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大兴安岭南部二叠系—三叠系界线及沉积环境演化

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提要:北方陆相二叠系—三叠系界线研究是界线地层研究的重要问题之一,对采自内蒙古巴林右旗幸福之路组二段建组剖面的安山质岩屑晶屑凝灰岩开展锆石LA-ICP-MS U-Pb测年,结果为(255.5±1.1)Ma,火山岩上部多个层位粉砂质泥岩中发现孢粉化石,计17属20种,时代为晚二叠世—早三叠世,推断幸福之路组的时代为晚二叠世—早三叠世,大兴安岭地区二叠系—三叠系界线在幸福之路组内部,二者为整合接触。幸福之路组以红层做为划分标志,岩性为正常沉积碎屑岩夹火山岩,见大量泥灰岩夹层、钙质结核及干裂现象,反映了炎热、干燥及强氧化条件的气候环境,大兴安岭地区晚二叠世晚期(幸福之路组二段下部)就已出现反映干旱气候的红层沉积,与相邻的华北及新疆准噶尔盆地相似。

关 键 词:二叠系—三叠系;锆石U-Pb年龄;火山岩;界线;连续沉积;沉积环境演化;地质调查工程;大兴安岭南部;内蒙古

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The sedimentary environment and boundary of Permian-Triassic strata in the southern Da Hinggan Mountains, Inner Mongolia

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Abstract: The continental Permian-Triassic boundary is one of the most important problems in the study of the global Permian-Triassic boundary. Based on collecting and analyzing tuff samples, the authors conducted LA-ICP-MS U-Pb dating of zircon and obtained an age of (255.5±1.1)Ma in the stratotype section of the middle part of Xingfuzhilu Formation. A total of 20 species of 17 genera sporopollen fossils were discovered on the top of the tuff in the stratotype section. The age of Xingfuzhilu Formation is late Late Permian- early Early Triassic according to the sporopollen fossils. It is considered that the middle part of Xingfuzhilu Formation should be late Late Permian whereas the upper part belongs to early Early Triassic. The boundary of Permian and Triassic strata in Da Hinggan Mountains is actually located inside Xingfuzhilu Formation. Moreover, the Late Permian-Early Triassic strata

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are of continuous deposition in Da Hinggan Mountains. With red−red features as a dividing point, Xingfuzhilu Formation totally reflects the thermal, arid and strong oxidation climate. It can be dated back to late Late Permian−early Early Triassic. The red beds came into existence from the late Late Permian in Da Hinggan Mountains. In addition, the climate changed from warm and rainless to arid and thermal, which is in accord with features of neighbouring North China and Junggar basin in Xinjiang. These data prove that the thermal, arid and strong oxidation climate did exert an profound influence on Da Hinggan Mountains.

Key words: Permian−Triassic strata; zircom U-Pb dating; volcanic rock; boundary; continuous deposition; sedimentary environment evolution; geological survey engineering; southern Da Hinggan Mountains; Inner mongolia

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1 引 言

中国南方海相晚二叠世—早三叠世地层研究程度较高,界线层型、生物地层、岩石地层、磁性地层、同位素年代和化学地层等方面均取得重要进展,上二叠统(乐平统)吴家坪阶和长兴阶建阶工作已完成,全球海相二叠系—三叠系界线层型剖面和点(GSSP)已在中国浙江省长兴县煤山确立(第三届全国地层委员会,2012)。近年来,对中国南方陆相及海陆交互相二叠—三叠系界线地层的研究也取得很多进展。王尚彦等(2001)在滇东黔西地区开展了陆相二叠—三叠系界线地层综合研究,发现了具有事件地层标志的陆相二叠系—三叠系界线黏土层,为进一步在该区开展陆相界线地层研究打下了基础,同时为海陆相界线地层对比和陆相二叠—三叠系界线的确定提供了有利条件;杨逢清等(2005)对贵州威宁岔河陆相二叠—三叠系剖面植物、孢粉化石、黏土岩及同位素测年、有机碳同位素测定和分子地层等开展综合研究,取得了一系列研究成果,该剖面现被做为二叠—三叠系陆相界线层型候选剖面。相比之下,北方的晚二叠世—早三叠世地层研究程度较低,陆相二叠—三叠系界线研究更是亟待解决的重大地质问题。新疆准噶尔盆地吉木萨尔大龙口剖面是我国北方研究比较深入的陆相二叠—三叠系界线剖面,该剖面二叠—三叠系发育齐全,沉积连续,出露良好,并含有丰富的孢粉、古植物、双壳类、介形虫、叶肢介、脊椎动物等化石,已开展了生物地层、磁性地层、事件地层、沉积、气候等多方面研究(庞其清,1985;扬基端等,1986;中国地质科学院地质研究所等,1986;周统顺等,1997;程政武等,1997;屈迅等,2002;李强等,2002;张健等,2003;李永安等,2003,2004;候静鹏,2004;欧阳舒等,2004;庞其清等,2004;柳益群等,2006),一度成为陆相二叠—三叠系界线层型候选剖面之一(周统顺等,1997;Cheng et al.,1997;彭元桥等,2001),但该剖面没有可供同位素测年的火山岩夹层,缺少界线研究中重要的绝对年龄数据,难以和我国南方海陆相界线剖面建立对比联系。

大兴安岭地区晚二叠世—早三叠世地层发育且与准噶尔盆地同处天山兴蒙造山带(张允平等,2018;乔牡冬等,2018),晚二叠世地层区划同属北部边缘地层区(金玉玕等,2000)。上二叠统—下三叠统自下而上为林西组、幸福之路组(老龙头组)。林西组沿北东方向广泛分布,岩性为湖相、潟湖相黑灰色为主色调的砂板岩组合,是东北地区晚古生代重要的生烃层系(陈树旺等,2010;吴桐等,2018;周成林等,2019),幸福之路组(老龙头组)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,亦沿北东方向分布,但出露较少,分布在北部内蒙古扎赉特旗、扎兰屯及黑龙江省龙江县至嫩江多宝山一线的称为老龙头组,含少量双壳及植物化石(黑龙江省地质矿产局,1997;张武等,2006);分布于大兴安岭南部巴林右旗地区的称为幸福之路组,含双壳、叶肢介、介形虫、孢粉及少量植物化石(朱儒峰等,1992;和政军等,1997;郑月娟等,2013b)。另有建组于科尔沁右翼前旗的哈达陶勒盖组(姜万德,1992),但辽宁省地质调查院(2013)[1]在哈达陶勒盖组建组剖面二段灰黑色页岩中发现了叶肢介和蛰虫化石,经沈阳地质矿产研究所王五力先生、中国科学院南京地质古生物研究所

