_3l$—林西组;$P_2zs$—哲斯组;$P_1d$—大石寨组;$P_1ss$—寿山沟组;ηγ—二长花岗岩;$\gamma_5^3$—细粒花岗岩;$\gamma\delta_5^3$—中粒花岗闪长岩;$q\eta\delta_5^1$—石英二长闪长岩;$\nu\beta_5^1$—辉绿岩

Tectonic and stratigraphic regions: ①—Altai—Xing'an Mongolian; ②—Eerqisi—Xar Moron; ③—North China; $J_3m$—Manketou'ebo Formation; $J_2x$—Xinmin Formation; $P_3l$—Linxi Formation; $P_2zs$—Zhesi Formation; $P_1d$—Dashizhai Formation; $P_1ss$—Shoushangou Formation; ηγ—monzonitic granite; $\gamma_5^3$—fine-grained granite; $\gamma\delta_5^3$—medium-grained granodiorite; $q\eta\delta_5^1$—quartz monzobiorite; $\nu\beta_5^1$—diabase

成守德等,2011;李益龙等,2012;张克信等,2015;汪相,2018);地层上,研究区晚古生代地层出露较广泛(图 1)。本次研究剖面为谭家湾剖面,位于巴林左旗碧流台乡谭家湾村北,笔者等对该剖面开展了实测工作。该剖面长约 430 m,顶部被第四系覆盖,底部因花岗斑岩侵入而出露不全。该剖面实测分层情况具体如下,在第 8 层的细粒长石岩屑杂砂岩、粉砂岩中分别采集了碎屑岩测年样品(BTP8-2TWS)、孢粉分析样品(BTP8-2BF)(图 2)。

**幸福之路组中段(未见顶,被第四系覆盖)**

358.5 m

31. 灰绿色中薄层细粒长石石英砂岩夹灰紫色薄层粉砂岩 26.1 m
30. 灰紫色中薄层粉砂岩夹灰绿色细砂岩透镜体 4.6 m
29. 紫灰色、灰色中薄层细粒长石石英砂岩,夹灰紫色薄层粉砂岩,粉砂岩具单斜层理、波状层理,灰色砂岩中见灰紫色冲刷角砾 5.6 m
28. 灰绿色薄层粗粉砂岩 3.1 m
27. 灰紫色薄层粉砂岩 9.0 m
26. 灰绿色中薄层粉砂岩夹灰紫色薄层粉砂岩 23.0 m
25. 灰紫色中薄层粉砂岩 3.3 m
24. 黄绿色中薄层粉砂岩夹同色细砂岩和紫灰色粉砂岩、粉砂质泥岩 5.0 m
23. 灰紫色粉砂岩,底部见 1 m 厚紫灰色细粒长石石英砂岩,粉砂岩中具水平层理 7.9 m
22. 黄绿色中薄层细粒岩屑长石砂岩 6.3 m
21. 紫灰色薄层粉砂岩 5.0 m
20. 灰色薄层细粒岩屑长石砂岩,夹绿灰色薄层粉砂质板岩 9.0 m
19. 灰紫色薄层细砂岩夹灰紫色薄层粉砂岩和黄绿色薄层细砂岩 24.7 m
18. 灰白色薄层细粒岩屑石英砂岩 7.4 m
17. 黄绿色中薄层中细粒长石岩屑砂岩,夹同色细砂岩、粉砂岩和灰白色薄层细粒石英砂岩 26.3 m
16. 灰紫色薄层粉砂岩 5.8 m
15. 黄绿色薄层细粒长石岩屑杂砂岩 4.7 m
14. 灰紫色薄层粗粉砂岩 2.4 m
13. 黄绿色粉砂岩夹同色含冲刷角砾中粗粒岩屑长石砂岩 10.0 m
12. 灰紫色薄层粉砂岩夹同色泥质粉砂岩 1.7 m
11. 黄绿色细粒岩屑长石杂砂岩 16.2 m
10. 灰紫色薄层细粒杂砂岩 4.5 m
9. 黄绿色中薄层中细粒长石岩屑砂岩 2.4 m

8. 灰紫色薄层粉砂岩夹黄绿色薄层粉砂岩和细粒长石岩屑杂砂岩　13.4 m
7. 黄绿色薄层细粒长石岩屑砂岩　3.2 m
6. 灰紫色薄层粉砂岩,夹同色薄层细砂岩,粉砂岩具水平层理　6.0 m
5. 灰紫色中粗粒含海绿石长石岩屑砂岩与绿灰色中薄层中粗粒岩屑长石砂岩不等厚互层,下部绿灰色砂岩中具灰紫色粉砂岩冲刷角砾,上部夹灰紫色薄层粉砂岩　21.9 m
4. 紫灰色中薄层中细粒长石岩屑砂岩,夹灰紫色薄层粉砂岩　11.0 m
3. 紫灰色中薄层中粗粒长石岩屑砂岩,夹灰紫色薄层含细砾粗砂岩和紫灰色薄层细砂岩　18.0 m
2. 杂色中薄层含细砾中细粒长石岩屑砂岩　7.4 m

**幸福之路组下段**

1. 灰绿色、绿灰色中厚层中细砾复成分砾岩,夹含砾粗砂岩透镜体,砾石略呈叠瓦状排列　63.6 m

**(未见底,被花岗斑岩侵入)**

谭家湾剖面底部主要沉积一套复成分砾岩,砾石分选差、磨圆多呈次圆状,砂质胶结;砾岩之上主要表现为一套岩性以紫灰、灰紫色砂岩、粉砂岩为主的红层沉积,局部可见灰绿色、黄绿色砂岩、粉砂岩夹层,红层中可见水平层理、小型板状交错层理等(图 3)。朱儒峰等(1992)总结大兴安岭南部幸福之路组地层剖面特征时,将幸福之路组自下而上划分成三个岩段:下段为杂色砾岩;中段以红层为标志,主要为紫红色杂砂岩、粉砂岩夹砂砾岩;上段沉积暗色细碎屑岩。通过区域地层对比可知,谭家湾剖面地层与内蒙古巴林右旗幸福之路苏木查干布拉格剖面幸福之路组的下段和中段在岩性组合特征上可以对比,即谭家湾剖面地层相当于大兴安岭南部幸福之路组建组剖面的下段和中段。通过上述分析,结合前人研究(朱儒峰等,1992),认为该剖面幸福之路组属河湖相沉积,气候环境为炎热干燥及强氧化条件。

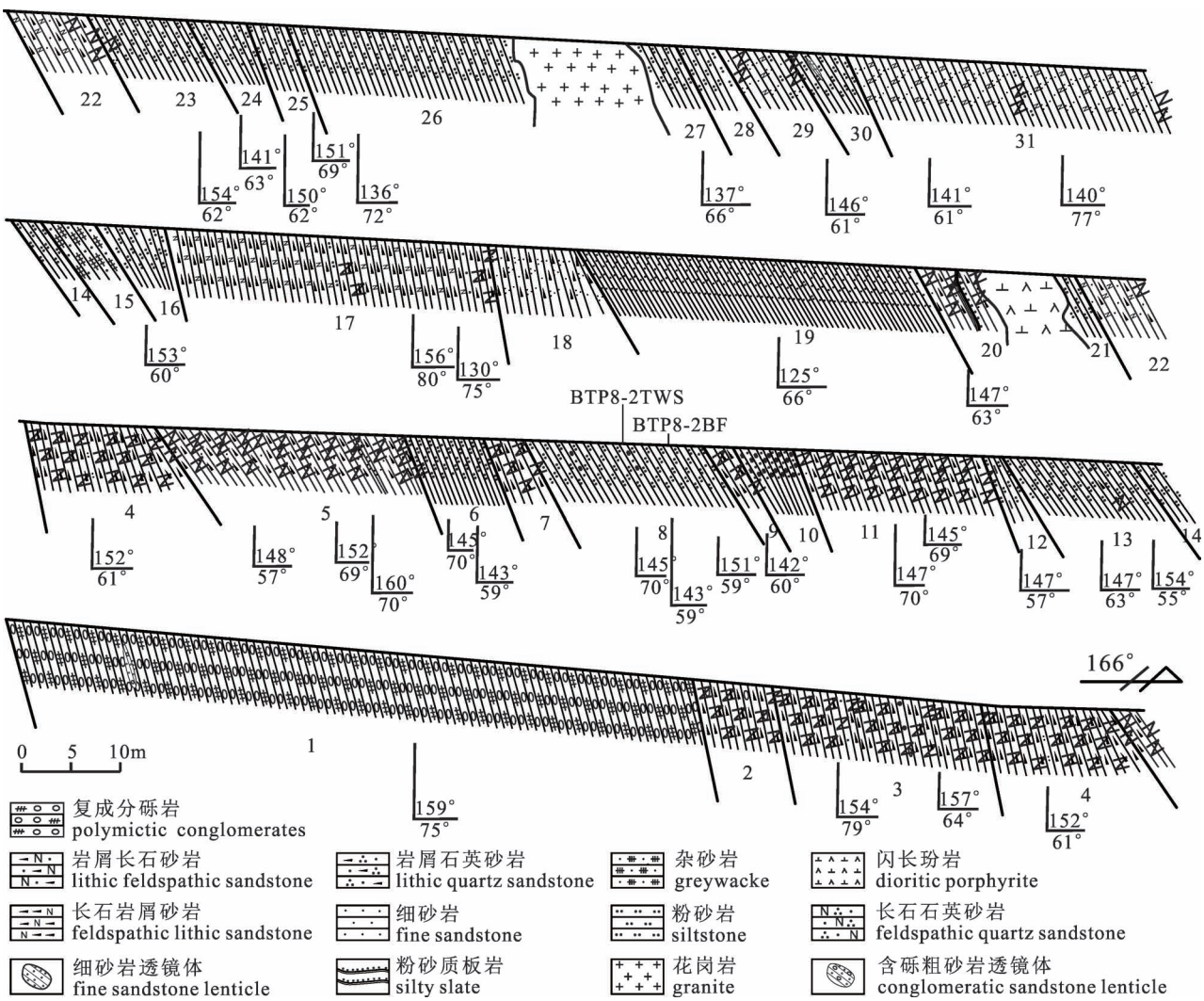



图 2 内蒙古巴林左旗谭家湾剖面幸福之路组实测地层剖面

Fig. 2 Measured stratigraphic section of Xingfuzhilu Formation along Tanjiawan section in Bairin Left Banner, Inner Mongolia

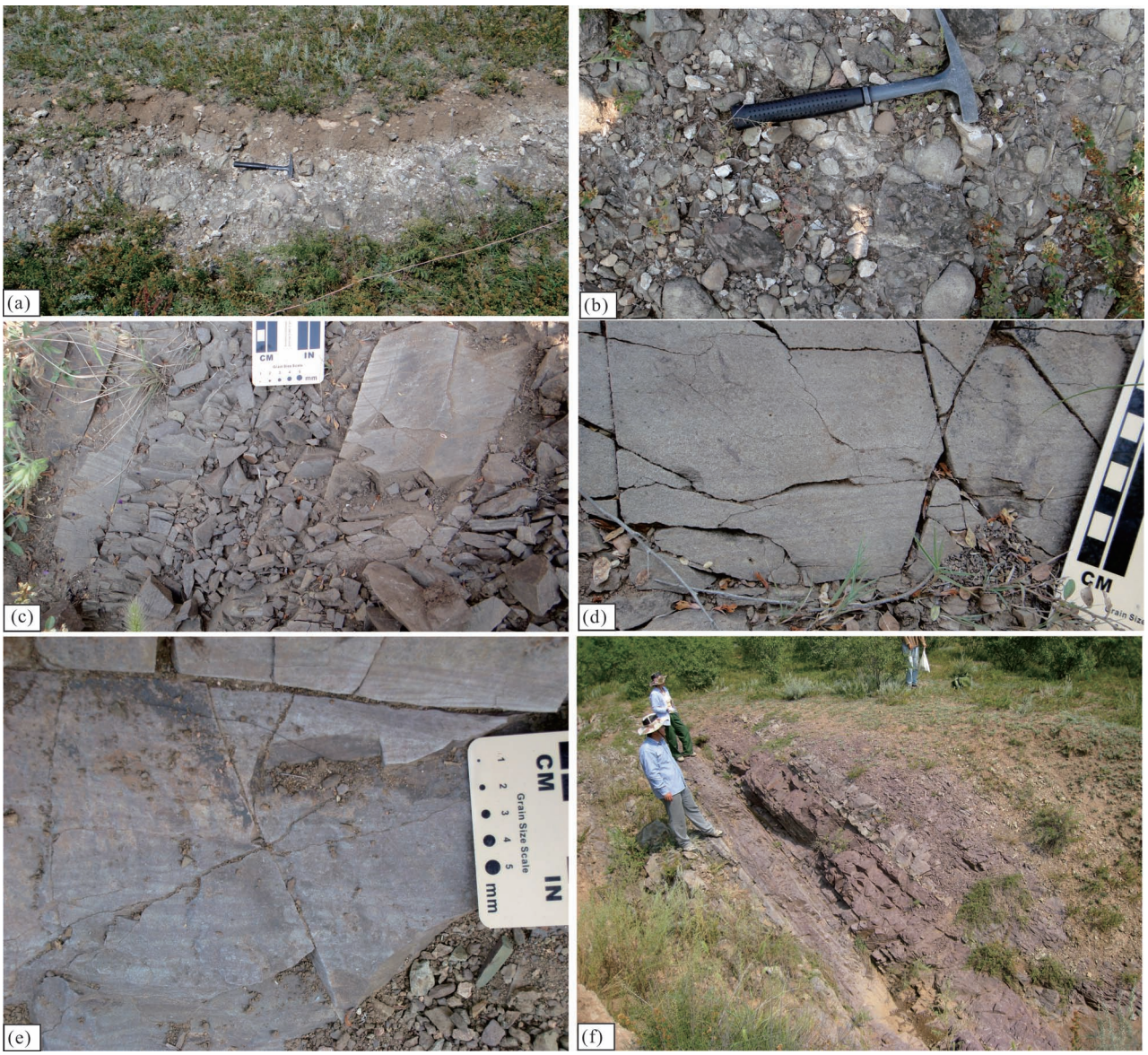



图 3 内蒙古巴林左旗谭家湾剖面幸福之路组野外露头照片

Fig. 3 Outcrop photos of Xingfuzhilu Formation along Tanjiawan section in Bairin Left Banner, Inner Mongolia

(a) 剖面底部砾岩整体岩貌; (b) 灰绿色中细砾复成分砾岩(第 1 层); (c) 紫灰色薄层粉砂岩中发育水平层理(第 6 层); (d) 黄绿色薄层状细砂岩(第 8 层); (e) 灰紫色薄层粉砂岩中发育小型板状交错层理(第 29 层); (f) 灰紫色中薄层粉砂岩夹灰绿色细砂岩透镜体(第 30 层)

