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大兴安岭南部幸福之路组的时代及二叠—三叠系界线研究——来自凝灰岩 LA-ICP-MS 锆石 U-Pb 年龄的证据

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摘要:多数研究者认为西拉木伦河—长春—延吉断裂带为华北与西伯利亚两大板块的最后缝合带,但最后拼合时间仍存在分歧,原因之一是对晚二叠世—早三叠世地层研究不足,尤其是对上二叠统与下三叠统接触关系研究更为欠缺。幸福之路组分布于大兴安岭南部,为一套以红层为主要特征的杂色碎屑岩组合,含有叶肢介、介形虫、双壳、植物及孢粉化石。笔者对采自巴林右旗幸福之路苏木幸福之路组上段的岩屑晶屑凝灰岩样品进行了 LA-ICP-MS 锆石 U-Pb 测年分析,结果为 (254.3 ± 2.6) Ma。结合已有的火山岩测年及化石资料认为,幸福之路组上段下部时代为晚二叠世,上部为早三叠世早期,大兴安岭地区上二叠统与下三叠统为连续沉积,晚二叠世晚期两大板块发生碰撞拼合,古亚洲洋消失,发生南北生物群的混生,早三叠世西伯利亚板块和华北板块碰撞结束。

关 键 词:大兴安岭南部 幸福之路组 凝灰岩;U-Pb 年龄;晚二叠世—早三叠世 接触关系;连续沉积

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Age of Xingfuzhilu Formation and Contact Relationship between Permian and Triassic strata in southern Da Hinggan Mountains: Constraints from the tuff zircon U-Pb ages

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Abstract: The final suture position between North China plate and Siberia plate remains a topic of much controversy. Lots of researchers prefer describing West Lamulun River - Changchun - Yanji fault as the final suture zone of the two plates, but dispute still exists concerning the final closure time. One of the reasons is that there exists controversy concerning the Late Permian - Early Triassic stratigraphy in the Da Hinggan Mountains due to insufficient research; in particular, the study of the contact relationship between Late Permian and Lower Triassic remains very insufficient. The Early Triassic Xingfuzhilu Formation is of fluvial-

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lacustrine facies with red bed features and contains fossils such as ostracoda, sporopollen, conchostracan, bivalves and megaplants, which are located in southern Da Hinggan Mountains. The authors collected tuff samples and made analysis. LA-ICP-MS U-Pb dating of zircon yielded an age of (254.3 ± 2.6) Ma. Combined with the existing volcanic dating and fossils in the upper part of the volcanic rocks, it is considered that the lower part of the third member of Xingfuzhulu Formation should be of Late Permian whereas the upper part belongs to Early Triassic, and that the Late Permian-Early Triassic strata are of continuous deposition. The Paleo-Asian Ocean experienced collision suturing and the biota mixture in late Late Permian, and the closing time of the two plates should be Early Triassic.

Key words: tuff of Xingfuzhulu Formation in southern Da Hinggan Mountains; U-Pb age; contact relationship between Late Permian and Lower Triassic; continuous deposition

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研究区位于华北与西伯利亚板块间的兴蒙造山带,华北板块与西伯利亚板块之间的最终缝合线位置、拼贴时代一直是区内长期争论的重大地质问题之一,主要是泥盆纪—石炭纪早期贺根山—黑河缝合带^[1-7]和西拉木伦河缝合带之争,目前主流意见倾向于西拉木伦河—长春—延吉断裂带是两大板块的最后缝合带,但拼合的最后时间仍有不同认识,有些学者倾向于晚二叠世^[8-11],大多数学者则认为最终拼合的时间为二叠纪末—早三叠世^[12-19]及早中三叠世^[20-21]。存在争议的关键之一是对大兴安岭地区晚二叠世—早三叠世地层尤其是二者接触关系的研究不足。大兴安岭地区晚二叠世地层统一称为林西组,沿北东方向广泛分布,南自西拉木伦河、北至爱辉,黑河一带,东至松辽盆地腹地,岩性为湖相、泻湖相黑灰、灰绿色的砂板岩组合,含双壳、叶肢介、介形虫、孢粉、植物化石,反映还原的沉积环境^[22-27];早三叠世地层研究程度相对较低,地层单位未统一,分别称为幸福之路组^[28-32]、哈达陶勒盖组^[33-34]、老龙头组^[35-36],同林西组一样,亦沿北东方向分布,但出露较少,零星分布于内蒙古巴林右旗、奈曼旗、科尔沁右翼前旗、扎赉特旗、扎兰屯及黑龙江省龙江县至嫩江多宝山一线,以红层作为划分的主要标志,岩性以正常沉积碎屑岩为主夹有火山岩层,含少量双壳、叶肢介、介形虫、植物及孢粉化石,代表河湖相的炎热、干燥及强氧化条件的沉积环境。关于研究区上二叠统与下三叠统的接触关系目前有两种认识:北部黑龙江省龙江地区为整合接触(林西组与老龙头组)^[35],南部内蒙古林西县—巴林右旗地区为平行不整合接触(林西组与幸福之路组)^[28-30],但上述认识主要是基于区域地质调查资