沈炎彬先生鉴定,属种为*Euestheria* cf. *haifanggouensis* Chen、*Eosolimnadiopsis* sp.、*Euestheria jingyuanensis* Chen及*Triops* sp.鲎虫(背甲目,未定种),时代为中侏罗世,应划入塔木兰沟组。笔者实地考察了该剖面,采获了少量叶肢介化石,同意上述观点。

大兴安岭地区晚二叠世—早三叠世古生物化石组合特征与准噶尔盆地关系密切,除晚二叠世时同属于安加拉植物地理区系外,双壳、叶肢介、及孢粉化石也可以相互对比(梁仲发,1982;王五力,1984;黄本宏,1987,1993;和政军等,1998;郑月娟等,2013a,2013b;杨兵等,2014)。尤为重要的是,该区发育有多层可供同位素测年的火山岩夹层(郑月娟等,2014,2015;张海华等,2015),对准噶尔盆地吉木萨尔大龙口剖面是一个补充,也将为与中国南方海、陆相二叠—三叠系界线建立对比关系提供依据。

大兴安岭地区上二叠统与下三叠统的接触关系前人有不同认识:北部黑龙江省龙江地区为整合接触,界线位于林西组与老龙头组之间(黑龙江省地质矿产局,1997;刘兵等,2014),南部内蒙古林西县—巴林右旗地区为平行不整合接触,界线位于林西组与幸福之路组之间(朱儒峰等,1992),杨兵等(2014)根据孢粉化石将林西组建组剖面上部的红色细碎屑岩划为老龙头组,时代为早三叠世,认为其与林西组为整合接触。

近几年来,笔者针对发育于大兴安岭南部的幸福之路组开展了较为细致的野外工作,通过对幸福之路组三段建组剖面的实测,丰富了幸福之路组化石组合内容,发现了多层火山岩夹层,对幸福之路组的时代、划分对比及二叠—三叠系接触关系等问题提出了新的认识(郑月娟等,2013b,2014,2015;张海华等,2015)。本次工作为了进一步确定幸福之路组的时代,重新实测了幸福之路组一段、二段建组剖面—巴林右旗幸福之路乡查干布拉格剖面,在典型的红层沉积—二段紫红色砂岩中发现安山质岩屑晶屑凝灰岩,火山岩上部多个层位发现孢粉化石。本文在综合分析同位素测年资料及生物化石组合特点的基础上,结合其他剖面资料,进一步讨论了幸福之路组的时代、二叠—三叠系的界线及环境演化特点,该研究将为中国北方二叠—三叠系界线研究及其与南方的对比提供依据,同时为大地构造研究及矿产资源调查提供基础资料。

2　查干布拉格剖面幸福之路组特征

实测剖面位于巴林右旗幸福之路乡查干布拉格西山,为幸福之路组一、二段的建组剖面,起点坐标: N43° 47.563′, E118° 46.910′,终点坐标: N43° 46.806′,E118°47.201′(图1),剖面共分68层,按照建组时的划分方案,1~6层应为林西组,岩性为灰绿色砂岩、粉砂岩;7~68层应为幸福之路组,二者为微角度不整合接触。幸福之路组分三部分:下部(7~8层)为砾岩,砾石主要为安山岩、英安岩、凝灰岩、砂岩及板岩,为幸福之路组一段,中部(9~45层)以红层为特色,岩性为砂岩、含砾砂岩,粉砂岩等,为幸福之路组二段,上部(46~68层)为杂色细碎屑岩,为幸福之路组三段,三段在该剖面出露不全,在剖面上部(35~63层)发现孢粉和叶肢介化石,在化石层下部紫红色砂岩中(第26层)发现安山质岩屑、晶屑凝灰岩夹层。但从本次研究来看,野外未见到确切的砾岩(原幸福之路组一段)与红色砂泥岩(幸福之路组二段)的接触关系,只是地层倾向均为东南。原划为林西组的1~6层的和原划为幸福之路组一段的7~8层时代可能新于中上部的红层沉积(具体见下文),其时代拟另撰文论述,故本文所列剖面从第9层开始,原第9层现划为第1层,其他以此类推,1~39层(原9~47层)暂划为幸福之路组二段,40~61层(原48~68层)暂划为幸福之路组三段。同位素测年的安山质岩屑、晶屑凝灰岩采自第18层(原26层),二段与原一段砾岩(原剖面7~8层)的关系暂划为断层接触(图2,图3)。具体层序如下:

晚二叠世—早三叠世幸福之路组	总厚度 1389.02 mm
61.灰紫色泥质粉砂岩	26.83 m
60.紫灰色粉砂岩	1.38 m
59.灰紫色泥质粉砂岩	6.23 m
58.灰紫色粗粉砂岩	2.08 m
57.灰紫色泥质粉砂岩	4.79 m
56.紫灰色细砂岩	6.39 m
55.灰紫色泥质粉砂岩、粉砂岩,含裸子植物花粉:*Klausipollenites* sp., *Psophosphaera* sp.	12.54 m
54.灰绿色粉砂岩夹紫灰色泥质粉砂岩	21.65 m
53.灰绿色粉砂岩	38.84 m
52.黄绿色粉砂质泥岩	21.85 m
51.黄绿色粉砂岩	27.53 m