(a) whole rock face of conglomerates located at the bottom of the section; (b) greyish-green medium—fine size polymictic conglomerates (1st layer); (c) horizontal beddings developed in the purple grey straticulate siltsands (6th layer); (d) yellow green straticulate fine sandstones (8th layer); (e) small scale laminar cross beddings developed in the grey purple straticulate siltsands (29th layer); (f) grey purple medium—thin bedded siltsands with intercalation of fine sandstone lens (30th layer)

## 2 样品特征与分析测试

BTP8-2TWS 样品岩性为细粒状长石岩屑杂砂岩。该样品风化面呈黄褐色,新鲜面呈浅灰色,细粒砂状结构,颗粒支撑,接触式胶结,砂屑由石英、方解石、斜长石、钾长石和岩屑组成。其中,石英呈棱角状、次棱角状,约占 30%;方解石呈聚片双晶发育,双晶带平行长对角线,棱角状,约占 3%;斜长石发育聚片双晶,双晶带细而密集,部分双晶带宽而稀,强烈绢云母化,约占 14%;钾长石发育格状双晶和条纹状嵌晶,棱角状、次棱角状,约占 3%;岩屑由硅质岩、安山岩、流纹岩等岩屑组成,其中硅质岩占多

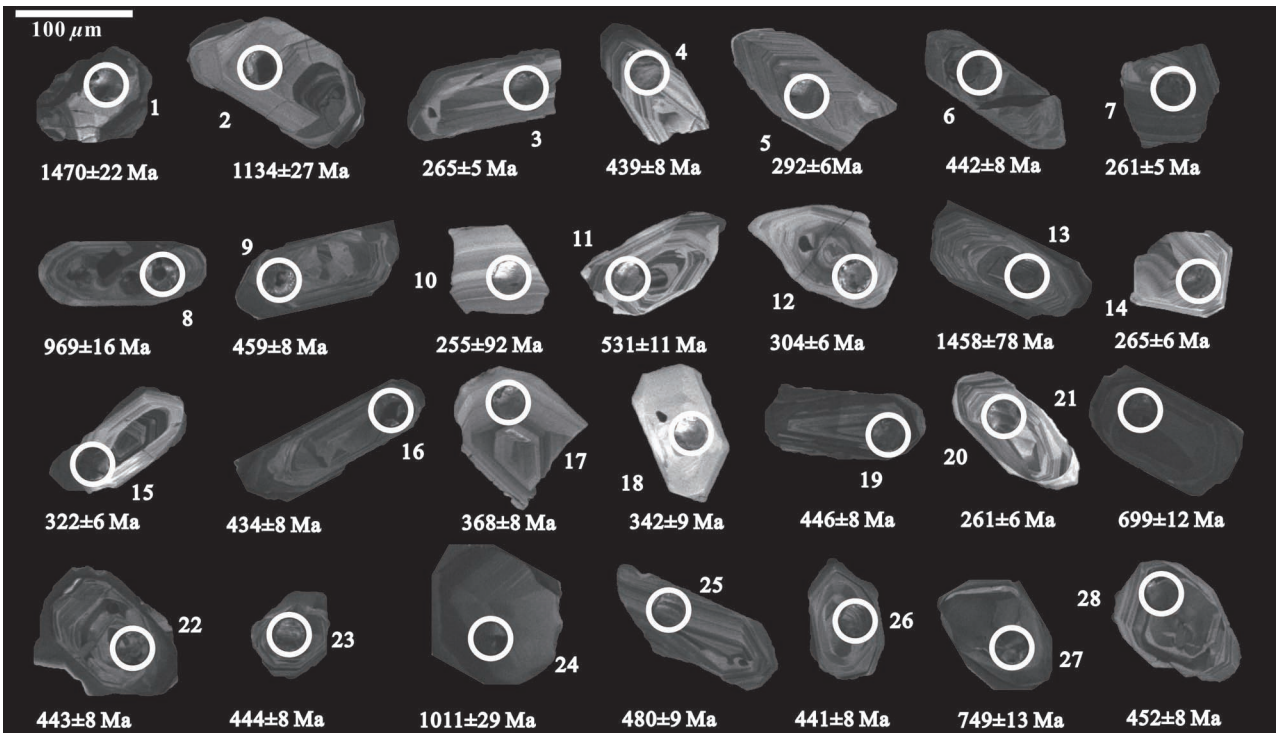



图 4 BTP8-2TWS 样品 1~28 号碎屑锆石阴极发光图像和年龄

Fig. 4 CL images and ages of No.1~28 detrital zircons of the sample BTP8-2TWS

数,约占 35%。砂屑粒径为 0.14~0.27 mm,少量 0.03~0.07 mm,分选好,磨圆呈次棱角状、少量次圆状。填隙物由绢云母、绿泥石、方解石、磁铁矿组成。

本次测年样品的锆石分选在廊坊市诚信地质服务有限公司完成,制靶、透/反射光图像采集和 LA ICP-MS U-Pb 及稀土元素测试均在中国地质大学(北京)地质过程与矿产资源国家重点实验室完成,锆石阴极发光(CL)图像在北京大学物理学院扫描电镜实验室完成。用于分析测试的锆石靶的制备过程与 SHRIMP 方法相似(宋彪等,2002)。

测试仪器为由激光剥蚀进样系统 UPI93SS 和 Agilent 7500a 型四级杆等离子质谱仪联合构成的激光等离子质谱仪。激光剥蚀斑束直径为 36 μm,激光频率为 10 Hz。激光取样过程包括 5 s 的预剥蚀时间、20 s 的冲洗样品池时间和 40 s 的剥蚀取样时间。一次激光剥蚀,同时测定稀土元素和 U—Th—Pb 同位素,测试点一一对应。微量元素含量计算采用 NIST610 玻璃作为外标、Si 作为内标进行,锆石年龄计算采用国际标准锆石 91500 作为外标进行 U-Pb 同位素分馏效应的校正计算,使用 TEM 和 QH 锆石标样作为监控盲样来监视测试过程的稳定性,使用标准玻璃 NIST612 和 NIST614 作为监控盲样检验微量元素测试精度。数据处理采用澳大利亚 Glitter(ver. 4.4, Macquarie University)程序完成,普通 Pb 校正方法见 Anderson(2002)。

## 3　测试结果

本次研究对 BTP8-2TWS 样品中的碎屑锆石进行了 LA-ICP-MS U-Pb 同位素分析。该样品锆石为自形到半自形,部分锆石保留了岩浆结晶锆石原来的晶体形态,主要呈长柱状和短柱状,粒径主要集中在 100~150 μm,个别小于 100 μm,部分锆石具有清晰的岩浆震荡环带,有少部分锆石有不同程度的破碎、磨圆(图 4),主体显示为岩浆成因锆石,个别锆石发育增生边和残留的晶核结构。

该样品锆石稀土元素配分曲线呈现出明显的重稀土富集、轻稀土亏损的左倾特征(图 5)。稀土元素分析结果显示,δEu 为 0.01~0.83,平均值为 0.23,呈现明显的负异常;δCe 值为 1.02~150.84,平均值为 20.41,呈现明显的正异常(表 1)。另外,样品碎屑锆石的 Th/U 值为 0.13~5.06,平均值为 0.63,呈现出较高的 Th/U 值(表 2),说明该样品中的碎屑锆石主要为岩浆成因。

对 BTP8-2TWS 样品的 100 颗锆石进行了 100

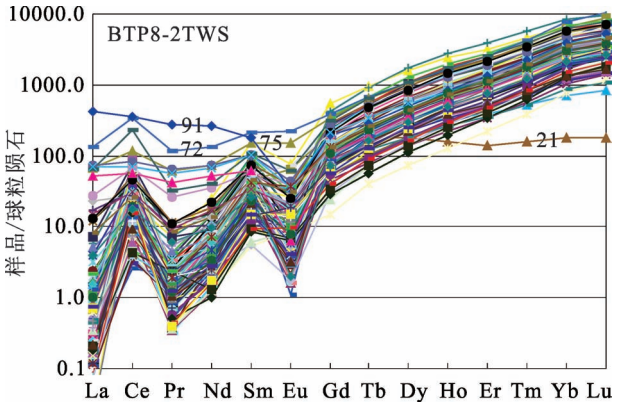



图 5 BTP8-2TWS 样品碎屑锆石微区球粒陨石标准化稀土元素配分曲线

Fig. 5 Chondrite-normalized rare earth element patterns of detrital zircons insitu in the sample BTP8-2TWS

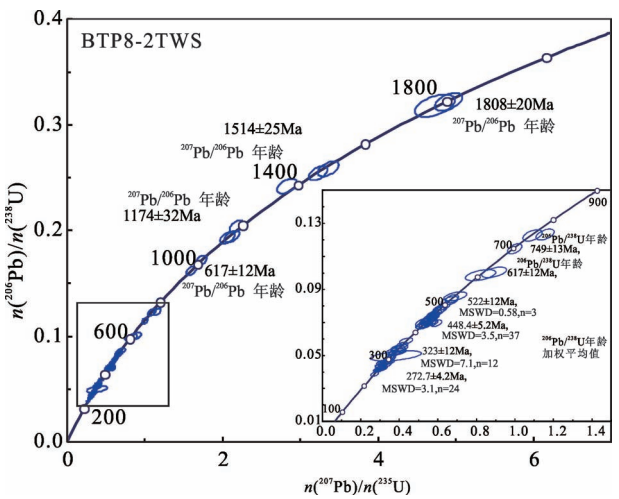



图 6 BTP8-2TWS 样品碎屑锆石 U-Pb 谐和图

Fig. 6 U-Pb concordia plot of detrital zircons of sample BTP8-2TWS

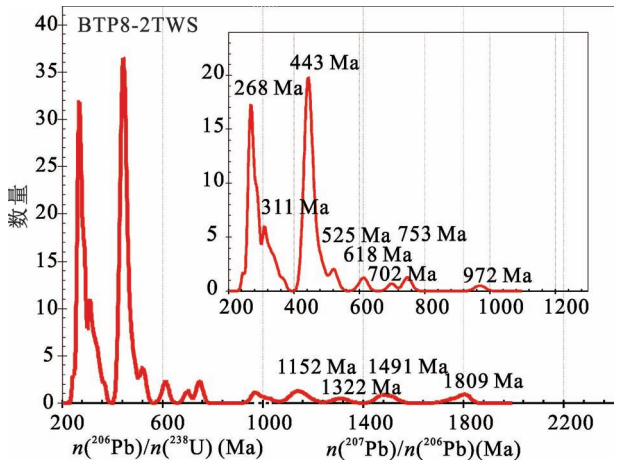



图 7 BTP8-2TWS 样品碎屑锆石 U-Pb 年龄频率分布图

Fig. 7 Age frequency distribution diagram of detrital zircons of sample BTP8-2TWS

个点的测试分析。该样品碎屑锆石 LA-ICP-MS U-Pb 分析结果显示,100 个测点中有 8 个点的锆石年龄不谐和(10、13、33、49、70、72、75、81 测点),谐和锆石年龄分布在 244~1808 Ma,时代跨度较大,说明谭家湾剖面幸福之路组沉积物来源多样。根据该样品碎屑锆石的$^{207}Pb/^{206}Pb$(>1000 Ma)和$^{206}Pb/^{238}U$年龄(<1000 Ma)的频率分布特征(图 6、图 7),排除不谐和年龄点,可将该样品的谐和锆石年龄分为 5 组:① 244~292 Ma,共有 25 颗锆石,其中有一颗锆石的年龄偏小(29 点),峰值年龄为 268 Ma,与该组锆石年龄的加权平均值(272.7±4.2 Ma)在误差范围内一致;②304~368 Ma,共有 12 颗锆石,峰值年龄为 311 Ma;③ 425~496 Ma,共有 37 颗锆石,该组锆石数量较多,峰值年龄为 443 Ma;④ 515~969 Ma,共 9 颗锆石,峰值年龄为 525 Ma、618 Ma、753 Ma 和 972 Ma;⑤ >1000 Ma,该组锆石共 9 颗,年龄主要分布在 1011~1134 Ma、1310~1514 Ma、1763~1808 Ma 这 3 个区间内,峰值年龄为 1152 Ma、1491 Ma、1809 Ma。

## 4 讨论

### 4.1 剖面沉积时代

BTP8-2TWS 样品采自谭家湾剖面幸福之路组中段下部,该样品的碎屑锆石年龄中,最年轻的年龄为 244 Ma,最年轻的峰值年龄为 268 Ma。BTP8-2BF 粉砂岩样品采自与 BTP8-2TWS 相同层位,其孢粉鉴定结果显示共统计鉴定出孢粉 10 粒(图 8),包括石松孢(未定种)*Lycopodiumsporites* sp.(2 粒)、单束松粉(未定种)*Abietineaepollenites* sp.(3 粒)、双束松粉(未定种)*Pinuspollenites* sp.(1 粒)、拟云杉粉(未定种)*Piceites* sp.(2 粒)、原始松柏粉(未定种)*Protoconiferus* sp.(2 粒)。其中,前三个未定种时代为中、新生代,后两个未定种时代为中生代。由此说明谭家湾剖面幸福之路组中段沉积时代应晚于 244 Ma,推测为中三叠世中期。对比前人关于幸福之路组沉积时代的研究成果(朱儒峰等,1992;和政军等,1997,1998;郑月娟等,2014,2015)可知,巴林左旗谭家湾剖面幸福之路组沉积时代相对较晚,可能是兴蒙造山带内区域构造岩浆活动的影响造成。