料,没有经过进一步深入研究。刘兵等^[37]运用碎屑锆石测年资料讨论了大兴安岭中段上二叠统与下三叠统(林西组与老龙头组)的接触关系。

相比之下,分布于大兴安岭南部的幸福之路组研究程度较高,化石最为丰富,且含有多层可供测年的火山岩夹层。1992年,朱儒峰等^[28]基于1:5万区域地质填图成果,将分布于巴林右旗查干布拉格—哈拉山一带,原划为林西组中—上部的红杂色沉积划为下三叠统幸福之路组,认为该组为一套河湖相沉积,反映了炎热、干燥及强氧化条件的气候环境。根据岩性组合特征分为三段: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;上段为细碎屑岩,顶部被上侏罗统不整合覆盖。和政军等^[29-30]报道了幸福之路中段及上段的叶肢介、介形虫、双壳及植物化石,认为其时代为早三叠世。郑月娟等^[31-32]对幸福之路组上段的孢粉、叶肢介化石及火山岩测年进行综合研究,认为其时代为早三叠世早期,与晚二叠世林西组之间没有大的时间间隔,并对原划为早三叠世的幸福之路组下、中段的时代提出疑问。为了确定幸福之路组的时代,笔者针对幸福之路组建组剖面开展了进一步的野外工作,在幸福之路组中段查干布拉格剖面发现了火山岩夹层(另文报道),本文对采自幸福之路组上段哈拉山东剖面第14层的火山岩样品进行同位素测年研究,并结合已有的测年资料及火山岩上部的化石资料,进一步讨论了幸福之路组上段的时代,该研究不仅为大兴安岭地区晚二叠世—早三叠世年代地层格架的建立提供了重要同位素年代学依据,对大兴安岭地区上二叠统与下三叠统界线及区域大地构造演化研究也具有重要意义。

1 区域地质概况及采样剖面

研究区位于巴林右旗幸福之路苏木,大地构造位置上处于西拉木伦河缝合带以北。区内只发育早三叠世幸福之路组(T_{1x})和晚侏罗世满克头鄂博组(J_3mk),侵入岩主要为燕山晚期花岗岩和燕山早期石英二长岩(图1)。郑月娟等曾对采样剖面下部第9层的火山岩及上部的化石资料进行研究^[31-32]。本次研究在该剖面第14层采集了岩屑晶屑凝灰岩样品(图1~图2)。

2 样品特征及分析方法

13HSP9-4Bb:样品为岩屑晶屑凝灰岩,岩屑晶屑凝灰结构,块状构造。岩石由晶屑、岩屑、火山尘组成。晶屑,呈棱角状一次棱角状,主要成分为斜长石、少量的石英,粒径0.05~2 mm,占岩石总量40%~45%;岩屑,呈棱角状一次棱角状,主要成分为安山岩碎屑,粒径0.05~2 mm,占岩石总量15%~20%;火山尘,粒径<0.05 mm,占岩石总量35%~40%。碎屑

被火山尘胶结。岩石局部强烈的碳酸盐化(图3)。

本文样品的锆石分选在廊坊市宇能岩石矿物分选技术服务有限公司完成,制靶、透射光和反射光图像采集和LA-ICP-MS锆石U-Pb测试,都在中国地质大学(北京)地质实验中心元素地球化学研究室完成,锆石阴极发光图像在北京大学电镜室扫描电镜上完成。用于分析测试的锆石靶的制备过程与SHRIMP方法相似^[38]。

用于锆石U-Pb测试的仪器为美国New Wave Research Inc.公司生产的激光剥蚀进样系统(UP 193SS)和美国AGILENT科技有限公司生产的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(LA-ICP-MS)。实验采用36 μm 的激光束斑直径和10 Hz的激光频率,激光取样过程采用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。实验采用NIST610玻璃作为外标,Si作为内标进行元素含量计算,采用标准锆石91500作为外标进行U-Pb同位素分馏效应的校正计算,澳大利亚锆石标样TEM和QH作为监控盲