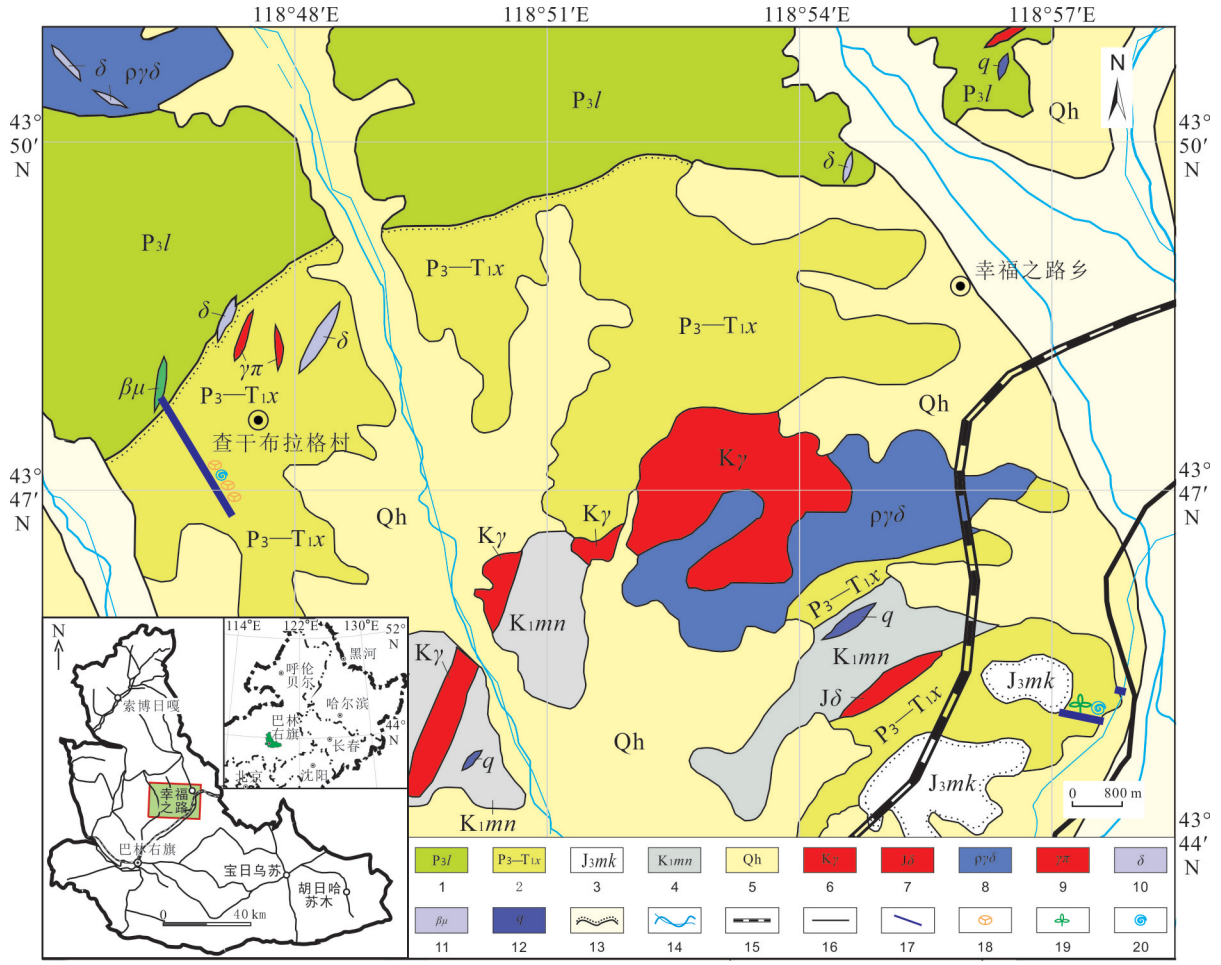

图1 内蒙古巴林右旗幸福之路地区地质简图

1—林西组;2—幸福之路组;3—满克头鄂博组;4—马尼吐组;5—第四系;6—钾长花岗岩;7—闪长岩;8—二长花岗岩;9—花岗斑岩;10—闪长岩脉;11—辉绿玢岩脉;12—石英脉;13—平行不整合;14—河流;15—铁路;16—公路;17—剖面线;18—孢粉化石;19—植物化石;20—动物化石

Fig.1 Geological sketch map of Xingfuzhilu in Balinyougi, Inner Mongolia

1−Linxi Formation;2−Xingfuzhilu Formation;3−Manketouebo Formation;4−Manitu Formation; 5−Quaternary; 6−Moyite;7−Diorite; 8−Adamellite; 9−Granite porphyry; 10−Diorite dyke; 11−Sillite dyke; 12−Quartz vein; 13−Parallel unconformity; 14−River;15−Railway; 16−Road; 17−Profile position;18−Pollen fossil;19−Fossil plants; 20−Animal fossil

50. 灰绿色粉砂质泥岩，含裸子植物花粉：*Piceaepollenites* sp., *Quadraeculina* sp. 65.88 m

49. 黄绿色细砂岩 23.00 m

48. 灰绿色粉砂岩 18.47 m

47. 灰绿色泥质粉砂岩 58.77 m

46. 黄绿色细砂岩 24.12 m

45. 灰绿色粗粉砂岩 4.51 m

44. 灰绿色粉砂岩夹粉砂质泥岩 49.66 m

43. 灰绿色粉细砂岩 57.81 m

42. 灰绿色粉砂岩 11.09 m

41. 深灰色细砂岩夹灰岩透镜体 13.31 m

40. 灰绿色粉砂质泥岩、灰绿色粉砂岩、粉砂质泥岩，含裸子植物花粉：*Alisporites* sp., *Alisporites indarraensis* *Segroves Pristinuspollenites* sp., *Piceites* sp., *Piceaepollenites* sp., *Protopinus* sp., *Lueckisporites virkkiae* R. Potonie et Klaus, *Pseudopicea* sp., *Pinuspollenites* sp. 107.61 m

39. 灰紫色粉砂岩夹灰绿色细砂岩及灰岩透镜体，*Piceaepollenites* sp., *Pristinuspollenites* sp., *Piceites* sp., *Paleoconiferae* sp., *Protoconiferus* sp., *Lueckisporites virkkiae* 56.20 m

38. 灰绿色泥质粉砂岩，含孢粉：*Cyclogranisporites* sp., *Protopinus* sp., *Quadraeculina* sp., *Alisporites parvus*, *Sulcatisporites rhombicus*, *Pristinuspollenites* sp., *Platysaccus* sp. 16.14 m