**表 1 BTP8-2TWS 样品碎屑锆石原位微区稀土元素分析测试数据**

**Table 1 Rare earth element test data of detrital zircons insitu in sample BTP8-2TWS**

| 测点编号 | 元素含量(×10⁻⁶) | | | | | | | | | | | | | | | $\frac{La_N}{Yb_N}$ | δEu | δCe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | La | Ce | Pr | Nd | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu | Y | | | |
| 1 | 0.043 | 8.09 | 0.358 | 7.1 | 12.36 | 1.004 | 55.25 | 18.69 | 216.9 | 74.15 | 304.5 | 67.73 | 692 | 121.6 | 1983 | 0.00004 | 0.10 | 6.69 |
| 2 | 0.065 | 55.19 | 0.115 | 2.19 | 5.11 | 0.775 | 25.71 | 9.39 | 116.9 | 43.36 | 197.5 | 49.99 | 567.5 | 110.3 | 1241 | 0.00008 | 0.17 | 121.5 |
| 3 | 0.164 | 13.69 | 0.676 | 11.69 | 22.69 | 4.36 | 109.8 | 35.97 | 410 | 135.3 | 530.8 | 116.5 | 1162 | 206 | 3519 | 0.00010 | 0.22 | 5.73 |
| 4 | 0.32 | 3.72 | 0.115 | 1.61 | 4.79 | 1.011 | 26.25 | 8.97 | 101.1 | 34.13 | 135.3 | 31.18 | 329.9 | 62.05 | 975.7 | 0.00070 | 0.22 | 4.75 |
| 5 | 0.33 | 46.84 | 0.048 | 1.17 | 2.34 | 0.42 | 17.6 | 7.8 | 99.37 | 41.18 | 202 | 55.01 | 678.9 | 133.8 | 1243 | 0.00035 | 0.14 | 80.66 |
| 6 | 0.556 | 8.76 | 0.179 | 1.73 | 2.52 | 0.172 | 17.34 | 6.22 | 84.84 | 33.2 | 146.2 | 35.03 | 388.4 | 72.18 | 924.6 | 0.00103 | 0.06 | 6.77 |
| 7 | 1.39 | 36.63 | 0.692 | 7.74 | 14.99 | 0.87 | 85.9 | 34.17 | 433.7 | 156.1 | 652.6 | 143.3 | 1426 | 240.3 | 4179 | 0.00070 | 0.06 | 9.10 |
| 8 | 0.043 | 1.58 | 0.201 | 1.35 | 6.63 | 0.065 | 39.3 | 16.11 | 211.3 | 74.64 | 308.2 | 68.53 | 702.5 | 124.3 | 2063 | 0.00004 | 0.01 | 2.25 |
| 9 | 0.074 | 9.02 | 0.03 | 0.7 | 2.42 | 0.293 | 12.62 | 5.18 | 62.25 | 25.5 | 120.8 | 29.89 | 351.5 | 66.24 | 759.9 | 0.00015 | 0.13 | 46.94 |
| 10 | 0.062 | 7.58 | 0.19 | 3.11 | 5.9 | 2.06 | 28.36 | 9.33 | 117.7 | 43.21 | 192.1 | 49.34 | 583.8 | 116.2 | 1248 | 0.00008 | 0.40 | 10.95 |
| 11 | 0.036 | 2.96 | 0.074 | 1.19 | 2.37 | 0.519 | 10.89 | 4.84 | 56.99 | 20.66 | 86.08 | 20.24 | 233 | 44.15 | 586.8 | 0.00011 | 0.26 | 10.39 |
| 12 | 0 | 9.16 | 0.198 | 1.57 | 2.56 | 0.591 | 16.13 | 6.24 | 81.17 | 32.77 | 151.5 | 37.87 | 435.1 | 85.62 | 956.3 | 0.00000 | 0.21 | 14.36 |
| 13 | 0.47 | 8.99 | 0.204 | 2.91 | 6.66 | 1.16 | 39.35 | 14.04 | 168.5 | 58.23 | 240.8 | 54.3 | 559.6 | 105.7 | 1596 | 0.00060 | 0.17 | 7.11 |
| 14 | 0.266 | 38.95 | 0.191 | 3.17 | 5.58 | 1.2 | 26.79 | 9.25 | 106.6 | 38.9 | 162.9 | 38.69 | 426.9 | 82.29 | 1031 | 0.00045 | 0.25 | 40.63 |
| 15 | 0.117 | 9.63 | 0.205 | 1.99 | 4.95 | 0.975 | 29.47 | 12.31 | 151.8 | 57.18 | 244.7 | 55.44 | 559.2 | 113.2 | 1538 | 0.00015 | 0.19 | 11.87 |
| 16 | 3.75 | 11.53 | 0.989 | 6.13 | 4.04 | 0.238 | 16.14 | 6.44 | 79.49 | 30.71 | 138.3 | 34.06 | 385.2 | 73.12 | 869.9 | 0.00698 | 0.08 | 1.44 |
| 17 | 0.34 | 14.78 | 0.167 | 3.32 | 7.27 | 0.744 | 36.72 | 13.26 | 160.1 | 55.61 | 229.8 | 50.63 | 527.6 | 93.67 | 1491 | 0.00046 | 0.113 | 15.13 |
| 18 | 0.019 | 8.78 | 0.064 | 1.35 | 4.02 | 0.753 | 21.75 | 7.79 | 96.41 | 35.8 | 160.4 | 39.11 | 439.5 | 83.01 | 1025 | 0.00003 | 0.197 | 38.06 |
| 19 | 0.379 | 5.02 | 0.133 | 1.16 | 4.13 | 0.344 | 24.4 | 9.16 | 115.9 | 44.27 | 191.5 | 45.74 | 507.7 | 91.25 | 1192 | 0.00054 | 0.081 | 5.47 |
| 20 | 0.163 | 40.21 | 0.218 | 3.99 | 6.88 | 3.65 | 43.09 | 16.67 | 207.1 | 81.36 | 370.8 | 94.51 | 1106 | 222.2 | 2331 | 0.00011 | 0.494 | 44.06 |
| 21 | 0.046 | 2.49 | 0.142 | 2.5 | 7.45 | 0.208 | 28.1 | 6.65 | 46.13 | 9.01 | 22.65 | 3.93 | 30.94 | 4.524 | 258.6 | 0.00107 | 0.039 | 4.82 |
| 22 | 0.043 | 11.73 | 0.094 | 2.12 | 5.02 | 0.48 | 25.1 | 9.4 | 116.6 | 44.19 | 194.4 | 46.1 | 485.1 | 90.09 | 1224 | 0.00006 | 0.107 | 32.74 |
| 23 | 0.041 | 13.68 | 0.092 | 2.59 | 6.06 | 0.485 | 30.72 | 12.24 | 154.5 | 57.74 | 246.7 | 58.09 | 621 | 110.5 | 1557 | 0.00005 | 0.088 | 39.17 |
| 24 | 0.041 | 15.99 | 0.142 | 2.54 | 4.26 | 1.15 | 20.26 | 6.87 | 80.5 | 29.42 | 128.3 | 31.68 | 367.4 | 66.96 | 816.1 | 0.00008 | 0.314 | 31.33 |
| 25 | 0.123 | 6.85 | 0.049 | 0.96 | 1.59 | 0.713 | 8.33 | 3.35 | 43.21 | 16.48 | 85.54 | 22.97 | 309.7 | 68.12 | 527.6 | 0.00028 | 0.483 | 21.63 |
| 26 | 0.039 | 10.15 | 0.124 | 2 | 3.59 | 1.007 | 13.5 | 5.28 | 66.38 | 25.49 | 124.3 | 34.65 | 428.8 | 90.76 | 781 | 0.00007 | 0.389 | 22.57 |
| 27 | 0.027 | 8.68 | 0.074 | 1.39 | 2.41 | 0.544 | 14.86 | 5.27 | 68.58 | 25.23 | 111.6 | 27.4 | 303.6 | 59.09 | 739.1 | 0.00006 | 0.213 | 31.77 |
| 28 | 3.03 | 23.94 | 1.054 | 7.28 | 5.63 | 0.64 | 23.66 | 9.29 | 111.8 | 41.52 | 180.7 | 42.62 | 462.2 | 84.65 | 1196 | 0.00470 | 0.145 | 3.28 |
| 29 | 0.066 | 29.86 | 0.035 | 1.56 | 3.69 | 1.01 | 17.43 | 5.81 | 71.1 | 26.28 | 115.7 | 28.79 | 334.2 | 64.44 | 753.5 | 0.00014 | 0.32 | 150.8 |
| 30 | 0.067 | 5.12 | 0.033 | 0.56 | 2.79 | 0.095 | 15.47 | 6.48 | 78.63 | 28.19 | 125.6 | 30.41 | 346.2 | 62.44 | 802.9 | 0.00014 | 0.035 | 26.56 |
| 31 | 0.247 | 11.75 | 0.075 | 1.07 | 2.060 | 0.42 | 10.15 | 3.72 | 47.12 | 16.35 | 71.32 | 17.59 | 201 | 38.19 | 481 | 0.00088 | 0.23 | 20.96 |
| 32 | 0.061 | 7.22 | 0.243 | 5.15 | 10.630 | 0.538 | 43.99 | 14.04 | 152.9 | 53.17 | 210.5 | 46.66 | 509.4 | 95.21 | 1459 | 0.00009 | 0.065 | 8.38 |

| 测点编号 | 元素含量($\times10^{-6}$) | | | | | | | | | | | | | | | $\frac{La_N}{Yb_N}$ | δEu | δCe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | La | Ce | Pr | Nd | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu | Y | | | |
| 33 | 0.056 | 7.46 | 0.218 | 4.39 | 8.05 | 0.597 | 44.9 | 18.87 | 246.9 | 97.76 | 414.1 | 98.75 | 1031 | 188.3 | 2682 | 0.00004 | 0.076 | 9.63 |
| 34 | 0.349 | 3.71 | 0.315 | 4.22 | 7.26 | 0.375 | 47.79 | 20.7 | 271.9 | 100.7 | 429.5 | 98.73 | 1046 | 179 | 2812 | 0.00024 | 0.046 | 2.53 |
| 35 | 0.078 | 2.56 | 0.405 | 6.99 | 14.71 | 1.75 | 71.55 | 25.48 | 323.4 | 112.5 | 466.3 | 108.7 | 1142 | 205.8 | 2909 | 0.00005 | 0.136 | 1.82 |
| 36 | 0.026 | 17.92 | 0.079 | 2.00 | 2.43 | 1.31 | 15.28 | 6.64 | 93.48 | 40.84 | 209.8 | 61.71 | 796.8 | 181.6 | 1233 | 0.00002 | 0.501 | 62.22 |
| 37 | 0.006 | 17.22 | 0.092 | 0.65 | 1.64 | 0.28 | 9.95 | 4.4 | 60.86 | 24.74 | 122.4 | 31.84 | 401.4 | 78.13 | 750 | 0.00001 | 0.163 | 56.53 |
| 38 | 0.072 | 8.14 | 0.128 | 2.77 | 7.63 | 0.843 | 40.85 | 15.53 | 197.6 | 72.15 | 313.5 | 73.23 | 797.2 | 149.2 | 1925 | 0.00006 | 0.117 | 16.11 |
| 39 | 0.374 | 7.29 | 0.223 | 3.37 | 6.74 | 1.92 | 30.51 | 8.01 | 71.19 | 19.21 | 63.92 | 13.23 | 121.2 | 21.52 | 522.9 | 0.00221 | 0.344 | 6.07 |
| 40 | 0.027 | 7.99 | 0.199 | 3.67 | 9.07 | 1.51 | 40.54 | 13.94 | 168.1 | 61.82 | 260.3 | 62.45 | 702 | 132.8 | 1702 | 0.00003 | 0.203 | 11.82 |
| 41 | 0.052 | 9.88 | 0.315 | 5.76 | 11.37 | 1.59 | 48.92 | 17.06 | 199.2 | 73.32 | 300.6 | 66.73 | 687.5 | 123.1 | 2000 | 0.00005 | 0.176 | 9.13 |
| 42 | 0.053 | 9.55 | 0.191 | 3.01 | 6.48 | 1.04 | 29.57 | 9.48 | 108.8 | 36.62 | 152.3 | 34.22 | 360.5 | 62.9 | 1045 | 0.00011 | 0.193 | 13.97 |
| 43 | 0.168 | 10.78 | 0.138 | 1.39 | 2.08 | 0.757 | 11.23 | 3.89 | 45.92 | 16.62 | 73.26 | 18.59 | 232.2 | 47.59 | 484.3 | 0.00052 | 0.383 | 16.30 |
| 44 | 0.031 | 1.90 | 0.135 | 1.74 | 2.98 | 0.246 | 16.03 | 5.07 | 56.79 | 18.93 | 78.48 | 18.23 | 194.9 | 36.4 | 513.6 | 0.00011 | 0.087 | 4.00 |
| 45 | 0.108 | 13.02 | 0.16 | 2.86 | 6.44 | 1.89 | 24.08 | 9.21 | 112.3 | 45.15 | 203.3 | 51.95 | 626.2 | 125.8 | 1247 | 0.00012 | 0.409 | 19.88 |
| 46 | 5.41 | 16.53 | 1.12 | 6.31 | 5.760 | 0.31 | 27.43 | 9.52 | 108.8 | 39.25 | 160.1 | 35.78 | 401.8 | 75.43 | 1023 | 0.00966 | 0.062 | 1.56 |
| 47 | 0.006 | 10.25 | 0.092 | 1.42 | 1.86 | 0.78 | 11.35 | 4.8 | 60.8 | 25.1 | 125.6 | 34.58 | 440.1 | 94.86 | 771.2 | 0.00001 | 0.399 | 33.71 |
| 48 | 1.213 | 10.37 | 0.433 | 3.17 | 4.24 | 0.212 | 16.01 | 5.71 | 63.61 | 21.59 | 90.31 | 20.86 | 225 | 40.6 | 597.6 | 0.00387 | 0.069 | 3.50 |
| 49 | 0.06 | 6.77 | 0.057 | 0.78 | 1.82 | 0.58 | 9.31 | 2.94 | 35.1 | 12.43 | 56.51 | 14.36 | 175.6 | 35.35 | 379.6 | 0.00025 | 0.350 | 25.93 |
| 50 | 0.148 | 3.66 | 0.039 | 0.58 | 0.83 | 0.494 | 3.09 | 1.52 | 18.16 | 7.18 | 36.11 | 9.95 | 127.8 | 29.91 | 223.8 | 0.00083 | 0.833 | 11.56 |
| 51 | 0.033 | 6.67 | 0.064 | 1.16 | 3.88 | 0.099 | 27.52 | 11.37 | 153.7 | 61.41 | 279.3 | 69.33 | 767.1 | 142.7 | 1720 | 0.00003 | 0.021 | 26.81 |
| 52 | 3.96 | 19.08 | 0.926 | 4.97 | 3.62 | 1.06 | 14.07 | 5.02 | 58.67 | 22.24 | 100.1 | 25.92 | 327.2 | 66.09 | 655.8 | 0.00868 | 0.397 | 2.36 |
| 53 | 0.299 | 18.23 | 0.32 | 2.97 | 6.63 | 0.093 | 24.9 | 9.09 | 107.5 | 38.08 | 161 | 38.46 | 413.4 | 69.3 | 1028 | 0.00052 | 0.019 | 12.87 |
| 54 | 0.045 | 4.84 | 0.119 | 0.94 | 2.47 | 0.164 | 14.97 | 6.32 | 77.79 | 30.62 | 129.5 | 31.16 | 341.7 | 62.16 | 827.9 | 0.00009 | 0.064 | 10.96 |
| 55 | 0.017 | 7.52 | 0.203 | 1.28 | 0.86 | 0.104 | 6.13 | 2.69 | 37.63 | 15.81 | 78.98 | 20.94 | 251.3 | 52.68 | 483.5 | 0.00005 | 0.101 | 11.13 |
| 56 | 1.72 | 46.85 | 0.677 | 4.24 | 8.72 | 0.218 | 48.07 | 19.47 | 258.9 | 91.03 | 381.2 | 84.74 | 865.2 | 148.7 | 2335 | 0.00143 | 0.026 | 10.64 |
| 57 | 0.039 | 3.71 | 0.112 | 1.82 | 4.15 | 0.196 | 17.41 | 5.59 | 61.11 | 20.92 | 84.32 | 19.22 | 206.7 | 38.28 | 561.3 | 0.00014 | 0.060 | 9.02 |
| 58 | 0.165 | 38.1 | 0.159 | 2.73 | 5.41 | 1.51 | 31.39 | 11.79 | 150.3 | 59.42 | 273 | 71.41 | 829.9 | 160.3 | 1665 | 0.00014 | 0.277 | 52.54 |
| 59 | 0.757 | 8.45 | 0.329 | 2.43 | 3.00 | 0.565 | 18.56 | 6.85 | 86.71 | 32.98 | 139.4 | 34.1 | 369.2 | 68.12 | 887 | 0.00147 | 0.177 | 4.15 |
| 60 | 0.021 | 22.67 | 0.056 | 0.87 | 1.75 | 0.883 | 11.08 | 3.52 | 44.78 | 17.35 | 81.42 | 23.08 | 286.4 | 63.23 | 523.6 | 0.00005 | 0.466 | 109.3 |
| 61 | 0.021 | 2.12 | 0.095 | 1.18 | 5.31 | 0.122 | 25.5 | 11.4 | 151.4 | 55.85 | 255.6 | 62.14 | 687.1 | 126.1 | 1526 | 0.00002 | 0.026 | 6.36 |
| 62 | 0.115 | 10.54 | 0.118 | 2.47 | 3.680 | 0.755 | 13.62 | 4.58 | 45.98 | 14.86 | 57.62 | 13.48 | 147.3 | 27.1 | 420.2 | 0.00056 | 0.288 | 19.94 |
| 63 | 0.372 | 8.25 | 0.146 | 1.85 | 3.82 | 0.45 | 18.41 | 7.04 | 80.66 | 30.02 | 126.1 | 28.98 | 317.5 | 60.22 | 805.1 | 0.00084 | 0.135 | 8.68 |
| 64 | 0.058 | 2.44 | 0.174 | 5.06 | 9.68 | 0.404 | 46.99 | 18.31 | 214.4 | 78.02 | 320.6 | 72.49 | 777.8 | 137.4 | 2010 | 0.00005 | 0.048 | 3.84 |
| 65 | 0.2 | 45.36 | 0.246 | 3.57 | 6.66 | 0.949 | 29.71 | 10.44 | 133.8 | 52.21 | 230.6 | 57.6 | 651.1 | 121 | 1570 | 0.00022 | 0.174 | 43.18 |
| 66 | 0.081 | 10.96 | 0.034 | 0.58 | 0.95 | 0.504 | 4.93 | 2.67 | 35.05 | 13.91 | 70.33 | 19.9 | 253.8 | 54.81 | 423.2 | 0.00023 | 0.575 | 51.19 |
| 67 | 0.037 | 4.71 | 0.157 | 2.75 | 5.61 | 0.232 | 25.24 | 8.82 | 98.6 | 34.38 | 144.5 | 33.72 | 370.9 | 67.05 | 936.8 | 0.00007 | 0.050 | 8.51 |
| 68 | 0.05 | 2.33 | 0.097 | 2.78 | 7.75 | 0.228 | 36.25 | 13.38 | 152.2 | 51.09 | 206.5 | 46.17 | 491.5 | 88.25 | 1342 | 0.00007 | 0.035 | 6.18 |
| 69 | 6.33 | 41.3 | 2.47 | 16.34 | 8.93 | 2.19 | 23.83 | 7.12 | 79.49 | 27.13 | 124.1 | 34.35 | 429.9 | 89.74 | 879.1 | 0.01056 | 0.433 | 2.56 |