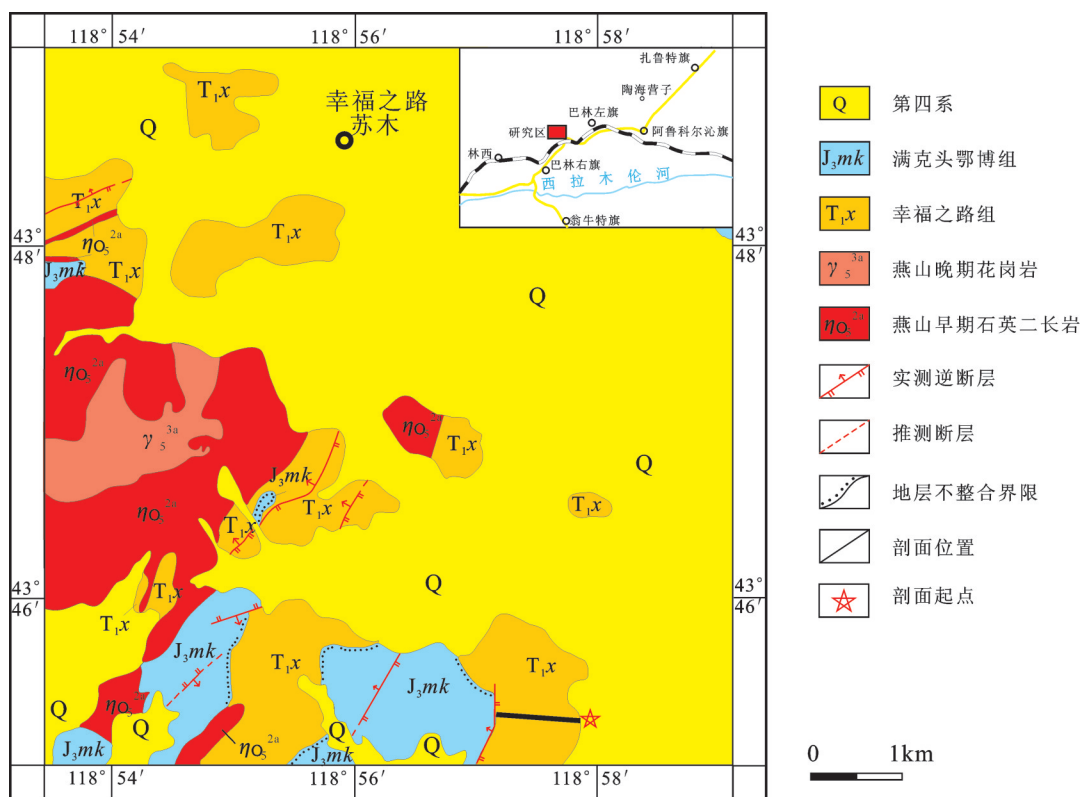


图1 幸福之路地区地质简图

Fig.1 Sketch geological map of Xingfuzhilu in Bairin Right Banner

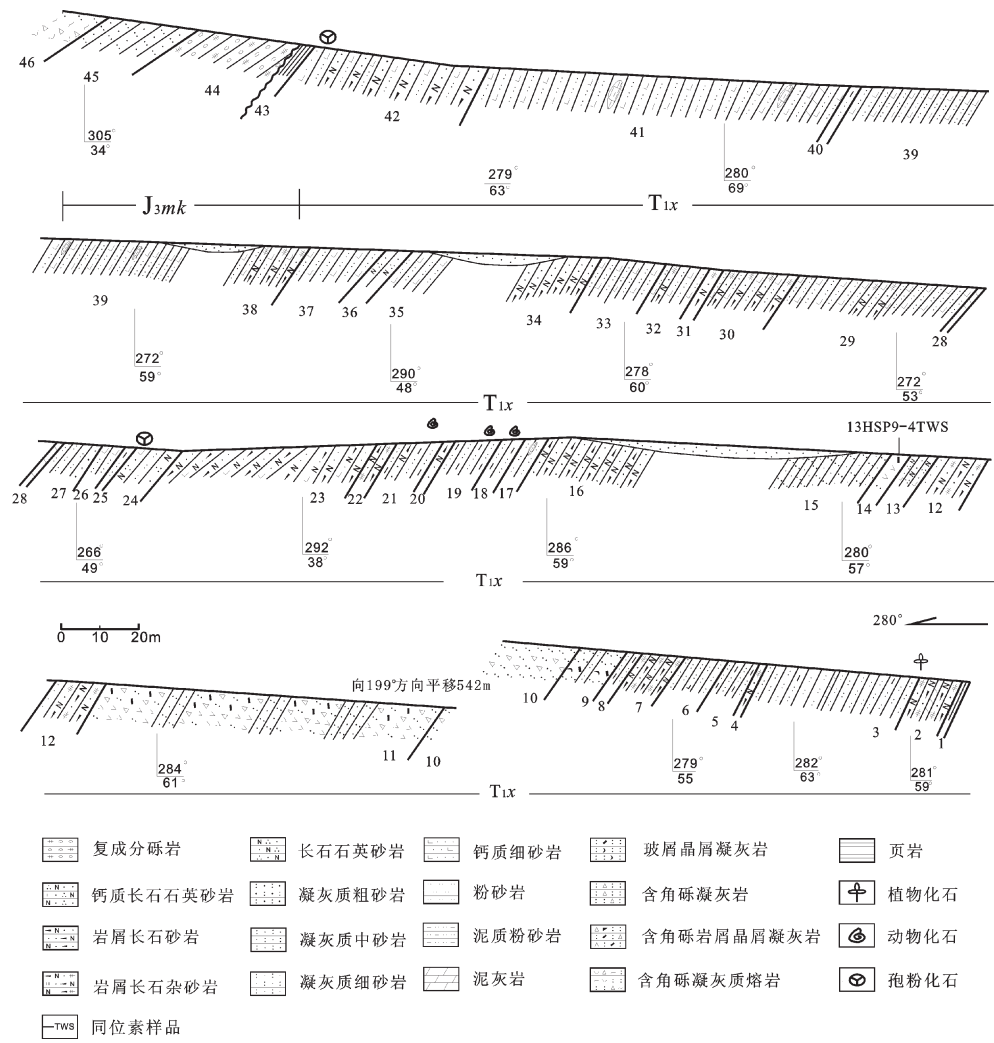


图2 巴林右旗幸福之路苏木哈拉山下三叠统幸福之路组(T_{1x})实测剖面图
Fig. 2 Stratigraphic section of the Lower Triassic Xingfuzhilu Formation (T_{1x}) at Xingfuzhilu, Bairin Right Banner, Inner Mongolia

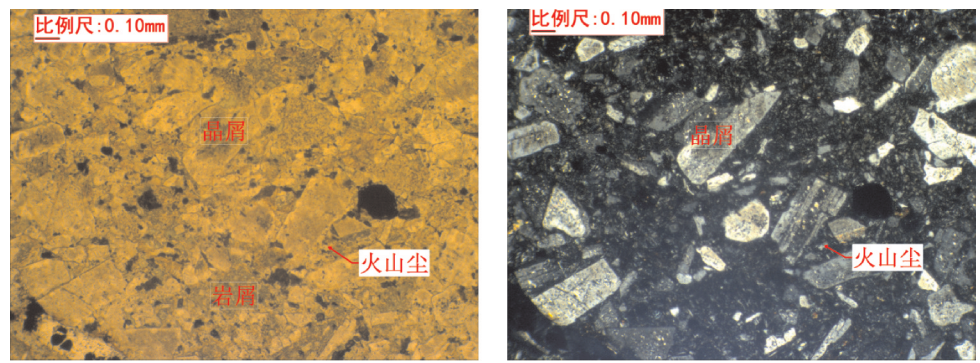


图3 幸福之路组凝灰岩镜下特征

Fig.3 Microphotograph of tuffs of Lower Triassic Xingfuzhilu Formation at Xingfuzhilu, Bairin Right Banner, Inner Mongolia

样来监视测试过程的稳定性。数据处理采用澳大利亚 Glitter(ver. 4.4, Macquarie University)完成, 普通铅校正方法同 Andersen(2002)^[39]。

3 测试结果

本文对凝灰岩样品(13HSP9-4Bb)的锆石进行了 LA-ICP-MS U-Pb 同位素分析, 分析结果列于表 1。从锆石阴极发光图像中(图 4)可以看出样品中锆石为自形到半自形, 主要呈长柱状和短柱状, 粒度主要集中在 100~150 μm , 内部结构清晰, 发育典型的振荡型环带, 少部分锆石有不同程度的溶蚀、破碎, 具有高的 Th/U 比值(0.54~0.99), 反映出岩浆成因锆石的特点(表 1)。

13BHP9-4Bb 共测试了 25 颗锆石的 25 个点, 25 个测试点都位于谐和线上(图 5), 25 个点的 $^{206}\text{Pb}/^{238}\text{U}$ 年龄值为 249~261 Ma, 25 个年龄数据的加权平均值为 (254.3 ± 2.6) Ma, MSWD = 0.20, 代表了该凝灰岩的岩浆结晶年龄, 即样品为晚二叠世火山活动的产物, 故该套地层的时代应为晚二叠世。