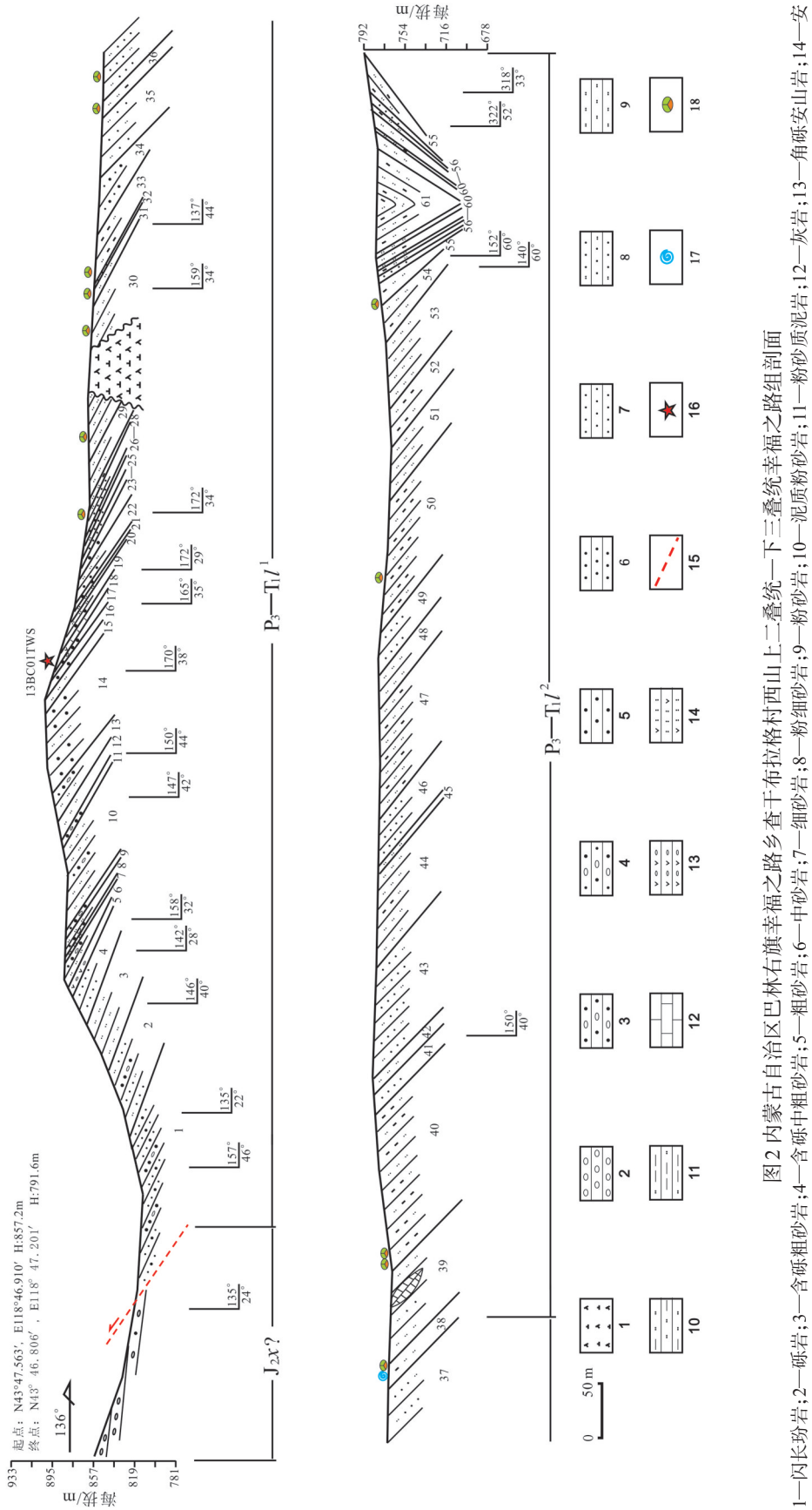

图2 内蒙古自治区巴林右旗幸福之路乡查干布拉格村西山上二叠统—下三叠统幸福之路组剖面

1—闪长玢岩;2—砾岩;3—含砾粗砂岩;4—含砾中粗砂岩;5—粗砂岩;6—中砂岩;7—细砂岩;8—粉细砂岩;9—粉砂岩;10—泥质粉砂岩;11—粉砂质泥岩;12—灰岩;13—角砾安山岩;14—安山质凝灰岩;15—断裂;16—同位素样品;17—动物化石;18—孢粉化石

Fig.2 Stratigraphic section of the Upper Permain–Lower Triassic Xingfuzhilu Formation (P3–T1x) at Xingfuzhilu, Balinyouqi, Inner Mongolia

1–Dioritic porphyrite; 2–Conglomerate; 3–Gritstone containing gravel; 4–Medium sandstone containing gravel; 5–Gritstone; 6–medium sandstone; 7–Fine sandstone; 8–Powder–finestone; 9–Siltstone; 10–Argillaceous siltstone; 11–Silty mudstone; 12–Limestone; 13–Breccia–Andesite; 14–Andesitic tuff; 15–Fault; 16–Isotope sample; 17–Animal fossil; 18–Pollen fossilA