| 测点编号 | 元素含量($\times10^{-6}$) | | | | | | | | | | | | | | | $\frac{La_N}{Yb_N}$ | δEu | δCe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | La | Ce | Pr | Nd | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu | Y | | | |
| 70 | 0.089 | 4.4 | 0.504 | 5.1 | 8.57 | 1.74 | 36.14 | 13 | 150.1 | 49.17 | 205.7 | 51.7 | 557.8 | 101 | 1399 | 0.00011 | 0.259 | 2.53 |
| 71 | 0.057 | 35.94 | 0.208 | 3.96 | 8.26 | 4.29 | 41.19 | 16.33 | 202.5 | 76.93 | 329.1 | 78.14 | 864.5 | 158.1 | 2050 | 0.00005 | 0.581 | 48.33 |
| 72 | 31.68 | 209 | 11.27 | 62.38 | 32.67 | 12.65 | 79.37 | 25.09 | 273.1 | 94.88 | 416.9 | 107.1 | 1308 | 269.6 | 2781 | 0.01738 | 0.727 | 2.71 |
| 73 | 0.36 | 20.03 | 0.153 | 2.87 | 5.42 | 1.19 | 20.56 | 8.05 | 93.86 | 35.1 | 153.2 | 36.18 | 401.8 | 75.14 | 957.6 | 0.00064 | 0.303 | 20.92 |
| 74 | 0.264 | 12.02 | 0.134 | 2.02 | 5.02 | 0.6 | 24.61 | 9.15 | 114.6 | 42.18 | 191.3 | 45.78 | 513.9 | 97.88 | 1232 | 0.00037 | 0.136 | 15.56 |
| 75 | 16.19 | 71.91 | 5.72 | 34.19 | 23.11 | 8.81 | 70.7 | 24.34 | 264 | 86.59 | 363.5 | 84.43 | 945.7 | 172 | 2480 | 0.01228 | 0.614 | 1.83 |
| 76 | 2.83 | 31.47 | 1.099 | 8.6 | 11.62 | 2.26 | 59.72 | 20.32 | 243.9 | 89.26 | 382.8 | 88.92 | 987.9 | 176.5 | 2433 | 0.00205 | 0.213 | 4.37 |
| 77 | 0.214 | 10.18 | 0.125 | 1.16 | 2.360 | 0.94 | 12.51 | 5.25 | 68.91 | 28.53 | 141.4 | 38.7 | 481.8 | 100.3 | 857.6 | 0.00032 | 0.425 | 14.99 |
| 78 | 17.22 | 50.06 | 5.96 | 33.37 | 15.79 | 2.51 | 53.6 | 18.9 | 210 | 72.85 | 311 | 72.81 | 801.4 | 139.3 | 2087 | 0.01541 | 0.238 | 1.21 |
| 79 | 0.113 | 4.56 | 0.219 | 3.84 | 10.16 | 0.657 | 39.16 | 13.24 | 150 | 54.22 | 221 | 50.27 | 557.6 | 101.7 | 1414 | 0.00015 | 0.088 | 5.36 |
| 80 | 0.308 | 5.89 | 0.178 | 1.58 | 2.7 | 0.218 | 18.74 | 6.97 | 88.92 | 34.23 | 151 | 36.23 | 396.1 | 71.96 | 934.3 | 0.00056 | 0.069 | 6.07 |
| 81 | 15.4 | 138.8 | 3.13 | 19.09 | 16.07 | 3.51 | 63.28 | 23.75 | 269.3 | 98.95 | 420.4 | 100.4 | 1065 | 196.9 | 2733 | 0.01038 | 0.293 | 4.63 |
| 82 | 0.044 | 9.56 | 0.049 | 0.48 | 1.32 | 0.365 | 5.79 | 2.1 | 28.65 | 11.16 | 56.72 | 16.03 | 217.5 | 47.2 | 351.6 | 0.00015 | 0.342 | 44.54 |
| 83 | 0.05 | 2.69 | 0.227 | 0.61 | 1.44 | 0.41 | 6.98 | 2.69 | 35.32 | 14.42 | 67.57 | 18.17 | 223.9 | 46.17 | 393.5 | 0.00016 | 0.326 | 3.38 |
| 84 | 0.051 | 5.62 | 0.098 | 1.57 | 3.27 | 0.186 | 13.67 | 4.65 | 57.12 | 21.51 | 87.24 | 21.16 | 231.9 | 42.64 | 568.4 | 0.00016 | 0.073 | 14.73 |
| 85 | 3.6 | 19.25 | 0.871 | 7.91 | 5.26 | 1.12 | 20.74 | 7.62 | 93.68 | 35.41 | 162.3 | 40.01 | 459.1 | 86.75 | 1003 | 0.00562 | 0.285 | 2.58 |
| 86 | 0.943 | 23.14 | 0.223 | 2.23 | 3.77 | 0.336 | 22.48 | 8.15 | 104.3 | 38.87 | 173.3 | 41.63 | 457.2 | 84.94 | 1063 | 0.00148 | 0.086 | 11.95 |
| 87 | 3.07 | 27.55 | 1.063 | 10.05 | 11.17 | 1.48 | 44.37 | 17.58 | 211 | 80.86 | 356.3 | 86.52 | 973 | 182.5 | 2204 | 0.00226 | 0.177 | 3.73 |
| 88 | 0.025 | 7.4 | 0.193 | 1.22 | 2.54 | 0.803 | 12.46 | 5.22 | 69.64 | 28.11 | 131 | 33.61 | 398 | 78.84 | 773.9 | 0.00005 | 0.359 | 11.32 |
| 89 | 0.021 | 9.49 | 0.042 | 0.74 | 1.45 | 0.57 | 8.14 | 3.41 | 42.27 | 16.77 | 79.56 | 21.17 | 262.3 | 51.16 | 483.5 | 0.00006 | 0.400 | 58.44 |
| 90 | 0.51 | 12.27 | 0.226 | 3.3 | 6.44 | 2.17 | 27.13 | 9.58 | 107.2 | 37.64 | 164.4 | 39.66 | 446.9 | 88.03 | 1055 | 0.00082 | 0.430 | 8.85 |
| 91 | 97.97 | 215.3 | 26.09 | 122.9 | 27.75 | 1.94 | 39.91 | 10.71 | 125.3 | 46.68 | 219.2 | 56.15 | 668.7 | 130.9 | 1367 | 0.10509 | 0.178 | 1.02 |
| 92 | 0.171 | 12.13 | 0.037 | 0.83 | 2.33 | 0.867 | 13.65 | 4.73 | 62.28 | 24.86 | 121 | 32.7 | 402 | 84.69 | 725 | 0.00031 | 0.366 | 35.68 |
| 93 | 12.34 | 33.93 | 3.95 | 24.29 | 9.27 | 0.371 | 21.99 | 6.85 | 88.58 | 32.95 | 146.3 | 35.21 | 398.1 | 73.12 | 916.9 | 0.02224 | 0.076 | 1.18 |
| 94 | 16.64 | 42.96 | 5.25 | 31.27 | 15.59 | 2.07 | 44.46 | 12.99 | 138.1 | 44.67 | 174.6 | 38.2 | 400.6 | 70.64 | 1150 | 0.02980 | 0.224 | 1.12 |
| 95 | 0.028 | 12.27 | 0.183 | 3.39 | 6.29 | 2.16 | 26.98 | 9.08 | 109.2 | 39.59 | 174.7 | 43.28 | 512.6 | 100.1 | 1115 | 0.00004 | 0.432 | 19.61 |
| 96 | 0.24 | 12.02 | 0.115 | 1.56 | 3.5 | 0.449 | 22.08 | 8.59 | 111 | 42.58 | 190.4 | 45.62 | 517.6 | 95.34 | 1202 | 0.00033 | 0.119 | 17.67 |
| 97 | 0.028 | 17 | 0.068 | 1.21 | 2.2 | 1.052 | 13.82 | 5.18 | 61.2 | 24.38 | 112.6 | 29.63 | 379.9 | 80.24 | 725 | 0.00005 | 0.444 | 66.62 |
| 98 | 1.94 | 16.05 | 0.805 | 6.35 | 7.1 | 1.79 | 27.26 | 9.67 | 112.1 | 41.6 | 189.2 | 49.3 | 599 | 115.9 | 1212 | 0.00232 | 0.345 | 3.15 |
| 99 | 0.178 | 11.94 | 0.121 | 1.34 | 2.31 | 0.244 | 11.79 | 4.77 | 64.14 | 24.88 | 117.1 | 28.92 | 333.3 | 62.25 | 717.6 | 0.00038 | 0.116 | 19.27 |
| 100 | 0.955 | 10.95 | 0.581 | 4.58 | 3.96 | 0.114 | 15.11 | 6.14 | 75.1 | 28.23 | 127.6 | 31.46 | 363.3 | 66.79 | 811.7 | 0.00189 | 0.040 | 3.53 |