4 讨 论

4.1 幸福之路组的时代及二叠—三叠系界线

据前人资料, 幸福之路组分为 3 个岩性段: 下段及中段的建组剖面为幸福之路苏木查干布拉格剖面, 上段在该剖面出露不完整, 上段建组剖面为幸福之路苏木哈拉山东剖面^[28]。查干布拉格剖面幸福之路组中段下部发现叶肢介化石: *Pseudestheria* sp., *Falsissa* sp., *Cornia* sp., *Huanghestheria* sp., *Costestheria*(*Protomonocarina*?) sp., *Cyclotunguzites* sp., 时代为早三叠世早期; 上段下部见有 *Cornia*、*Palaeolimnadia* 及 *Trisitum* ? 等, 具有中三叠世早期的组合面貌^[29-30]。哈拉山东剖面见有介形虫、叶肢介、双壳、植物和孢粉等多门类化石, 且含有多层可供同位素测年的火山岩夹层^[30-31]。介形虫有: *Darwinula triassiana* Belousova, *D. rotundata* Lubimova, *D. aff. oblonga* Schneider, *D. subovatiformis* Su, Li, Pang et Chen, 为早三叠世特征性介形虫种群^[30]; 叶肢介有: *Cyclotunguzites* cf. *gazimuri* Novojilov, *Cy. cf. altus* Molin, *Cy. cf. elongates* Molin, *Cy. sp.*, *Rhyssesstheria perfecta* W. Wang, *R. lampra* W. Wang, *Euestheria* sp., 时代为晚二叠世—早三叠

世, 更倾向于早三叠世^[31]; 孢粉有: *Kraeuselisporites spinulosus* Hou et Wang, *Alisporites communis* Ouyang, *Alisporites auritus* Ouyang et Li, *Protohaploxypinus* sp., *Falcisporites* sp., *Crucisaccites variosulcatus* Djupina, *Vittatina costabilis* Wilson, *Cycadopites caperatus* (Luber, 1941) Hart, *Lunatisporites tersus* Ouyang, *Vitreisporites pallidus* (Reissinger) Nilsson, *Striatopodocarpites crassus* Singh, *Striatoabietes multis triatus* (Balme et Hennelly, 1955) Hart, *Hamiapollenites* sp., *Vestigisporites* sp., 时代属晚二叠世晚期—早三叠世早期^[31]; 另外还有双壳 *Palaeonodonta dubia*, *P. sinuatifformis*, *P. cf. pseudolongissima*, *P. castor*, *Palaeomutela subparallel*, *P. cf. hahaiensis*, *P. oblonga*, *Anthraconauta magniforma*, *Neamnigenia longa*, *N. cf. longa*, *Dictys* sp. 及植物: *Noeggerathiopsis* sp., *N. cf. insignis* Rabcz, *Paracalamites* sp., *Lepeophyllum* sp., cf. *Podozamites* sp., *Rhipidopsis* ? sp.^[28]。从化石组合特点来看, 哈拉山东剖面地层时代应为早三叠世早期。该剖面化石层下部含有 4 层火山岩夹层, 郑月娟等^[32]测得第 9 层凝灰岩的年龄为 (252.6 ± 1.7) Ma (MSWD = 0.64) 和 (249.9 ± 1.6) (MSWD = 0.22), 认为其时代应为早三叠世早期, 结合生物化石年代资料将该剖面与陶海营子剖面林西组^[27]进行对比, 认为幸福之路组上段与晚二叠世林西组之间没有大的沉积间断, 并对幸福之路组下、中段的时代提出了疑问。本次工作测得该剖面第 14 层安山质岩屑晶屑凝灰岩的年龄为 (254.3 ± 2.6) Ma, 故地层时代应属晚二叠世, 据上述化石资料, 哈拉山东剖面火山岩层之上含化石层位时代为早三叠世早期^[31], 推测大兴安岭南二叠—三叠系界线在幸福之路组内部, 上二叠统一三叠统为连续沉积。另在查干布拉格剖面幸福之路组中段紫红色砂岩、粉砂岩中也发现了火山岩夹层, 其年龄为 (255 ± 2.0) Ma (另文报道), 进一步说明幸福之路组包括晚二叠世沉积。但如上文所述, 根据生物化石研究, 查干布拉格剖面幸福之路组中段下部的时代为早三叠世, 上段的介形虫化石具有中三叠世早期的组合面貌^[29-30], 这一认识与本文的研究结果相悖, 因此, 幸福之路组的时代、查干布拉格剖面 and 哈拉山东剖面的对比关