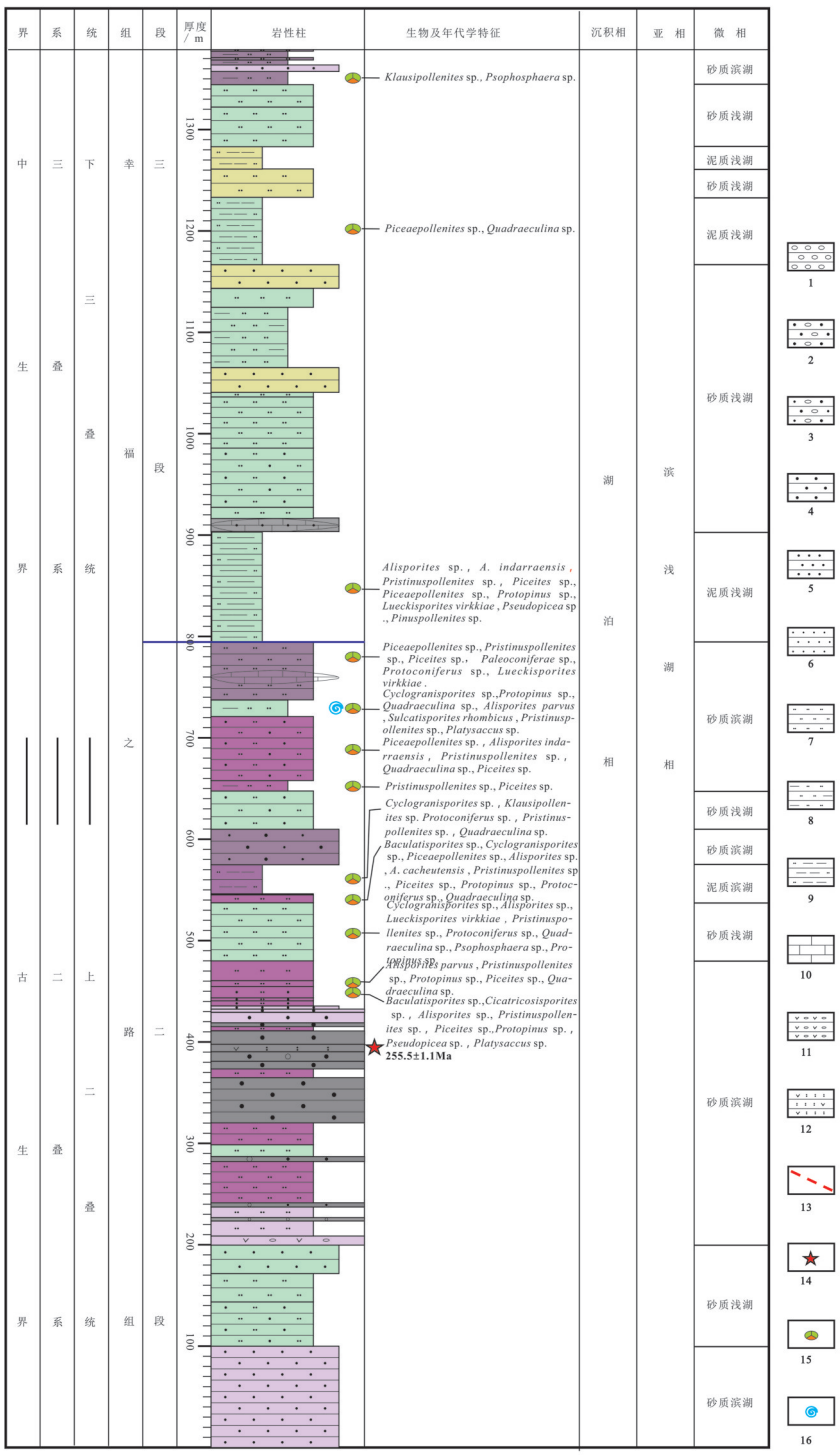

图3 内蒙古自治区巴林右旗幸福之路乡查干布拉格村西山上二叠统—下三叠统幸福之路组综合柱状图

1—砾岩;2—含砾粗砂岩;3—含砾中粗砂岩;4—粗砂岩;5—中砂岩;6—细砂岩;7—粉砂岩;8—泥质粉砂岩;9—粉砂质泥岩;10—灰岩;11—角砾安山岩;12—安山质凝灰岩;13—断裂;14—同位素样品;15—孢粉化石;16—动物化石

Fig.3 Stratigraphic column of the Upper Permain−Lower Triassic Xingfuzhilu Formation(P3−T1x)at Xingfuzhilu, Balinyouqi, Inner Mongolia

1−Conglomerate; 2−Gritstone containing gravel; 3−Medium sandstone containing gravel; 4−Gritstone; 5−Medium sandstone; 6−Fine sandstone; 7−Siltstone; 8−Argillaceous siltstone; 9−Silty mudstone; 10−Limestone; 11−Breccia−andesite; 12−Andesitic tuff; 13−Fault; 14−Isotope sample; 15−Pollen fossil; 16−Animal fossil

37. 紫红色、灰绿色粉细砂岩,含裸子植物花粉:*Piceaepollenites* sp., *Alisporites indarraensis* Segroves, *Pristinuspollenites* sp., *Quadraeculina* sp., *Piceites* sp. 62.59 m

36. 紫红色泥质粉砂岩夹灰绿色粉砂岩,含裸子植物花粉:*Pristinuspollenites* sp., *Piceites* sp. 10.28 m

35. 紫红色、灰绿色粉细砂岩 37.25 m

34. 灰紫色中层中细砂岩,夹紫色粉砂质泥砾 34.73 m

33. 紫色粉砂质泥岩,局部夹灰绿色粉砂岩,含孢粉:*Cyclogranisporites* sp., *Klausipollenites* sp. *Protoconiferus* sp., *Pristinuspollenites* sp., *Quadraeculina* sp. 28.32 m

32. 紫灰色中薄层细砂岩 1.03 m

31. 紫红色粉砂岩,含孢粉:*Baculatisporites* sp., *Cyclogranisporites* sp., *Piceaepollenites* sp., *Alisporites* sp., *Alisporites cacheutensis* (Join) Song, *Pristinuspollenites* sp., *Piceites* sp., *Protopinus* sp., *Protoconiferus* sp., *Quadraeculina* sp. 7.68 m

30. 灰绿色粉砂岩, 含孢粉:*Cyclogranisporites* sp., *Alisporites* sp., *Lueckisporites virkkiae* R. Potonie et Klaus, *Pristinuspollenites* sp., *Protoconiferus* sp., *Quadraeculina* sp., *Psophosphaera* sp., *Protopinus* sp. 56.63 m

29. 紫红色粉砂岩 19.31 m

28. 紫红色粉砂岩与灰色中粗砂岩互层,含裸子植物花粉:*Alisporites parvus* De Jersey, *Pristinuspollenites* sp., *Protopinus* sp., *Piceites* sp., *Quadraeculina* sp. 5.65 m

27. 紫红色中层粉细砂岩夹灰色细砂岩,含孢粉:*Baculatisporites* sp., *Cicatricosisporites* sp., *Alisporites* sp., *Pristinuspollenites* sp., *Piceites* sp., *Protopinus* sp., *Pseudopicea* sp.,*Platysaccus* sp. 11.02 m

26. 紫红色中层粉细砂岩与深灰色中层中砂岩互层 2.66 m

25. 紫红色中薄层粉细砂岩夹灰色中层中砂岩 4.98 m

24. 紫灰色中薄层细砂岩夹中层灰色粗砂岩 2.99 m

23. 紫灰色中厚层粗砂岩夹紫红色粉砂岩 2.75 m

22. 紫灰色厚层中砂岩夹紫红色粉砂岩 10.16 m

21. 灰色厚层粗砂岩夹紫红色粉砂岩 3.53 m

20. 紫红色粉砂岩夹灰色粗砂岩 4.07 m

19. 灰色粗砂岩与紫红色粉砂岩互层 12.96 m

18. 灰色灰色安山质岩屑晶屑凝灰岩 7.40 m

17. 灰色含砾粗砂岩与紫红色粉砂岩、泥质粉砂岩互层 9.23 m

16. 灰色粗砂岩 7.18 m

15. 紫红色粉砂岩夹灰色粗砂岩 8.69 m

14. 灰色厚层粗砂岩夹紫红色粉砂岩 44.17 m

13. 紫红色粉砂岩夹灰色砂砾岩 21.56 m

12. 灰绿色粉砂岩 11.18 m

11. 灰色含砾粗砂岩 4.97 m

10. 紫红色粉砂岩夹灰色砂砾岩 40.12 m

9. 灰色砂砾岩夹紫红色粉砂岩 4.29 m

8. 紫灰色粉砂岩夹灰色砂砾岩 10.19 m

7. 深灰色砾岩 3.22 m

6. 紫灰色粉砂岩,夹灰色砂砾岩 14.69 m

5. 紫灰色角砾安山岩 8.73 m

4. 灰绿色细砂岩 27.84 m

3. 灰绿色粉砂岩 27.77 m

2. 灰绿色中薄层粉细砂岩,局部夹含砾粗砂岩,含裸子植物花粉:*Piceaepollenites* sp., *Protoconiferus* sp. 43.34 m