**表 2 BTP8-2TWS 样品碎屑锆石 LA-ICP-MS U-Pb 分析结果**

**Table 2 LA-ICP-MS U-Pb test and analysis data of detrital zircons of sample BTP8-2TWS**

| 测点号 | 元素含量($\times10^{-6}$) | | | Th/U | 同位素比值 | | | | | | 同位素年龄(Ma) | | | | | | 不谐和度(%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Th | U | Pb | | $n(^{207}Pb)/n(^{206}Pb)$ | | $n(^{207}Pb)/n(^{235}U)$ | | $n(^{206}Pb)/n(^{238}U)$ | | $n(^{207}Pb)/n(^{206}Pb)$ | | $n(^{207}Pb)/n(^{235}U)$ | | $n(^{206}Pb)/n(^{238}U)$ | | |
| | | | | | 测值 | 1σ | 测值 | 1σ | 测值 | 1σ | 测值 | 1σ | 测值 | 1σ | 测值 | 1σ | |
| 1 | 115.0 | 209.6 | 60.07 | 0.55 | 0.09215 | 0.00199 | 3.22896 | 0.07768 | 0.25409 | 0.00448 | 1470 | 22 | 1464 | 19 | 1460 | 23 | 0.68 |
| 2 | 116.7 | 149.2 | 35.56 | 0.78 | 0.07751 | 0.00195 | 2.17788 | 0.05877 | 0.20374 | 0.00372 | 1134 | 27 | 1174 | 19 | 1195 | 20 | −5.10 |
| 3 | 254.0 | 305.8 | 15.15 | 0.83 | 0.05158 | 0.00278 | 0.29888 | 0.01614 | 0.04202 | 0.00086 | 267 | 86 | 266 | 13 | 265 | 5 | 0.38 |
| 4 | 141.7 | 177.5 | 14.68 | 0.80 | 0.05569 | 0.00207 | 0.54069 | 0.02029 | 0.07040 | 0.00141 | 440 | 49 | 439 | 13 | 439 | 8 | 0.00 |
| 5 | 179.4 | 255.2 | 13.73 | 0.70 | 0.05212 | 0.00319 | 0.33348 | 0.02039 | 0.04639 | 0.00096 | 291 | 102 | 292 | 16 | 292 | 6 | 0.00 |
| 6 | 175.0 | 339.3 | 26.34 | 0.52 | 0.05569 | 0.00186 | 0.54463 | 0.01883 | 0.07091 | 0.00131 | 440 | 45 | 441 | 12 | 442 | 8 | −0.23 |
| 7 | 439.6 | 740.0 | 34.31 | 0.59 | 0.05155 | 0.00178 | 0.29370 | 0.01042 | 0.04131 | 0.00078 | 266 | 48 | 261 | 8 | 261 | 5 | 0.00 |
| 8 | 126.4 | 316.2 | 55.55 | 0.40 | 0.07146 | 0.00178 | 1.59754 | 0.04284 | 0.16212 | 0.00290 | 971 | 28 | 969 | 17 | 969 | 16 | 0.00 |
| 9 | 144.0 | 273.7 | 22.13 | 0.53 | 0.05628 | 0.00181 | 0.57229 | 0.01891 | 0.07374 | 0.00140 | 463 | 41 | 459 | 12 | 459 | 8 | 0.00 |
| 10 | 78.62 | 15.55 | 5.621 | 5.06 | 0.05131 | 0.00329 | 2.21328 | 0.15290 | 0.31277 | 0.01175 | 255 | 92 | 1185 | 48 | 1754 | 58 | −85.46 |
| 11 | 54.23 | 130.2 | 12.23 | 0.42 | 0.05826 | 0.00333 | 0.68991 | 0.03948 | 0.08587 | 0.00178 | 540 | 89 | 533 | 24 | 531 | 11 | 0.38 |
| 12 | 132.4 | 207.9 | 11.48 | 0.64 | 0.05248 | 0.00309 | 0.34964 | 0.02057 | 0.04831 | 0.00101 | 306 | 96 | 304 | 15 | 304 | 6 | 0.00 |
| 13 | 266.1 | 524.4 | 137.8 | 0.51 | 0.09156 | 0.00365 | 2.85860 | 0.10134 | 0.22643 | 0.00412 | 1458 | 78 | 1371 | 27 | 1316 | 22 | 10.79 |
| 14 | 160.3 | 183.0 | 9.104 | 0.88 | 0.05151 | 0.00270 | 0.29836 | 0.01544 | 0.04200 | 0.00093 | 264 | 78 | 265 | 12 | 265 | 6 | 0.00 |
| 15 | 132.1 | 218.6 | 12.36 | 0.60 | 0.05300 | 0.00314 | 0.37494 | 0.02219 | 0.05130 | 0.00106 | 329 | 97 | 323 | 16 | 322 | 6 | 0.31 |
| 16 | 165.8 | 382.0 | 29.11 | 0.43 | 0.06176 | 0.00186 | 0.59256 | 0.01859 | 0.06957 | 0.00129 | 666 | 37 | 473 | 12 | 434 | 8 | 8.99 |
| 17 | 159.6 | 211.5 | 14.30 | 0.75 | 0.05371 | 0.00278 | 0.43519 | 0.02246 | 0.05875 | 0.00124 | 359 | 78 | 367 | 16 | 368 | 8 | −0.27 |
| 18 | 55.03 | 81.29 | 4.955 | 0.68 | 0.05326 | 0.00404 | 0.39993 | 0.02974 | 0.05445 | 0.00140 | 340 | 122 | 342 | 22 | 342 | 9 | 0.00 |
| 19 | 179.3 | 382.4 | 29.78 | 0.47 | 0.05572 | 0.00188 | 0.54993 | 0.01914 | 0.07157 | 0.00135 | 441 | 45 | 445 | 13 | 446 | 8 | −0.22 |
| 20 | 258.8 | 212.5 | 11.36 | 1.22 | 0.05167 | 0.00284 | 0.29454 | 0.01609 | 0.04134 | 0.00090 | 271 | 85 | 262 | 13 | 261 | 6 | 0.38 |
| 21 | 103.2 | 775.6 | 89.07 | 0.13 | 0.06323 | 0.00140 | 0.99877 | 0.02463 | 0.11454 | 0.00200 | 716 | 26 | 703 | 13 | 699 | 12 | 0.57 |
| 22 | 244.5 | 304.3 | 25.45 | 0.80 | 0.05616 | 0.00192 | 0.55098 | 0.01934 | 0.07114 | 0.00135 | 459 | 45 | 446 | 13 | 443 | 8 | 0.68 |
| 23 | 375.0 | 503.7 | 41.70 | 0.74 | 0.05596 | 0.00174 | 0.55054 | 0.01781 | 0.07134 | 0.00133 | 451 | 40 | 445 | 12 | 444 | 8 | 0.23 |
| 24 | 182.5 | 196.8 | 41.13 | 0.93 | 0.07288 | 0.00190 | 1.72511 | 0.04792 | 0.17164 | 0.00314 | 1011 | 29 | 1018 | 18 | 1021 | 17 | −0.98 |
| 25 | 106.9 | 235.8 | 18.44 | 0.45 | 0.05677 | 0.00191 | 0.60557 | 0.02087 | 0.07734 | 0.00149 | 483 | 43 | 481 | 13 | 480 | 9 | 0.21 |
| 26 | 165.8 | 302.4 | 23.71 | 0.55 | 0.05583 | 0.00181 | 0.54553 | 0.01818 | 0.07086 | 0.00135 | 446 | 41 | 442 | 12 | 441 | 8 | 0.23 |
| 27 | 161.7 | 436.8 | 59.13 | 0.37 | 0.06807 | 0.00169 | 1.15617 | 0.03092 | 0.12316 | 0.00220 | 871 | 28 | 780 | 15 | 749 | 13 | 4.14 |
| 28 | 321.4 | 385.2 | 33.13 | 0.83 | 0.05565 | 0.00169 | 0.55719 | 0.01758 | 0.07260 | 0.00135 | 438 | 38 | 450 | 11 | 452 | 8 | −0.44 |
| 29 | 173.4 | 208.6 | 9.562 | 0.83 | 0.05109 | 0.00256 | 0.27233 | 0.01350 | 0.03865 | 0.00085 | 245 | 74 | 245 | 11 | 244 | 5 | 0.41 |
| 30 | 136.6 | 440.8 | 32.29 | 0.31 | 0.05951 | 0.00171 | 0.57486 | 0.01732 | 0.07005 | 0.00130 | 586 | 35 | 461 | 11 | 436 | 8 | 5.73 |
| 31 | 83.45 | 182.8 | 13.45 | 0.46 | 0.05525 | 0.00241 | 0.51971 | 0.02276 | 0.06821 | 0.00140 | 422 | 61 | 425 | 15 | 425 | 8 | 0.00 |
| 32 | 218.4 | 462.4 | 36.36 | 0.47 | 0.05591 | 0.00192 | 0.55683 | 0.01973 | 0.07222 | 0.00134 | 449 | 46 | 449 | 13 | 450 | 8 | −0.22 |

| 测点号 | 元素含量(×10⁻⁶) | | | Th/U | 同位素比值 | | | | | | 同位素年龄(Ma) | | | | | | 不谐和度(%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Th | U | Pb | | $n(^{207}Pb)/n(^{206}Pb)$ | | $n(^{207}Pb)/n(^{235}U)$ | | $n(^{206}Pb)/n(^{238}U)$ | | $n(^{207}Pb)/n(^{206}Pb)$ | | $n(^{207}Pb)/n(^{235}U)$ | | $n(^{206}Pb)/n(^{238}U)$ | | |
| | | | | | 测值 | 1σ | 测值 | 1σ | 测值 | 1σ | 测值 | 1σ | 测值 | 1σ | 测值 | 1σ | |
| 33 | 101.9 | 258.8 | 56.56 | 0.39 | 0.08349 | 0.00222 | 2.25089 | 0.06352 | 0.19548 | 0.00360 | 1281 | 28 | 1197 | 20 | 1151 | 19 | 11.29 |
| 34 | 98.68 | 354.0 | 45.49 | 0.28 | 0.06453 | 0.00186 | 1.09154 | 0.03300 | 0.12265 | 0.00226 | 759 | 34 | 749 | 16 | 746 | 13 | 0.40 |
| 35 | 164.0 | 289.4 | 14.04 | 0.57 | 0.05171 | 0.00219 | 0.31016 | 0.01314 | 0.04350 | 0.00090 | 273 | 60 | 274 | 10 | 274 | 6 | 0.00 |
| 36 | 210.6 | 384.8 | 20.64 | 0.55 | 0.05244 | 0.00197 | 0.35658 | 0.01359 | 0.04930 | 0.00096 | 305 | 52 | 310 | 10 | 310 | 6 | 0.00 |
| 37 | 155.9 | 306.9 | 13.88 | 0.51 | 0.05148 | 0.00220 | 0.29243 | 0.01250 | 0.04119 | 0.00084 | 262 | 61 | 260 | 10 | 260 | 5 | 0.00 |
| 38 | 117.2 | 257.8 | 13.87 | 0.45 | 0.05289 | 0.00213 | 0.36388 | 0.01471 | 0.04989 | 0.00102 | 324 | 55 | 315 | 11 | 314 | 6 | 0.32 |
| 39 | 84.51 | 88.81 | 7.470 | 0.95 | 0.05578 | 0.00389 | 0.53959 | 0.03634 | 0.07014 | 0.00196 | 444 | 100 | 438 | 24 | 437 | 12 | 0.23 |
| 40 | 87.2 | 174.8 | 50.62 | 0.50 | 0.09431 | 0.00234 | 3.35969 | 0.08955 | 0.25831 | 0.00473 | 1514 | 25 | 1495 | 21 | 1481 | 24 | 2.23 |
| 41 | 118.8 | 116.5 | 7.447 | 1.02 | 0.05419 | 0.00421 | 0.38921 | 0.02988 | 0.05208 | 0.00124 | 379 | 130 | 334 | 22 | 327 | 8 | 2.14 |
| 42 | 68.17 | 73.07 | 4.571 | 0.93 | 0.05286 | 0.00480 | 0.38392 | 0.03423 | 0.05266 | 0.00143 | 323 | 153 | 330 | 25 | 331 | 9 | −0.30 |
| 43 | 102.8 | 368.2 | 26.45 | 0.28 | 0.05606 | 0.00202 | 0.53497 | 0.01969 | 0.06919 | 0.00132 | 455 | 48 | 435 | 13 | 431 | 8 | 0.93 |
| 44 | 90.16 | 304.7 | 26.78 | 0.30 | 0.05784 | 0.00190 | 0.67315 | 0.02262 | 0.08438 | 0.00163 | 524 | 41 | 523 | 14 | 522 | 10 | 0.19 |
| 45 | 161.1 | 229.7 | 18.75 | 0.70 | 0.05588 | 0.00211 | 0.54509 | 0.02077 | 0.07073 | 0.00141 | 448 | 50 | 442 | 14 | 441 | 8 | 0.23 |
| 46 | 92.24 | 129.1 | 15.26 | 0.71 | 0.06440 | 0.00308 | 0.89188 | 0.04271 | 0.10042 | 0.00208 | 755 | 66 | 647 | 23 | 617 | 12 | 4.86 |
| 47 | 95.73 | 185.3 | 14.58 | 0.52 | 0.05584 | 0.00275 | 0.54537 | 0.02688 | 0.07082 | 0.00145 | 446 | 73 | 442 | 18 | 441 | 9 | 0.23 |
| 48 | 95.53 | 251.2 | 21.45 | 0.38 | 0.05720 | 0.00192 | 0.63078 | 0.02168 | 0.07997 | 0.00154 | 499 | 43 | 497 | 13 | 496 | 9 | 0.20 |
| 49 | 70.22 | 359.2 | 34.45 | 0.20 | 0.08178 | 0.00340 | 0.99829 | 0.03707 | 0.08854 | 0.00165 | 1240 | 83 | 703 | 19 | 547 | 10 | 28.52 |
| 50 | 40.33 | 128.8 | 6.085 | 0.31 | 0.05204 | 0.00337 | 0.32948 | 0.02101 | 0.04591 | 0.00110 | 287 | 102 | 289 | 16 | 289 | 7 | 0.00 |
| 51 | 273.0 | 1113 | 48.70 | 0.25 | 0.05386 | 0.00146 | 0.31803 | 0.00917 | 0.04282 | 0.00078 | 365 | 34 | 280 | 7 | 270 | 5 | 3.70 |
| 52 | 149.3 | 259.0 | 20.68 | 0.58 | 0.05576 | 0.00226 | 0.55299 | 0.02269 | 0.07191 | 0.00141 | 443 | 57 | 447 | 15 | 448 | 8 | −0.22 |
| 53 | 267.8 | 502.3 | 184.6 | 0.53 | 0.11055 | 0.00233 | 4.90570 | 0.11628 | 0.32176 | 0.00565 | 1808 | 20 | 1803 | 20 | 1798 | 28 | 0.56 |
| 54 | 165.1 | 388.2 | 29.56 | 0.43 | 0.05597 | 0.00180 | 0.54780 | 0.01818 | 0.07097 | 0.00133 | 451 | 41 | 444 | 12 | 442 | 8 | 0.45 |
| 55 | 172.3 | 413.3 | 33.93 | 0.42 | 0.05688 | 0.00183 | 0.60312 | 0.01991 | 0.07689 | 0.00147 | 487 | 40 | 479 | 13 | 478 | 9 | 0.21 |
| 56 | 576.7 | 849.1 | 42.00 | 0.68 | 0.05176 | 0.00150 | 0.31082 | 0.00946 | 0.04354 | 0.00080 | 275 | 38 | 275 | 7 | 275 | 5 | 0.00 |
| 57 | 105.4 | 173.3 | 16.24 | 0.61 | 0.05762 | 0.00251 | 0.66105 | 0.02888 | 0.08319 | 0.00170 | 515 | 60 | 515 | 18 | 515 | 10 | 0.00 |
| 58 | 242.9 | 382.3 | 18.26 | 0.64 | 0.05157 | 0.00240 | 0.30300 | 0.01414 | 0.04260 | 0.00087 | 266 | 70 | 269 | 11 | 269 | 5 | 0.00 |
| 59 | 61.85 | 116.9 | 6.961 | 0.53 | 0.05317 | 0.00323 | 0.39419 | 0.02332 | 0.05375 | 0.00136 | 336 | 88 | 337 | 17 | 338 | 8 | −0.30 |
| 60 | 230.2 | 381.2 | 30.57 | 0.60 | 0.05572 | 0.00201 | 0.54795 | 0.02021 | 0.07131 | 0.00136 | 441 | 49 | 444 | 13 | 444 | 8 | 0.00 |
| 61 | 78.02 | 224.5 | 10.91 | 0.35 | 0.05197 | 0.00245 | 0.32887 | 0.01534 | 0.04588 | 0.00100 | 284 | 67 | 289 | 12 | 289 | 6 | 0.00 |
| 62 | 128.3 | 213.2 | 17.45 | 0.60 | 0.05626 | 0.00265 | 0.56446 | 0.02676 | 0.07274 | 0.00147 | 463 | 69 | 454 | 17 | 453 | 9 | 0.22 |
| 63 | 130.1 | 317.2 | 24.89 | 0.41 | 0.05629 | 0.00252 | 0.56817 | 0.02550 | 0.07319 | 0.00151 | 464 | 63 | 457 | 17 | 455 | 9 | 0.44 |
| 64 | 138.0 | 255.4 | 12.66 | 0.54 | 0.05196 | 0.00292 | 0.32296 | 0.01809 | 0.04507 | 0.00095 | 284 | 89 | 284 | 14 | 284 | 6 | 0.00 |
| 65 | 1849 | 1699 | 104.3 | 1.09 | 0.05280 | 0.00135 | 0.35774 | 0.00981 | 0.04913 | 0.00088 | 320 | 32 | 311 | 7 | 309 | 5 | 0.65 |
| 66 | 218.6 | 383.9 | 30.13 | 0.57 | 0.05546 | 0.00182 | 0.53839 | 0.01813 | 0.07040 | 0.00135 | 431 | 42 | 437 | 12 | 439 | 8 | −0.46 |
| 67 | 261.8 | 649.5 | 47.98 | 0.40 | 0.05561 | 0.00176 | 0.52929 | 0.01744 | 0.06901 | 0.00127 | 437 | 42 | 431 | 12 | 430 | 8 | 0.23 |