表1 幸福之路组凝灰岩锆石 LA-ICP-MS U-Pb 分析结果
Table 1 LA-ICP-MS U-Pb data of the tuffs in the Lower Triassic Xingfuzhulu Formation at Xingfuzhulu, Balinyouqi, Inner Mongolia

测点编号	Pb / 10^{-6}	Th ²³² / 10^{-6}	U ²³⁸ / 10^{-6}	Th/U	²⁰⁷ Pb/ ²⁰⁶ Pb		²⁰⁷ Pb/ ²³⁵ U		²⁰⁶ Pb/ ²³⁸ U		²⁰⁷ Pb/ ²⁰⁶ Pb		²⁰⁷ Pb/ ²³⁵ U		²⁰⁶ Pb/ ²³⁸ U		谐和度
					比值	1σ	比值	1σ	比值	1σ	年龄/Ma	1σ	年龄/Ma	1σ	年龄/Ma	1σ	
1	1.740314	22.85	37.22	0.6139172	0.05121	0.0077	0.28816	0.04296	0.04081	0.00112	250	279	257	34	258	7	-0.388%
2	2.313842	41.88	47.75	0.8770681	0.05128	0.00776	0.28943	0.04334	0.04093	0.00116	253	278	258	34	259	7	-0.386%
3	1.697291	21.42	36.12	0.5930233	0.05122	0.01071	0.28233	0.05858	0.03997	0.00129	251	347	253	46	253	8	0.0009%
4	1.598706	24.34	35.06	0.6942384	0.05181	0.00828	0.28511	0.04513	0.0399	0.00113	277	295	255	36	252	7	1.190%
5	3.93005	57.75	86.39	0.6684801	0.05112	0.00437	0.28313	0.02396	0.04016	0.00088	246	152	253	19	254	5	-0.394%
6	1.929683	36.04	39.55	0.9112516	0.05156	0.00706	0.28642	0.03879	0.04028	0.00112	266	254	256	31	255	7	0.392%
7	2.071304	41.25	41.49	0.9942155	0.05193	0.00831	0.28353	0.04497	0.03959	0.00114	282	294	253	36	250	7	1.200%
8	1.733077	20.35	37.48	0.5429562	0.05173	0.00631	0.29366	0.03525	0.04116	0.00119	273	217	261	28	260	7	0.385%
9	1.915424	31.49	39.26	0.8020886	0.05211	0.00684	0.29677	0.0385	0.0413	0.00112	290	242	264	30	261	7	1.149%
10	1.509989	22.83	33.82	0.6750444	0.05161	0.00818	0.28062	0.04385	0.03943	0.00129	268	285	251	35	249	8	0.803%
11	1.455203	23.66	32.67	0.7242118	0.05242	0.01625	0.29285	0.09032	0.04051	0.00149	304	498	261	71	256	9	1.953%
12	1.59644	23.54	34.48	0.6827146	0.05143	0.00672	0.28357	0.03646	0.03998	0.00118	260	235	253	29	253	7	0.000%
13	1.504817	22.34	32.17	0.6944358	0.05331	0.01631	0.29106	0.0885	0.03959	0.00153	342	499	259	70	250	9	3.600%
14	3.998689	53.03	71.19	0.744908	0.05209	0.00385	0.29198	0.02128	0.04065	0.00091	289	125	260	17	257	6	1.167%
15	1.94833	30.35	41.44	0.7323842	0.05137	0.00889	0.28859	0.04942	0.04073	0.00126	257	302	257	39	257	8	0.000%
16	2.731752	34.98	60.46	0.5785643	0.05216	0.00413	0.29074	0.02259	0.04041	0.00097	292	133	259	18	255	6	1.569%
17	1.657789	24.39	35.89	0.6795765	0.05261	0.00843	0.29381	0.04661	0.0405	0.00118	312	298	262	37	256	7	2.344%
18	2.321109	38.18	48.66	0.784628	0.05199	0.00591	0.28598	0.03212	0.03989	0.00101	285	206	255	25	252	6	1.190%
19	2.270219	27.48	50.24	0.5469745	0.05158	0.0044	0.28633	0.02397	0.04026	0.00099	267	145	256	19	254	6	0.787%
20	2.069126	31.42	44.32	0.708935	0.05149	0.00486	0.28231	0.02621	0.03976	0.00102	263	163	252	21	251	6	0.398%
21	4.807602	89.42	97.74	0.9148762	0.05246	0.00368	0.29182	0.02019	0.04034	0.00088	306	118	260	16	255	5	1.961%
22	2.281389	34.46	48.62	0.7087618	0.05181	0.00645	0.28607	0.03533	0.04004	0.00097	277	234	255	28	253	6	0.791%
23	1.333318	18.3	29.4	0.622449	0.05119	0.01077	0.28152	0.05878	0.03988	0.00129	249	347	252	47	252	8	0.000%
24	3.553214	71.22	72.19	0.9865632	0.05196	0.00372	0.28573	0.02008	0.03987	0.0009	284	119	255	16	252	6	1.190%
25	2.364469	45.94	47.58	0.9655317	0.05139	0.00647	0.28463	0.03534	0.04016	0.00114	258	227	254	28	254	7	0.000%