1. 紫灰色中薄层细砂岩,局部夹含砾粗砂岩 99.18 m

========== 断 层 ==========

紫灰色复成分砾岩夹中薄层紫红色砂岩

3　同位素测年样品特征及分析方法

测年样品(13BC01TWS)采自剖面第18层(幸福之路组二段)(图2):岩性为安山质岩屑晶屑凝灰岩,凝灰结构,块状构造。主要由岩屑(25%)+晶屑(65%)+火山灰(10%)组成。岩屑粒径0.2~0.8 mm,以安山岩、燧石和凝灰岩碎屑为主,呈次棱角状,部分呈浑圆状;晶屑粒径0.2~0.5 mm,少量小者0.1 mm左右,主要矿物成分为斜长石、正长石、黑云母和少量石英晶屑,其中斜长石多数呈棱角-次棱角状,普遍发生绢云母化蚀变,局部可见聚片双晶发育,正长石呈半自形柱状,表面浑浊,部分可见卡式双晶,黑云母保存部分片状晶形并见暗化现象。石英晶屑多发育溶蚀现象;胶结物主要为火山灰,部分碳酸盐化(图4)。

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)地学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(宋彪等,2002)。

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(UPI93SS)和美国AGILENT科技有限公司生产的

表1 幸福之路组晶质凝灰岩LA-ICP-MS锆石U-Th-Pb分析结果

Table 1 The zircon LA-ICP-MS U-Pb data from crystal stuff in the middle part of Xingfuzhilu Formation

样号	Pb /10^{-6}	Th^{232} /10^{-6}	U^{238} /10^{-6}	Th/U	谐和度	同位素比值						表面年龄/Ma					
						$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$	
1	3.29462	42.39	73.95	0.57323	0.992	0.05161	0.0047	0.28883	0.02619	0.04057	0.00085	268	167	258	21	256	5
2	8.00001	76.97	187.18	0.41121	1	0.05136	0.00178	0.28783	0.01013	0.04063	0.00071	257	49	257	8	257	4
3	5.721701	43.22	131.09	0.3297	0.996	0.05185	0.00259	0.30259	0.01509	0.04231	0.00081	279	79	268	12	267	5
4	8.33455	117.14	186.1	0.62945	0.984	0.05218	0.00259	0.28928	0.01448	0.04019	0.00071	293	82	258	11	254	4
5	4.117694	36.75	98.37	0.37359	0.996	0.05143	0.00235	0.28497	0.013	0.04017	0.00077	260	70	255	10	254	5
6	5.960141	47.7	140.45	0.33962	1	0.05135	0.00235	0.29002	0.0133	0.04094	0.00076	257	71	259	10	259	5
7	5.672636	55.39	133.48	0.41497	0.988	0.05188	0.00343	0.28651	0.01897	0.04004	0.00074	280	118	256	15	253	5
8	3.816353	30.34	86.57	0.35047	0.996	0.05152	0.0032	0.30246	0.01876	0.04256	0.00082	264	107	268	15	269	5
9	4.613487	37.89	107.16	0.35358	0.985	0.05229	0.00294	0.30162	0.01686	0.04182	0.00082	298	92	268	13	264	5
10	4.703803	37.91	111.47	0.34009	0.988	0.05209	0.00349	0.29227	0.01955	0.04068	0.00078	289	118	260	15	257	5
11	7.34835	82.91	164.57	0.5038	0.996	0.05174	0.00222	0.29569	0.01277	0.04143	0.00075	274	66	263	10	262	5
12	5.914208	59.96	140.45	0.42691	0.996	0.05148	0.00369	0.28298	0.02028	0.03985	0.00076	262	129	253	16	252	5
13	7.96112	118.96	179.28	0.66354	0.992	0.05156	0.00286	0.28408	0.01579	0.03994	0.00072	266	94	254	12	252	4
14	6.15054	58.13	144.89	0.4012	0.992	0.05162	0.00258	0.28774	0.01445	0.04041	0.00073	269	82	257	11	255	5
15	5.694285	53.4	129.78	0.41147	0.992	0.05193	0.00243	0.30046	0.01406	0.04194	0.00079	282	72	267	11	265	5
16	2.702637	26.44	64.1	0.41248	0.992	0.05144	0.00421	0.28111	0.02281	0.03962	0.00087	261	144	252	18	250	5
17	6.71407	73.6	157.24	0.46807	0.996	0.05149	0.00272	0.28341	0.01502	0.0399	0.00072	263	88	253	12	252	4
18	12.68146	215.85	277.73	0.77719	1	0.05117	0.0016	0.27809	0.00891	0.0394	0.00068	248	43	249	7	249	4
19	2.904944	21.35	69.62	0.30666	1	0.05133	0.00347	0.29008	0.0194	0.04098	0.00086	256	115	259	15	259	5
20	6.129227	74.46	134.82	0.55229	1	0.05155	0.00244	0.29697	0.01408	0.04176	0.00076	266	75	264	11	264	5
21	3.758624	33.9	87.89	0.38571	0.988	0.05207	0.00281	0.29323	0.01566	0.04083	0.00082	288	85	261	12	258	5