| 测点号 | 元素含量(×10⁻⁶) | | | Th/U | 同位素比值 | | | | | | 同位素年龄(Ma) | | | | | | 不谐和度(%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Th | U | Pb | | $n(^{207}Pb)/n(^{206}Pb)$ | | $n(^{207}Pb)/n(^{235}U)$ | | $n(^{206}Pb)/n(^{238}U)$ | | $n(^{207}Pb)/n(^{206}Pb)$ | | $n(^{207}Pb)/n(^{235}U)$ | | $n(^{206}Pb)/n(^{238}U)$ | | |
| | | | | | 测值 | 1σ | 测值 | 1σ | 测值 | 1σ | 测值 | 1σ | 测值 | 1σ | 测值 | 1σ | |
| 68 | 103.9 | 140.3 | 32.04 | 0.74 | 0.07908 | 0.00232 | 2.11728 | 0.06463 | 0.19415 | 0.00373 | 1174 | 32 | 1154 | 21 | 1144 | 20 | 2.62 |
| 69 | 347.8 | 1027 | 76.15 | 0.34 | 0.05578 | 0.00280 | 0.52374 | 0.02436 | 0.06810 | 0.00127 | 444 | 114 | 428 | 16 | 425 | 8 | 0.71 |
| 70 | 95.45 | 608.9 | 47.39 | 0.16 | 0.07846 | 0.00308 | 0.79958 | 0.02758 | 0.07392 | 0.00138 | 1158 | 80 | 597 | 16 | 460 | 8 | 29.78 |
| 71 | 106.3 | 120.2 | 6.308 | 0.88 | 0.05184 | 0.00453 | 0.31457 | 0.02721 | 0.04400 | 0.00109 | 278 | 150 | 278 | 21 | 278 | 7 | 0.00 |
| 72 | 714.0 | 1179 | 105.8 | 0.61 | 0.06452 | 0.00460 | 0.61237 | 0.04190 | 0.06884 | 0.00137 | 759 | 155 | 485 | 26 | 429 | 8 | 13.05 |
| 73 | 164.1 | 275.4 | 12.72 | 0.60 | 0.05105 | 0.00303 | 0.29065 | 0.01721 | 0.04128 | 0.00088 | 243 | 97 | 259 | 14 | 261 | 5 | −0.77 |
| 74 | 218.1 | 291.2 | 25.10 | 0.75 | 0.05573 | 0.00208 | 0.57287 | 0.02161 | 0.07454 | 0.00150 | 442 | 49 | 460 | 14 | 463 | 9 | −0.65 |
| 75 | 865.1 | 1089 | 88.86 | 0.79 | 0.07042 | 0.00197 | 0.66826 | 0.01960 | 0.06881 | 0.00129 | 941 | 31 | 520 | 12 | 429 | 8 | 21.21 |
| 76 | 432.8 | 475.5 | 25.79 | 0.91 | 0.05209 | 0.00218 | 0.32214 | 0.01361 | 0.04484 | 0.00090 | 289 | 60 | 284 | 10 | 283 | 6 | 0.35 |
| 77 | 120.0 | 193.1 | 12.06 | 0.62 | 0.05343 | 0.00284 | 0.41275 | 0.02152 | 0.05601 | 0.00132 | 347 | 75 | 351 | 15 | 351 | 8 | 0.00 |
| 78 | 493.8 | 1035 | 48.01 | 0.48 | 0.05473 | 0.00194 | 0.31967 | 0.01157 | 0.04235 | 0.00082 | 401 | 47 | 282 | 9 | 267 | 5 | 5.62 |
| 79 | 154 | 298.9 | 24.80 | 0.52 | 0.05634 | 0.00211 | 0.58562 | 0.02225 | 0.07538 | 0.00150 | 466 | 50 | 468 | 14 | 468 | 9 | 0.00 |
| 80 | 216.3 | 446.4 | 36.02 | 0.48 | 0.05622 | 0.00197 | 0.57791 | 0.02066 | 0.07454 | 0.00145 | 461 | 46 | 463 | 13 | 463 | 9 | 0.00 |
| 81 | 320.6 | 250.1 | 148.0 | 1.28 | 0.04605 | 0.03054 | 0.37959 | 0.25130 | 0.05979 | 0.00245 | | 1009 | 327 | 185 | 374 | 15 | −12.57 |
| 82 | 128.4 | 216.3 | 18.77 | 0.59 | 0.05679 | 0.00226 | 0.61173 | 0.02448 | 0.07811 | 0.00161 | 483 | 53 | 485 | 15 | 485 | 10 | 0.00 |
| 83 | 39.82 | 104.3 | 10.89 | 0.38 | 0.06033 | 0.00386 | 0.82150 | 0.05218 | 0.09873 | 0.00221 | 615 | 98 | 609 | 29 | 607 | 13 | 0.33 |
| 84 | 22.07 | 35.42 | 13.19 | 0.62 | 0.10784 | 0.00389 | 4.73107 | 0.17017 | 0.31811 | 0.00706 | 1763 | 35 | 1773 | 30 | 1780 | 35 | −0.96 |
| 85 | 163.9 | 242.8 | 20.06 | 0.68 | 0.05589 | 0.00236 | 0.55524 | 0.02365 | 0.07204 | 0.00146 | 448 | 59 | 448 | 15 | 448 | 9 | 0.00 |
| 86 | 69.15 | 168.0 | 34.70 | 0.41 | 0.07745 | 0.00223 | 2.06058 | 0.06208 | 0.19291 | 0.00367 | 1133 | 31 | 1136 | 21 | 1137 | 20 | −0.35 |
| 87 | 395.9 | 551.8 | 26.72 | 0.72 | 0.05160 | 0.00194 | 0.30203 | 0.01153 | 0.04244 | 0.00083 | 268 | 52 | 268 | 9 | 268 | 5 | 0.00 |
| 88 | 16.21 | 29.59 | 1.631 | 0.55 | 0.05584 | 0.01281 | 0.38331 | 0.08701 | 0.04977 | 0.00201 | 446 | 393 | 329 | 64 | 313 | 12 | 5.11 |
| 89 | 84.18 | 195.1 | 9.101 | 0.43 | 0.05160 | 0.00238 | 0.30906 | 0.01414 | 0.04343 | 0.00095 | 268 | 65 | 273 | 11 | 274 | 6 | −0.36 |
| 90 | 149.4 | 146.8 | 8.187 | 1.02 | 0.05188 | 0.00489 | 0.32770 | 0.03073 | 0.04580 | 0.00106 | 280 | 170 | 288 | 24 | 289 | 7 | −0.35 |
| 91 | 347.7 | 668.0 | 31.63 | 0.52 | 0.05271 | 0.00205 | 0.31117 | 0.01226 | 0.04280 | 0.00085 | 316 | 54 | 275 | 9 | 270 | 5 | 1.85 |
| 92 | 62.25 | 103.5 | 5.407 | 0.60 | 0.05226 | 0.00451 | 0.33232 | 0.02831 | 0.04611 | 0.00117 | 297 | 147 | 291 | 22 | 291 | 7 | 0.00 |
| 93 | 203.7 | 390.7 | 31.09 | 0.52 | 0.05580 | 0.00178 | 0.55869 | 0.01837 | 0.07260 | 0.00140 | 444 | 40 | 451 | 12 | 452 | 8 | −0.22 |
| 94 | 105.0 | 151.9 | 7.709 | 0.69 | 0.05221 | 0.00433 | 0.31797 | 0.02618 | 0.04416 | 0.00101 | 295 | 145 | 280 | 20 | 279 | 6 | 0.36 |
| 95 | 170.3 | 360.6 | 28.70 | 0.47 | 0.05612 | 0.00181 | 0.57250 | 0.01903 | 0.07397 | 0.00142 | 457 | 41 | 460 | 12 | 460 | 9 | 0.00 |
| 96 | 218.7 | 338.1 | 27.67 | 0.65 | 0.05630 | 0.00202 | 0.56187 | 0.02056 | 0.07237 | 0.00141 | 464 | 47 | 453 | 13 | 450 | 8 | 0.67 |
| 97 | 134.5 | 166.6 | 47.81 | 0.81 | 0.08474 | 0.00241 | 2.82725 | 0.08418 | 0.24192 | 0.00459 | 1310 | 30 | 1363 | 22 | 1397 | 24 | −6.23 |
| 98 | 258.6 | 331.5 | 16.67 | 0.78 | 0.05154 | 0.00208 | 0.30608 | 0.01241 | 0.04306 | 0.00088 | 265 | 56 | 271 | 10 | 272 | 5 | −0.37 |
| 99 | 159.5 | 285.3 | 23.41 | 0.56 | 0.05612 | 0.00189 | 0.57120 | 0.01968 | 0.07380 | 0.00144 | 457 | 43 | 459 | 13 | 459 | 9 | 0.00 |
| 100 | 171.3 | 611.6 | 44.13 | 0.28 | 0.05698 | 0.00176 | 0.54994 | 0.01767 | 0.06999 | 0.00133 | 491 | 39 | 445 | 12 | 436 | 8 | 2.06 |

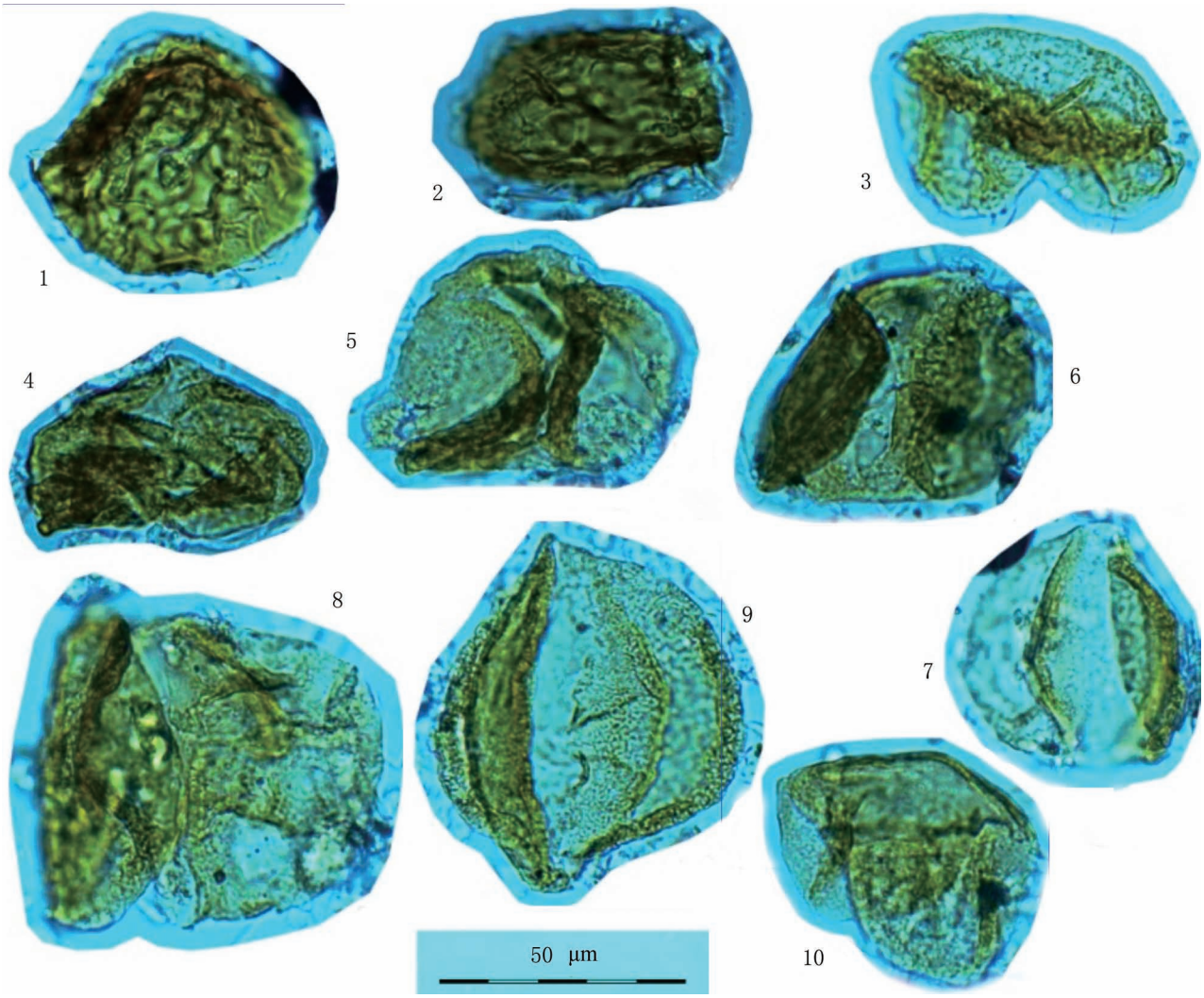



图 8 BTP8-2BF 样品孢粉化石鉴定结果

Fig. 8 The identification result of the sporopollen fossils within the sample BTP8-2BF

1、2—石松孢(未定种);3、4、5—单束松粉(未定种);6—双束松粉(未定种);7、8—拟云杉粉(未定种);9、10—原始松柏粉(未定种)

1,2—*Lycopodiumsporites* sp.; 3,4,5—*Abietineaepollenites* sp.; 6—*Pinuspollenites* sp.; 7,8—*Piceites* sp.; 9,10—*Protoconiferus* sp.