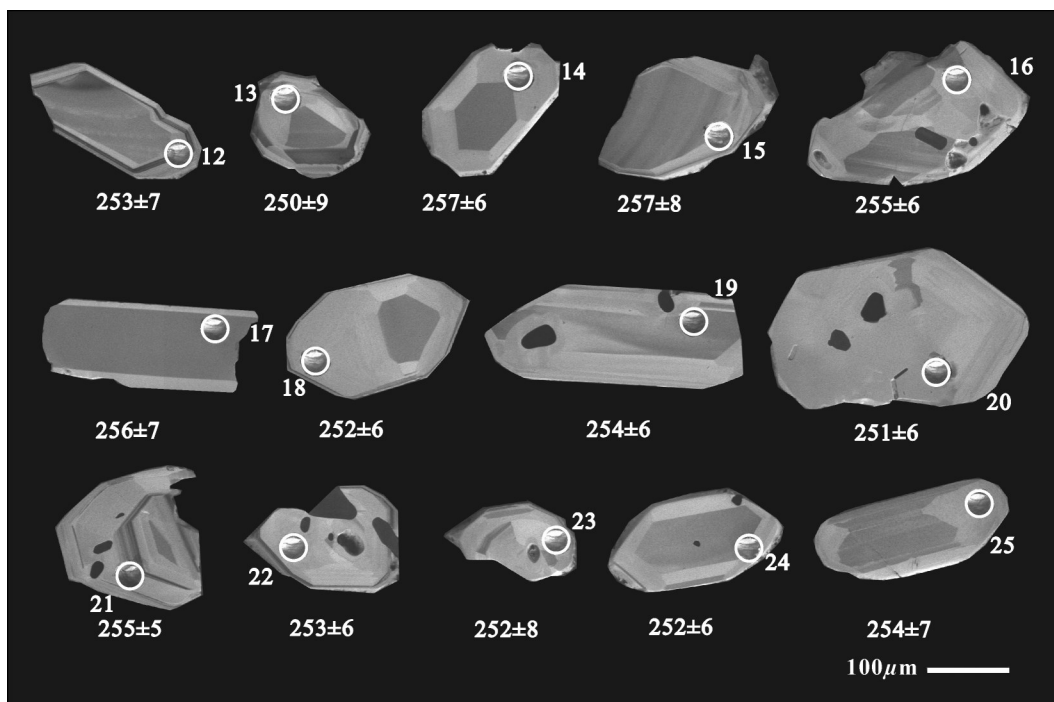


图4 幸福之路组凝灰岩的锆石阴极发光图像和 $^{206}\text{Pb}/^{238}\text{U}$ 年龄(Ma)

Fig.4 CL images of tuffs of Lower Triassic Xingfuzhulu Formation at Xingfuzhulu, Bairin Right Banner, Inner Mongolia (using the age of $^{206}\text{Pb}/^{238}\text{U}$)