22	3.124835	28.42	71.81	0.39577	0.996	0.05169	0.00454	0.29548	0.02579	0.04144	0.00088	272	159	263	20	262	5
23	4.104074	46.22	95.04	0.48632	0.984	0.05204	0.0046	0.28629	0.02525	0.03988	0.0008	287	163	256	20	252	5
24	3.448479	45.07	78.23	0.57612	1	0.05124	0.00583	0.28081	0.03187	0.03973	0.00083	252	217	251	25	251	5
25	4.848621	51.27	111.41	0.46019	0.984	0.05227	0.00245	0.29371	0.01371	0.04074	0.00078	297	72	261	11	257	5
26	3.837531	48.21	87.88	0.54859	1	0.05112	0.00606	0.27798	0.03282	0.03943	0.00085	246	227	249	26	249	5
27	2.110668	16.48	49.87	0.33046	0.956	0.05369	0.00803	0.29548	0.0438	0.0399	0.00108	358	281	263	34	252	7
28	2.683872	24.3	64.06	0.37933	0.992	0.05173	0.00384	0.28515	0.02092	0.03997	0.00087	273	128	255	17	253	5
29	3.872301	39.54	90.63	0.43628	0.988	0.05198	0.0038	0.28673	0.02077	0.03999	0.00083	285	128	256	16	253	5
30	8.86361	130.33	199.54	0.65315	0.984	0.05213	0.00233	0.28604	0.01283	0.03978	0.00071	291	70	255	10	251	4
31	4.518102	57.36	104.54	0.54869	0.996	0.0514	0.00388	0.27811	0.0209	0.03923	0.00078	259	135	249	17	248	5
32	7.17638	77.41	168.98	0.4581	0.988	0.05205	0.00274	0.28696	0.0151	0.03997	0.00074	288	86	256	12	253	5
33	33.20346	26.31	70.79	0.37166	0.972	0.05271	0.00345	0.28759	0.01857	0.03956	0.00085	316	108	257	15	250	5
34	5.243423	53.96	120.93	0.44621	1	0.05132	0.00322	0.28446	0.01776	0.04018	0.00077	255	108	254	14	254	5
35	6.03265	52.98	143.18	0.37002	0.988	0.052	0.00307	0.29216	0.01724	0.04074	0.00077	285	100	260	14	257	5
36	4.3071	55.9	94.37	0.59235	0.985	0.05217	0.0029	0.29518	0.01623	0.04103	0.00083	293	88	263	13	259	5
37	9.73185	64.59	229.61	0.2813	0.985	0.05231	0.00251	0.29923	0.01447	0.04147	0.00074	299	78	266	11	262	5
38	3.211675	42.1	69.98	0.6016	0.989	0.05205	0.00524	0.30022	0.03004	0.04182	0.00091	288	186	267	23	264	6
39	3.921113	45.14	88.23	0.51162	0.996	0.05154	0.0055	0.29274	0.03108	0.04118	0.00088	265	200	261	24	260	5
40	3.871694	34.87	89.77	0.38844	0.981	0.05255	0.00571	0.29661	0.03205	0.04093	0.00088	309	204	264	25	259	5
41	6.84624	71.02	163.08	0.43549	0.992	0.05164	0.00233	0.28157	0.01272	0.03953	0.00073	270	70	252	10	250	5
42	8.61105	79.01	201.13	0.39283	0.988	0.05192	0.00185	0.29128	0.0105	0.04068	0.00072	282	50	260	8	257	4
43	9.96058	153.54	221.15	0.69428	0.988	0.05183	0.00258	0.28003	0.01402	0.03917	0.00069	278	82	251	11	248	4
44	5.121269	45.92	116.76	0.39329	0.985	0.05232	0.0024	0.30312	0.01383	0.04201	0.00081	299	69	269	11	265	5
45	4.993322	45.03	113.67	0.39615	0.973	0.05288	0.00388	0.30163	0.02202	0.04136	0.00082	324	130	268	17	261	5
46	8.27799	93.68	189.25	0.49501	0.976	0.05273	0.00186	0.29196	0.01042	0.04014	0.00071	317	49	260	8	254	4
47	7.90874	79.29	187.9	0.42198	0.996	0.05135	0.00182	0.28234	0.01012	0.03987	0.0007	257	50	253	8	252	4
48	2.318782	19.99	52.2	0.38295	0.985	0.05247	0.00372	0.30556	0.02132	0.04223	0.00095	306	118	271	17	267	6
49	3.959625	36.88	89.42	0.41244	0.996	0.05177	0.00302	0.29712	0.01721	0.04161	0.00083	275	96	264	13	263	5
50	8.62748	99.87	198.18	0.50394	0.996	0.0514	0.00179	0.28262	0.00997	0.03987	0.0007	259	49	253	8	252	4