### 4.2　剖面物源特征

黄本宏等(1998)研究认为早二叠世末或晚二叠世初,大兴安岭地区以西拉木伦河为界,南北古大陆拼接后,南部华夏古陆少数植物分子向北迁移与安加拉植物群混生。李锦轶等(2007)研究认为西伯利亚与中朝古板块之间沿西拉木伦缝合带的碰撞开始于二叠纪中期,结束于三叠纪中期。但吕洪波等(2018)认为中亚造山带可能最终于白垩纪在狼山—阴山—燕山一线与华北地台拼合。晚二叠世林西组沉积时期,古亚洲洋残余洋盆沿着索伦—西拉木伦—长春一延吉一线最终完全或部分闭合,西拉木伦河缝合带北侧林西组沉积具有华北板块北缘与其北侧地块混合物源特征(李双林等,1998;韩国卿等,2011;李益龙等,2012)。大兴安岭南部幸福之路组平行不整合于上二叠统林西组之上,可知谭家湾剖面幸福之路组同样具有南北两侧混合物源特征。谭家湾剖面位于兴蒙造山带内部,介于苏尼特左旗—锡林浩特—西乌旗南缝合线和西拉木伦河缝合带之间(韩国卿等,2011)。以 BTP8-2TWS 碎屑锆石 LA-ICP-MS U-Pb 测年分析结果为依据,结合谭家湾剖面所处位置,对该剖面的物源特征进行分析。

(1)244~292 Ma 的碎屑锆石。该组锆石是最年轻的,占谐和年龄锆石总数的 27%,最小年龄为 244 Ma,峰值年龄为 268 Ma。赵英利等(2015)在讨论内蒙东部上二叠统林西组砂岩物源时,认为~270~290 Ma 的锆石年龄峰期在大兴安岭中南部地区

广泛存在,时代相当于早二叠世大石寨组火山;李益龙等(2009)对内蒙古赤峰市林西县房框子沟花岗质片麻岩进行 LA-ICP-MS 锆石 U-Pb 原位定年,获得 271.9±1.6 Ma、264.8±1.8 Ma 的花岗岩侵位年龄和 231~262 Ma 花岗岩变形变质为花岗质片麻岩的形成时代;刘建峰等(2014)在研究内蒙古东南部早三叠世花岗岩带构造环境过程中,获得林西县北西转山子岩体锆石 U-Pb 年龄为 245.6±0.9 Ma。依据上述锆石年龄资料推测,大兴安岭中南部地区早二叠世大石寨组火山岩、林西地区中二叠世—中三叠世花岗岩(花岗质片麻岩)为谭家湾剖面幸福之路组的沉积提供了重要的物源。

(2)304~368 Ma 的碎屑锆石。该组锆石年龄在区间内分布较平均,占谐和年龄锆石总数的 13%,峰值年龄为 311 Ma。陈斌等(2001)在探讨苏尼特左旗两类花岗岩同位素年代学意义时获得了 309±8 Ma 的弧岩浆岩锆石平均年龄;刘建峰等(2009)在研究西乌旗南部石炭纪石英闪长岩时获得了 325±3 Ma 和 322±3 Ma 两个锆石年龄,该岩浆岩的出现与古亚洲洋板片向北俯冲有关;施光海等(2003)对内蒙古锡林郭勒杂岩进行锆石 U-Pb 定年研究时获得了 316±3 Ma 的未变形石榴子石花岗岩年龄;薛怀民等(2009)研究锡林郭勒杂岩年代学特征时获得了花岗片麻岩原岩侵位年龄为 382±2 Ma。根据上述锆石年龄资料推测,苏尼特左旗—锡林浩特—西乌旗一带晚古生代岩浆弧、锡林郭勒杂岩为谭家湾剖面幸福之路组的沉积提供了物源。

(3)425~496 Ma 的碎屑锆石。该组锆石占谐和年龄锆石总数的 40%,峰值年龄为 443 Ma。郭峰等(2009)在研究内蒙古大石寨地区玄武岩地质年代学特征时获得 439±3 Ma 的 SHRIMP 锆石 U-Pb 年龄,认为大石寨中奥陶世喷发玄武岩为早古生代古亚洲洋俯冲板片交代地幔楔的熔融产物;石玉若等(2004,2005)在探讨内蒙古苏左旗白音宝力道岩体年代学特征及成因时,获得了 464±8 Ma 和 479±8 Ma 的闪长质岩类 SHRIMP 锆石 U-Pb 年龄和 423±8 Ma 的二长花岗岩 SHRIMP 锆石 U-Pb 年龄,并认为该岩体与洋壳俯冲、板块碰撞作用有关;刘敦一等(2003)在对内蒙古图林凯蛇绿岩中高锶低钇中酸性岩(即 Adakite)进行 SHRIMP 测年研究时获得 467±13 Ma、459±8 Ma、451±7 Ma 和 429±7 Ma 的锆石年龄,并认为该高锶低钇中酸性岩证实了温都尔庙—图林凯早古生代洋壳消减带的存在。谷丛楠等(2012)对内蒙古白乃庙地区白音都西群地层中两块变质石英砂岩样品进行了 LA-ICP-MS 测年,得到锆石 $^{206}Pb/^{238}U$ 表面年龄介于 518~294 Ma,峰值年龄约为 450 Ma 和 480 Ma。根据上述锆石年龄资料推测,大石寨地区早古生代玄武岩、苏左旗白音宝力道弧岩浆岩、华北板块北缘早古生代弧岩浆岩、蛇绿岩为谭家湾剖面幸福之路组的沉积提供了重要的物源。

(4)515~969 Ma 的碎屑锆石。该组锆石占谐和年龄锆石总数的 10%,峰值年龄为 525 Ma、618 Ma、753 Ma、和 972 Ma。苗来成等(2007)在对兴安地块兴华渡口群变质杂岩进行地球年代学研究时获得了 506~547 Ma 的年龄数据。郭晓丹等(2011)在研究内蒙古西乌珠穆沁旗本巴图组碎屑锆石时发现本巴图组沉积岩存在一组 724~996 Ma(峰期为 945 Ma)的碎屑锆石年龄,进而推测中亚造山带东段的多个微陆块或佳蒙地块存在新元古代岩浆热事件。根据上述锆石年龄资料推测,新元古代岩浆岩和兴安地块兴华渡口群变质杂岩可能为谭家湾剖面幸福之路组贡献了物源。

(5)>1000 Ma 的碎屑锆石。该组锆石占谐和年龄锆石总数的 10%,其中年龄大于 1800 Ma 的锆石仅有 1 颗(1808 Ma)。裴福萍等(2006)对松辽盆地南部基底变辉长岩开展锆石 LA-ICP-MS U-Pb 定年,获得的核部定年结果为 1808±21 Ma;孙立新等(2013)从苏左旗 2 件样品中获得了 1516 Ma 和 1390 Ma 的中元古代中期岩浆事件年龄,证实了锡林浩特地块存在前寒武纪变质基底;1700~2000 Ma 是华北克拉通基底的重要年龄区间(翟明国等,2000)。由此推测该组年龄的锆石可能来自锡林浩特地块、松辽盆地前寒武纪基底,但也不排除物源来自华北克拉通基底。

综上可知,巴林左旗谭家湾剖面幸福之路组沉积物来源多样,推测主要物源为苏尼特左旗—锡林浩特—西乌旗一带古生代岩浆岩、林西地区中二叠世—中三叠世花岗岩(花岗质片麻岩)、华北板块北缘早古生代岩浆岩。

## 5 结论

(1)通过区域地层对比认为,内蒙古巴林左旗谭家湾剖面相当于幸福之路组建组剖面的中、下段。

(2)综合谭家湾剖面幸福之路组中段碎屑锆石 U-Pb 测年和孢粉化石鉴定结果,认为该剖面幸福之路组中段沉积时代应晚于 244 Ma,推测为中三叠世中期。

(3)根据样品碎屑锆石谐和年龄的组成和分布特征,认为巴林左旗谭家湾剖面幸福之路组沉积物来源多样,推测主要物源为苏尼特左旗—锡林浩特—西乌旗一带古生代岩浆岩、林西地区中二叠世—中三叠世花岗岩(花岗质片麻岩)、华北板块北缘早古生代岩浆岩。

## 参 考 文 献 / References


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

陈斌,赵国春,Wilde S. 2001. 内蒙古苏尼特左旗南两类花岗岩同位素年代学及其构造意义.地质论评,47(4):361~367.

成守德,徐新. 2001. 新疆及邻区大地构造编图研究.新疆地质,19(1):33~37.

谷丛楠,周志广,张有宽,柳长峰,刘文灿,於炀森. 2012. 内蒙古白乃庙地区白音都西群的碎屑锆石年龄及其构造意义. 现代地质,26(1):1~9.

郭峰,范蔚茗,李超文, 苗来成,赵亮. 2009. 早古生代古亚洲洋俯冲作用: 来自内蒙古大石寨玄武岩的年代学与地球化学证据. 中国科学 D 辑:地球科学,39(5):569~579.

郭晓丹,周建波,张兴洲,邱海峻. 2011. 内蒙古西乌珠穆沁旗本巴图组碎屑锆石 LA-ICP-MS U-Pb 年龄及其意义. 地质通报,30(2/3):278~290.

韩国卿,刘永江, 温泉波, 李伟,吴琳娜,赵英利,丁凌,赵立敏,梁琛岳. 2011. 西拉木伦河缝合带北侧二叠纪砂岩碎屑锆石 LA-ICP-MS U-Pb 年代学及其构造意义. 地球科学, 36(4):687~702.

和政军,刘淑文,任纪舜,王瑜. 1997. 内蒙古林西地区晚二叠世—早三叠世沉积演化及构造背景. 中国区域地质,16(4):403~427.

和政军,刘淑文,王瑜,任纪舜. 1998. 内蒙古巴林右旗三叠纪化石的新发现. 地层学杂志,22(4):293~294.

黄本宏,丁秋红. 1998. 中国北方安加拉植物群. 地球学报,19(1):97~104.

李锦轶,高立明,孙桂华,李亚萍,王彦斌. 2007. 内蒙古东部双井子中三叠世同碰撞壳源花岗岩及其对西伯利亚与中朝古板块碰撞时限的约束. 岩石学报,23(3):565~582.

李双林,欧阳自远. 1998. 兴蒙造山带及邻区的构造格局与构造演化. 海洋地质与第四纪地质,18(3):45~54.

李益龙,周汉文, 钟增球, 张雄华,廖群安,葛梦春. 2009. 华北与西伯利亚板块的对接过程:来自西拉木伦缝合带变形花岗岩锆石 LA-ICP-MS U-Pb 年龄证据. 地球科学,34(6):931~938.

李益龙,周汉文,肖文交,钟增球,尹淑苹,李福林. 2012. 古亚洲构造域和西太平洋构造域在索伦缝合带东段的叠加:来自内蒙古林西县西拉木伦断裂带内变形闪长岩的岩石学、地球化学和年代学证据. 地球科学——中国地质大学学报,37(3):433~450.

刘敦一,简平,张旗,张福勤,石玉若,施光海,张履桥,陶华. 2003. 内蒙古图林凯蛇绿岩中埃达克岩 SHRIMP 测年:早古生代洋壳消减的证据.地质学报,77(3): 318~327.

刘建峰,迟效国,张兴洲,马志红,赵芝,王铁夫,胡兆初,赵秀羽. 2009. 内蒙古西乌旗南部石炭纪石英闪长岩地球化学特征及其构造意义. 地质学报,83(3):365~376.

刘建峰, 李锦轶, 迟效国, 曲军峰, 胡兆初, 郭春丽. 2014. 内蒙古东南部早三叠世花岗岩带岩石地球化学特征及其构造环境. 地质学报,88(9):1677~1690.

吕洪波,冯雪东,王俊,朱晓青,董晓朋,张海春,章雨旭.2018.狼山发现蛇绿混杂岩——华北克拉通与中亚造山带 碰撞边界的关键证据.地质论评, 64(4):777~805.

苗来成, 刘敦一, 张福勤, 范蔚茗, 石玉若 , 颉颃强. 2007. 大兴安岭韩家园子和新林地区"兴华渡口群"和"扎兰屯群"锆石 SHRIMP U-Pb 年龄.科学通报,52(5):591~601.

潘桂棠,肖庆辉,陆松年,邓晋福,冯益民,张克信,张智勇,王方国,邢光福,郝国杰,冯艳芳.2009. 中国大地构造单元划分.中国地质,36(1):1~28.

裴福萍,许文良,杨德彬,赵全国,柳小明,胡兆初. 2006. 松辽盆地基底变质岩中锆石 U-Pb 年代学及其地质意义. 科学通报,51(24):2881~2887.

宋彪, 张玉海, 万渝生,简平. 2002. 锆石 SHRIMP 样品靶制作、年龄测定及有关现象讨论. 地质论评,48(增刊): 26~30.

孙立新,任邦方,赵凤清,谷永昌,李艳峰,刘卉. 2013. 内蒙古锡林浩特地块中元古代花岗片麻岩的锆石 U-Pb 年龄和 Hf 同位素特征. 地质通报,32(2/3) :327~340.

施光海,刘敦一,张福勤,简平,苗来成,石玉若,陶华. 2003. 中国内蒙古锡林郭勒杂岩 SHRIMP 锆石 U-Pb 年代学及意义. 科学通报,48(20):2187~2192.

石玉若,刘敦一,张旗,简平,张福勤,苗来成,施光海,张履桥,陶华. 2004. 内蒙古苏左旗地区闪长—花岗岩类 SHRIMP 年代学. 地质学报,78(6):789~799.

石玉若,刘敦一,张旗,简平,张福勤,苗来成,施光海,张履桥,陶华. 2005. 内蒙古苏左旗白音宝力道 Adakite 质岩类成因探讨及其 SHRIMP 年代学研究. 岩石学报,21(1):143~150.

汪相.2018.白云鄂博超大型稀土铌—铁矿床的成矿时代及成因探析——兼论 P—T 之交生物群灭绝事件和"阿蒙兴造山运动". 地质论评,64(2):299~345.

徐备, 赵盼, 鲍庆中, 周永恒, 王炎阳, 罗志文. 2014. 兴蒙造山带前中生代构造单元划分初探. 岩石学报, 30(7):1841~1857.

薛怀民,郭利军,侯增谦,周喜文,童英,潘晓菲. 2009. 中亚—蒙古造山带东段的锡林郭勒杂岩: 早华力西期造山作用的产物而非古老陆块——锆石 SHRIMP U-Pb 年代学证据. 岩石学报,25(8):2001~2010.

翟明国,卞爱国. 2000. 华北克拉通新太古代末超大陆拼合及古元古代末—中元古代裂解. 中国科学(D 辑),30(增刊):129~137.

张海华,郑月娟,陈树旺,张健,苏飞,公繁浩,黄欣,甄甄. 2015. 内蒙古巴林左旗二叠系碎屑锆石 LA-ICP-MS U-Pb 年龄及构造意义. 地质学报,89(10):1703~1717.

张克信,潘桂棠,何卫红,肖庆辉,徐亚东,张智勇,陆松年,邓晋福,冯益民,李锦轶,赵小明,邢光福,王永和,尹福光,郝国杰,张长捷,张进,龚一鸣. 2015. 中国构造—地层大区划分新方案.地球科学,40(2):206~233.

张克信,何卫红,徐亚东,骆满生,宋博文,寇晓虎,张志勇,肖庆辉,潘桂棠. 2016. 中国洋板块地层分布及构造演化. 地学前缘,23(6):24~30.

赵英利,刘永江,李伟民,温泉波,冯志强. 2015. 大兴安岭中—南段古生代构造演化:来自内蒙东部上二叠统林西组砂岩物源分析的证据. 吉林大学学报(地球科学版),45(增刊1):1~2.

郑月娟,黄欣,陈树旺,张海华,苏飞,公繁浩,张健. 2014. 内蒙古巴林右旗下三叠统幸福之路组凝灰岩 LA-ICP-MS 锆石 U-Pb 年龄及其地质意义. 地质通报,33(2~3):370~377.

郑月娟,张海华,张健,甄甄,张德军,黄欣. 2015. 大兴安岭南部幸福之路组的时代——来自侵入岩脉 LA-ICP-MS 锆石 U-Pb 年龄的证据. 地质学报,89(增刊):58~61.

朱俊宾,和政军. 2017. 内蒙古林西地区上二叠统-中三叠统沉积序列的碎屑锆石记录及对古亚洲洋(东段)闭合时间的制约.地质学报,91(1):232~248.