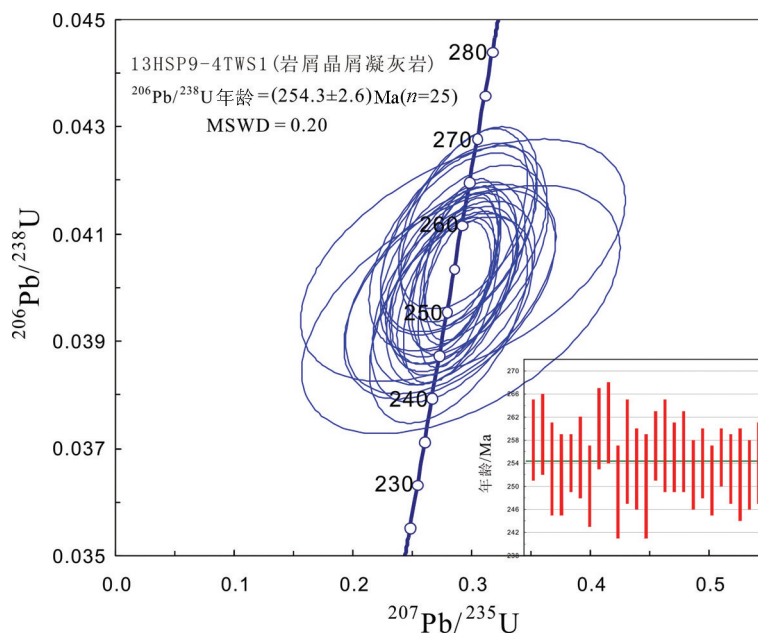


图5 幸福之路组凝灰岩样品的锆石U-Pb谐和图

Fig.5 Zircon U-Pb concordant diagram of tuffs from the Xingfuzhulu Formation

系还需进一步加强研究。

4.2 华北板块与西伯利亚板块碰撞时限

关于华北与西伯利亚两大板块碰撞的地点和时限,一直存有争议,目前主流意见倾向于西拉木伦河—长春—延吉一线是两大板块的最后缝合带,时间为晚二叠世—早三叠世,不同学者基于不同研究对象,对此问题进行了论述。从内蒙古东部到吉林中部,出露了大量与板块碰撞拼合相关的早—中三叠世的侵入岩及火山岩^[12, 20-21, 40-48],刘兵等^[37]根据对岩浆作用的年代学与地球化学的分析研究,认为“华北板块北缘与其北侧地块最终闭合的时间应在P₃-T₁”;张磊等^[15]在综合分析前人对蛇绿岩带、古地磁、古生物学及岩浆作用的年代学与地球化学等研究成果的基础上,认为晚二叠世—三叠纪,两大板块碰撞拼合于温都尔庙—西拉木伦河—延吉一线,伴随着三叠纪沿拼合带发育的大量同碰撞壳源花岗岩;郑月娟等^[32]将生物化石资料与大兴安岭南部早中三叠世的岩浆活动进行综合分析,认为华北板块和西伯利亚板块之间的古亚洲洋至少在250 Ma之前就已闭合;李锦轶等^[49]从构造变形的角度提出古生代洋盆沿索伦—西拉木伦—吉林—延吉一线在古生代晚期关闭;从古生物地理区系来看,晚二叠世晚期开始已经出现了南北生物群的混生^[31, 50-52]。

除了岩浆活动、古地磁、古生物学、古生物地理区系及构造变形外,地层的分布特征、沉积环境的改变,尤其是地层的接触关系也是板块碰撞的重要判别标志。幸福之路组沉积在空间分布上与上二叠统林西组具有一致性,二者均呈北东向展布;林西组为湖相、潟湖相黑灰色、灰绿色的砂板岩组合,幸福之路组以红层作为划分的主要标志,岩性以正常沉积碎屑岩为主夹有火山岩层,虽然沉积环境上已有了较大的改观,气候条件也转为干热,但这种变化总体上为渐变的,上二叠统与下三叠统接触关系的研究也充分证明了这一认识。刘兵等^[37]根据碎屑锆石的年代学研究,认为大兴安岭中段上二叠统与下三叠统为整合接触关系。本文研究的大兴安岭南部幸福之路组上段下部凝灰岩年龄的加权平均值为(254.3±2.6)Ma,时代为晚二叠世,而火山岩层上部的孢粉、叶肢介化石时代为早三叠世^[31],说明大兴安岭地区上二叠统—下三叠统为连续沉积,这一沉积期的构造背景具有继承关系,华北与西伯利

亚板块的碰撞拼合持续到早中三叠世,这一认识与沿索伦—西拉木伦—吉林—延吉一线广泛分布的早—中三叠世岩浆岩相吻合。

5 结 论

本次所测凝灰岩年龄数据表明研究区存在晚二叠世火山岩浆事件,所采集的凝灰岩样品中也含有大量的安山岩岩屑,且剖面多个层位发育火山岩夹层,推测在(254.3±2.6)Ma时期华北板块和西伯利亚板块处于俯冲碰撞阶段。综合生物地层及同位素测年的研究成果,巴林右旗幸福之路苏木哈拉山东剖面幸福之路组上段下部沉积时代为晚二叠世晚期,上部为早三叠世早期,幸福之路组的沉积时代应为晚二叠世—早三叠世,大兴安岭地区上二叠统与下三叠统为整合接触。推测晚二叠世晚期华北板块和西伯利亚板块碰撞拼合,古亚洲洋消失,南北生物群混生,早三叠世西伯利亚和华北板块碰撞结束。

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