朱儒峰,郑广瑞. 1992. 大兴安岭南部下三叠统幸福之路组的建立及其地质意义.中国区域地质,(3):219~225.

Anderson T. 2002. Correction of common lead in U-Pb analyses that do not report $^{204}$Pb.Chemical Geology, 192:59~79.

Chen Bin, Zhao Guochun, Wilde S. 2001&. Subduction- and collision-related granitoids from southern Sonidzuoqi, Inner Mongolia :isotopic ages and tectonic implications. Geological Review, 47(4): 361~367.

Cheng Shoude, Xu Xin. 2001&. On compiling of map of tectonics of Xinjiang and neighbouring areas. Xingjiang Geology, 19(1):33~37.

Fedo C M, Sircombe K N, Rainbird R H. 2003. Detrital zircon analysis of the sedimentary record. Review of Mineral Geochemistry, 53:227~303.

Griffin W L, Belousova E A, Shee S R, Pearson N J, Reilly S Y. 2004. Archean crustal evolution in the northern Yilgarn Carton:U- Pb and Hf- isotope evidence from detrital zircons. Precambrian Research, 131(3/4):231~282.

Gu Congnan, Zhou Zhiguang, Zhang Youkuan, Liu Changfeng, Liu Wencan, Yu Yangsen. 2012#. Detrital zircon dating and its tectonic significance of Baiyinduxi Group in Bainaimiao area, Inner Mongolia. Geoscience, 26(1):1~9.

Guo Feng, Fan Weimin, Li Chaowen, Miao Laicheng, Zhao Liang. 2009#. The Early Paleozoic subduction of Paleo-Asian Ocean: Geochronology and geochemistry evidences from the basalts in Dashizhai area, Inner Mongolia. Science China (Series D): Earth Sciences, 39(5):569~579.

Guo Xiaodan, Zhou Jianbo, Zhang Xingzhou, Qiu Haijun. 2011&. The detrital zircon LA-ICP-MS U-Pb ages and its significance of Benbatu Formation in Xiwuzhumuqinqi, Inner Mongolia, China. Geological Bulletin of China, 30(2/3):278~290.

Han Guoqing, Liu Yongjiang, Wen Quanbo, Li Wei, Wu Linna, Zhao Yingli, Ding Ling, Zhao Limin, Liang Chenyue. 2011&. LA-ICP-MS U-Pb dating of detrital zircons from the Permian sandstones in north side of Xar Moron River suture belt and its tectonic implications. Earth Science——Journal of China University of Geosciences, 36(4):687~702.

He Zhengjun, Liu Shuwen, Ren Jishun, Wang Yu. 1997&. Late Permian—Early Triassic sedimentary evolution and tectonic setting of the Linxi region, Inner Mongolia. Regional Geology of China, 16(4):403~427.

He Zhengjun, Liu Shuwen, Wang Yu, Ren Jishun. 1998#. A new discovery of Triassic fossils in Bairin Youqi, Inner Mongolia. Journal of Stratigraphy, 22(4):293~294.

Huang Benhong, Ding Qiuhong. 1998&. The angara flora from northern China. Bulletin of the Chinese Academy of Geological Sciences, 19(1):97~104.

Li Jinyi, Gao Liming, Sun Guihua, Li Yaping, Wang Yanbin. 2007&. Shuangjingzi middle Triassic syn-collisional crust-derived granite in the east Inner Mongolia and its constraint on the timing ofcollision between Siberian and Sino-Korean paleo-plates. Acta Petrologica Sinica, 23(3) :565~582.

Li Shuanglin, Ouyang Ziyuan. 1998&. Tectonic framework and evolution of Xing'anling—Mongolian Orogenic Belt(XMOB) and its adjacent region. Marine Geology & Quaternary Geology, 18(3):45~54.

Li Yilong, Zhou Hanwen, Zhong Zengqiu, Zhang Xionghua, Liao Qunan, Ge Mengchun. 2009&. Collision processes of north China and Siberian plates: evidence from LA -ICP-MS zircon U -Pb age on deformed granite in Xar Moron suture zone. Earth Science —— Journal of China University of Geosciences, 34(6):931~938.

Li Yilong, Zhou Hanwen, Xiao Wenjiao, Zhong Zengqiu, Yin Shuping, Li Fulin. 2012&. Superposition of Paleo-Asian and West-Pacific tectonic domains in the easter section of the Solonker suture zone: Insights from Petrology, geochemistry and geochronology of deformed diorite in Xarmoron fault zone, Inner Mongolia. Earth Science—Journal of China University of Geosciences, 37(3):433~450.

Liu Dunyi, Jian Ping, Zhang Qi, Zhang Fuqin, Shi Yuruo, Shi Guanghai, Zhang Lüqiao, Tao Hua. 2003&. SHRIMP dating of adakites in the Tulingkai ophiolite, Inner Mongolia: Evidence for the Early Paleozoic subduction. Acta Geologica Sinica, 77(3):318~327.

Liu Jianfeng, Chi Xiaoguo, Zhang Xingzhou, Ma Zhihong, Zhao Zhi, Wang Tiefu, Hu Zhaochu, Zhao Xiuyu. 2009&. Geochemical characteristic of carboniferous Quartz diorite in the Southern Xiwuqi area, Inner Mongolia and its tectonic significance. Acta Geological Sinica, 83(3):365~376.

Liu Jianfeng, Li Jinyi, Chi Xiaoguo, Qu Junfeng, Hu Zhaochu, Guo Chunli. 2014&. Petrological and geochemical characteristics of the Early Triassic granite belt in southeastern Inner Mongolia and its tectonic setting. 2014&. Acta Geological Sinica, 88(9):1677~1690.

Lü Hongbo, Feng Xuedong, Wang Jun, Zhu Xiaoqing, Dong Xiaopeng, Zhang Haichun, Zhang Yuxu. 2018&. Ophiolitic Melanges Foud in Mount Langshan as the Crucial Evidence of Collisional Margin between North China Craton and Central Asian Orogenic Belt, Geological Review, 64(4):777~805.

Miao Laicheng, Fan Weiming, Zhang Fuqin, Liu Dunyi, Jian Ping, Shi Guanghai, Tao Hua, Shi Yuruo. 2004. Zircon SHRIMP geochronology of the Xinkailing—Kele complex in the north western Lesser Xing'an Range, and its geological implications. Chinese Science Bulletin, 49:2201~2209.

Miao Laicheng, Liu Dunyi, Zhang Fuqin, Fan Weiming, Shi Yuruo, Xie Hangqiang. 2007#. Zircon SHRIMP U-Pb ages of the Xinghuadukou Group in Hanjiayuanzi and xinlin areas and the Zhalantun Group in Inner Mongolia, Da Hinggan mountains. Chinese Science Bulletin, 52(5):591~601.

Pan Guitang, Xiao Qinghui, Lu Songnian, Deng Jinfu, Feng Yimin, Zhang Kexin, Zhang Zhiyong, Wang Fangguo, Xing Guangfu, Hao Guojie, Feng Yanfang. 2009&. Subdivision of tectonic units in China. Geology in China, 36(1):1~28.

Pei Fuping, Xu Wenliang, Yang Debin, Zhao Quanguo, Liu Xiaoming, Hu Zhaochu. 2006#. Zircon U-Pb chronology and its geological implication of basement metamorphic rocks of Songliao Basin. Chinese Science Bulletin, 51(24):2881~2887.

Song Biao, Zhang Yuhai, Wan Yusheng, Jian Ping. 2002&. Mount making and procedure of the SHRIMP dating. Geological Review, 48(Supp.): 26~30.

Sun Lixin, Ren Bangfang, Zhao Fengqing, Gu Yongchang, Li Yanfeng, Liu Hui. 2013&. Zircon U-Pb dating and Hf isotopic compositions of the Mesoporterozoic granitic gneiss in Xilinhot Block, Inner Mongolia. Geological Bulletin of China, 32(2/3):327~340.

Shi Guanghai, Liu Dunyi, Zhang Fuqin, Jian Ping, Miao Laicheng, Shi Yuruo, Tao Hua. 2003#. SHRIMP zircon U-Pb geochronology and its significance of Xilingele complex in Inner Mongolia, China. Chinese Science Bulletin, 48(20):2187~2192.

Shi Yuruo, Liu Dunyi, Zhang Qi, Jian Ping, Zhang Fuqin, Miao Laicheng, Shi Guanghai, Zhang Lüqiao, Tao Hua. 2004&. SHRIMP dating of diorites and granites in southern Suzuoqi, Inner Mongolia. Acta Gologica Sinica, 78(6):789~799.

Shi Yuruo, Liu Dunyi, Zhang Qi, Jian Ping, Zhang Fuqin, Miao Laicheng, Shi Guanghai, Zhang Lüqiao, Tao Hua. 2005&. The petrogenesis and Shrimp dating of the Baiyinbaolidao adakitic rocks in southern Suzuoqi, Inner Mongolia. Acta Petrologica Sinica, 21(1): 143~150.

Wang Xiang. 2018&. Analysis on the Oreforming Time and Genesis of the Bayan Obo REE-Nb-Fe Deposit: With a Discussion on the Mass Extinction at the P—T Boundary and "AMH Orogeny". Geological Review, 64(2): 299~345.

Xu Bei, Zhao Pan, Bao Qingzhong, Zhou Yongheng, Wang Yanyang, Luo Zhiwen. 2014&. Preliminary study on the pre-Mesozoic tectonic unit division of the Xing—Meng Orogenic Belt (XMOB). Acta Petrologica Sinica, 30(7): 1841~1857.

Xue Huaimin, Guo Lijun, Hou Zengqian, Zhou Xiwen, Tong Ying, Pan Xiaofei. 2009&. The Xilingele complex from the eastern part of the central Asian—Mongolia orogenic belt, China: products of early variscan orogeny other than ancient block: evidence from zircon SHRIMP U-Pb ages. Acta Petrologica Sinica, 25(8): 2001~2010.

Zhai Mingguo, Bian Aiguo. 2000#. Convergence at the end of Neoarchean and breakup from the end of Paleoproterozoic to Mesoproterozoic of supercontinent, North China Craton. Science in China (Series D), 30(supp.): 129~137.

Zhang Haihua, Zheng Yuejuan, Chen Shuwang, Zhang Jian, Su Fei, Gong Fanhao, Huang Xin, Zhen Zhen. 2015&. LA-ICP-MS U-Pb geochronology of the Permian detrital zircons in Bairin Left Banner of Inner Mongolia and its tectonic significance. Acta Geologica Sinica, 89(10): 1703~1717.

Zhang Kexin, Pan Guitang, He Weihong, Xiao Qinghui, Xu Yadong, Zhang Zhiyong, Lu Songnian, Deng Jinfu, Feng Yimin, Li Jinyi, Zhao Xiaoming, Xing Guangfu, Wang Yonghe, Yin Fuguang, Hao Guojie, Zhang Changjie, Zhang Jin, Gong Yiming. 2015&. New division of tectonic—strata superregion in China. Earth Science—Journal of China University of Geosciences, 40(2): 206~233.

Zhang Kexin, He Weihong, Xu Yadong, Luo Mansheng, Song Bowen, Kou Xiaohu, Zhang Zhiyong, Xiao Qinghui, Pan Guitang. 2016&. Palaeogeographic distribution and tectonic evolution of OPS in China. Earth Science Frontiers, 23(6): 24~30.

Zhao Yingli, Liu Yongjiang, Li Weimin, Wen Quanbo, Feng Zhiqiang. 2015#. Paleozoic tectonic evolution of central and southern Da Hinggan Mountains: Evidence from provenance analysis on the sandstone of Linxi Formation of Upper Permian in the east of Inner Mongolia. Journal of Jilin University (Earth Science Edition), 45 (Supp.1): 1~2.

Zheng Yuejuan, Huang Xin, Chen Shuwang, Zhang Haihua, Su Fei, Gong Fanhao, Zhang Jian. 2014&. LA-ICP-MS zircon U-Pb age of the tuffs of the Lower Triassic Xingfuzhilu Formation in Bairin Right Banner, Inner Mongolia. Geological Bulletin of China, 33(2/3): 370~377.

Zheng Yuejuan, Zhang Haihua, Zhang Jian, Zhen Zhen, Zhang Dejun, Huang Xin. 2015#. The stratigraphic age of Xingfuzhilu Formation in the south of the Daxing'anling area——Evidence from the LA-ICP-MS U-Pb age of zircons from the intrusive vein. Acta Geological Sinica, 89(Supp.): 58~61.

Zhu Junbin, He Zhengjun. 2017. Detrital zircon records of Upper Permian—Middle Triassic sedimentary sequence in the Linxi area, Inner Mongolia and constraints on timing of final closure of the Paleo-Asian Ocean (eastern segment). Acta Geologica Sinica, 91 (1): 232~248.

Zhu Rufeng, Zheng Guangrui. 1992&. The establishment of the Lower Triassic Xingfuzhilu Formation in the southern sector of the greater Khingan Mountains and its geological implications. Regional Geology of China, (3): 219~225.

# The stratigraphic age determination and provenance analyses of Xingfuzhilu Formation of Middle Triassic along Tanjiawan section in Bairin Left Banner, Inner Mongolia: evidence from detrital zircon LA-ICP-MS U-Pb dating

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**Objectives**: The Tanjiawan section in Bairin Left Banner of Inner Mongolia located in the Xing'an—Mongolian Orogenic belt, North China. Combined with petrological study, LA-ICP-MS U-Pb zircon age and palynological study of the section, we could determine the stratigraphic age and analyze the provenances of the red-layer detrital rocks with the typical features of sediment associations and discuss the possbile geological significances.

**Methods**: Based on the data of the Tanjiawan section measuring, through the regional stratigraphic correlation, the LA-ICP-MS U-Pb detrital zircon dating and rare earth element test analysis of the sandstone sample from the lower part of the section, the identification of the sporopollen fossils within the siltstone from the same horizon as the sandstone sample, and the provenance analyses.

**Results**: The strata of the section were corresponding to the middle and low parts of the Xingfuzhilu Formation, through the regional stratigraphic correlation. The LA-ICP-MS U-Pb detrital zircon dating gained the youngest age of 244 Ma and the youngest peak ages of 268Ma. The composition and distribution characteristics of concordant ages of detrital zicrons from the sandstone sample suggests the multiplicity of the provenance of the section.

**Conclusions**: The deposition time of the middle part of Xingfuzhilu Formation of the section ought to be later than 244Ma. Combining the identification of the sporopollen fossils, it could be speculated that the deposition time of the middle part of Xingfuzhilu Formation of the section was Middle stage of Middle Triassic. Combining the relevant data of the regional structure and Zircon U-Pb dating, it could be speculated that the provenances were consisted of the Paleozoic magmatic rocks in the area around Sonid zuoqi—Xilinhot— Xi Ujimqin Qi, the granites or granitic gneisses of Middle Permian to Middle Triassic in Linxi area, and the Early Paleozoic magmatic rocks in the northern margin of North China Plate.

**Keywords**: Middle Triassic; Xingfuzhilu Formation; detrital zircon LA-ICP-MS U-Pb dating; provenance analyses; Tanjiawan section

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