续表1

样号	Pb /10^{-6}	Th^{232} /10^{-6}	U^{238} /10^{-6}	Th/U	谐和度	同位素比值						表面年龄/Ma					
						$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$	
51	3.379993	31.67	75.32	0.42047	0.996	0.0517	0.00335	0.30021	0.01935	0.0421	0.00084	272	111	267	15	266	5
52	5.811556	65.65	133.91	0.49025	0.996	0.05123	0.00223	0.28336	0.01231	0.04011	0.00075	251	66	253	10	254	5
53	3.572979	35.55	79.22	0.44875	0.996	0.05174	0.00315	0.29993	0.01807	0.04204	0.00086	274	100	266	14	265	5
54	5.174886	65.12	119.49	0.54498	0.98	0.05232	0.00276	0.28342	0.01489	0.03928	0.00075	299	85	253	12	248	5
55	2.166531	17.14	49.75	0.34452	0.992	0.05199	0.00434	0.30111	0.02483	0.042	0.00097	285	145	267	19	265	6
56	2.868702	35.27	66.31	0.5319	0.992	0.05174	0.00351	0.28189	0.01888	0.03951	0.00085	274	114	252	15	250	5
57	4.832894	45.7	112.91	0.40475	0.984	0.05215	0.00317	0.28993	0.01756	0.04031	0.00076	292	104	259	14	255	5
58	3.69022	38.79	82.29	0.47138	0.969	0.05324	0.00566	0.30299	0.03201	0.04127	0.00092	339	198	269	25	261	6
59	3.076897	31.77	69.46	0.45739	0.992	0.05177	0.00455	0.2909	0.02539	0.04075	0.00086	275	159	259	20	257	5
60	8.75211	111.56	190.98	0.58414	0.977	0.05258	0.00181	0.29377	0.01023	0.04051	0.00071	311	48	262	8	256	4
61	3.079683	30.18	72.65	0.41542	1	0.05131	0.00483	0.28044	0.02621	0.03963	0.00086	255	171	251	21	251	5
62	3.750666	41.79	87.02	0.48023	1	0.0512	0.00339	0.27812	0.01828	0.03939	0.0008	250	114	249	15	249	5
63	4.73769	66.02	105.75	0.6243	0.976	0.05254	0.00422	0.29049	0.0232	0.0401	0.00081	309	145	259	18	253	5
64	4.939014	41.92	116.4	0.36014	0.996	0.05164	0.00234	0.28825	0.01301	0.04048	0.00076	270	69	257	10	256	5
65	2.773659	23.91	64.2	0.37243	0.996	0.05168	0.00558	0.29103	0.03116	0.04084	0.00094	271	199	259	25	258	6
66	3.187137	32.57	73.31	0.44428	0.988	0.05204	0.00378	0.29241	0.02103	0.04074	0.00087	287	125	260	17	257	5
67	5.97925	67.51	136.17	0.49578	0.98	0.05251	0.00225	0.28835	0.01232	0.03982	0.00075	308	63	257	10	252	5
68	6.97474	78.12	160.53	0.48664	0.984	0.05215	0.00211	0.2861	0.01156	0.03978	0.00073	292	59	255	9	251	5
69	5.953556	49.84	144.32	0.34534	0.964	0.05311	0.00309	0.28766	0.01667	0.03927	0.00075	333	97	257	13	248	5
70	4.50422	43.31	105.35	0.41111	0.996	0.05158	0.00347	0.28726	0.0192	0.04039	0.00081	267	116	256	15	255	5
71	4.15258	24.73	52.92	0.46731	0.934	0.05512	0.01629	0.31057	0.09093	0.04086	0.00162	417	553	275	70	258	10
72	5.94806	70.36	137.85	0.51041	0.992	0.05169	0.0023	0.27707	0.01228	0.03887	0.00073	272	67	248	10	246	5
73	4.896146	55.89	111.83	0.49978	0.992	0.05187	0.00346	0.28734	0.01902	0.04017	0.0008	280	115	256	15	254	5
74	2.592915	26.96	61.3	0.4398	0.988	0.05183	0.00464	0.28413	0.02512	0.03975	0.00091	278	158	254	20	251	6
75	3.259595	31.07	77.74	0.39967	0.992	0.0516	0.00327	0.28139	0.01758	0.03954	0.00085	268	104	252	14	250	5
76	5.4408	62.05	128.33	0.48352	0.996	0.05129	0.00403	0.27503	0.02152	0.03888	0.00076	254	142	247	17	246	5
77	3.849921	34.43	89.54	0.38452	0.992	0.05184	0.00386	0.29155	0.0215	0.04078	0.00085	278	130	260	17	258	5
78	7.28359	81.78	161.93	0.50503	0.992	0.05182	0.00259	0.29376	0.01466	0.0411	0.00075	277	81	262	12	260	5
79	5.81538	59.41	128.78	0.46133	1	0.05163	0.00316	0.29722	0.0181	0.04175	0.0008	269	105	264	14	264	5
80	6.51296	76.22	152.94	0.49837	0.992	0.05155	0.00281	0.28026	0.01525	0.03942	0.00073	266	91	251	12	249	5
81	3.578619	33.48	82.18	0.4074	0.996	0.05154	0.00416	0.29026	0.02321	0.04084	0.00088	265	142	259	18	258	5
82	5.8267	65.75	133.91	0.491	0.996	0.05136	0.00335	0.28361	0.01844	0.04004	0.00076	257	114	254	15	253	5
83	3.866182	45.76	88.81	0.51526	1	0.05115	0.0042	0.27949	0.02279	0.03962	0.00082	248	147	250	18	250	5
84	6.48119	80.19	143.08	0.56046	0.996	0.0513	0.00217	0.29095	0.01225	0.04113	0.00076	254	63	259	10	260	5
85	2.572557	32.18	55.65	0.57826	1	0.05155	0.00901	0.29858	0.05181	0.042	0.00119	266	309	265	41	265	7
86	2.828066	25.9	64.68	0.40043	0.992	0.05185	0.00334	0.2927	0.01858	0.04093	0.00087	279	106	261	15	259	5
87	4.47264	63.06	99.27	0.63524	0.976	0.05253	0.0049	0.28682	0.0266	0.03959	0.00083	309	172	256	21	250	5
88	4.050432	33.03	96.38	0.34271	0.98	0.05241	0.00266	0.28803	0.01446	0.03985	0.00079	303	78	257	11	252	5
89	4.180565	40.07	92.43	0.43352	0.985	0.05249	0.00319	0.3026	0.01817	0.04181	0.00085	307	100	268	14	264	5
90	3.406104	30.68	79.06	0.38806	0.992	0.05176	0.00387	0.2877	0.0213	0.04031	0.00085	275	131	257	17	255	5
91	7.35642	98.05	157.67	0.62187	0.992	0.05193	0.00207	0.2896	0.01154	0.04044	0.00074	282	58	258	9	256	5
92	3.956255	33.43	87.25	0.38315	0.996	0.05177	0.00303	0.30427	0.01768	0.04262	0.00084	275	97	270	14	269	5
93	3.891004	36.82	92.71	0.39715	0.98	0.05243	0.00379	0.28726	0.02049	0.03973	0.00086	304	123	256	16	251	5
94	4.60344	53.82	108.11	0.49783	0.98	0.05228	0.00363	0.28209	0.01937	0.03913	0.00083	298	118	252	15	247	5
95	5.11026	43.05	117.63	0.36598	0.996	0.05134	0.00367	0.29244	0.02084	0.04131	0.00078	256	128	260	16	261	5
96	3.118959	47.25	68.88	0.68598	0.992	0.05154	0.00443	0.27747	0.0236	0.03904	0.00087	265	152	249	19	247	5
97	2.709199	28.89	60.26	0.47942	0.996	0.05122	0.00343	0.29072	0.01916	0.04116	0.00089	251	112	259	15	260	6
98	3.449465	36.98	78.71	0.46983	0.984	0.05213	0.00338	0.29152	0.01868	0.04055	0.00085	291	108	260	15	256	5
99	2.537769	26.05	60.92	0.42761	0.984	0.052	0.00607	0.2775	0.03205	0.0387	0.00097	285	214	249	25	245	6
100	3.443047	36.49	77.23	0.47248	0.988	0.05193	0.00534	0.29167	0.02977	0.04073	0.0009	282	189	260	23	257	6

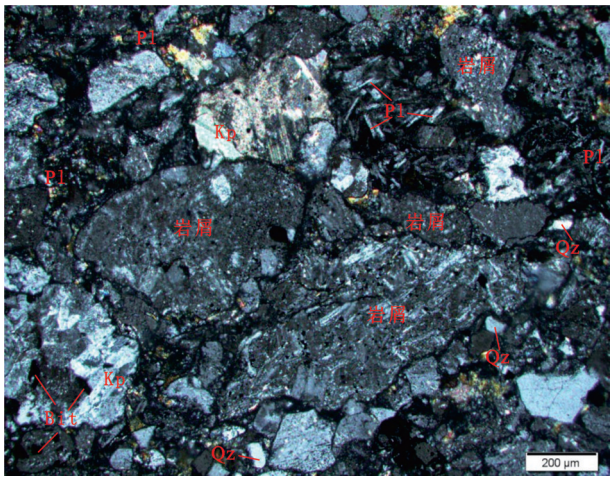

图4 幸福之路组中段凝灰岩镜下特征

Fig.4 The microphotograph of the tuffs in the middle part of Xingfuzhilu Formation in Xingfuzhilu, Bairin Right Banner, Inner Mongolia

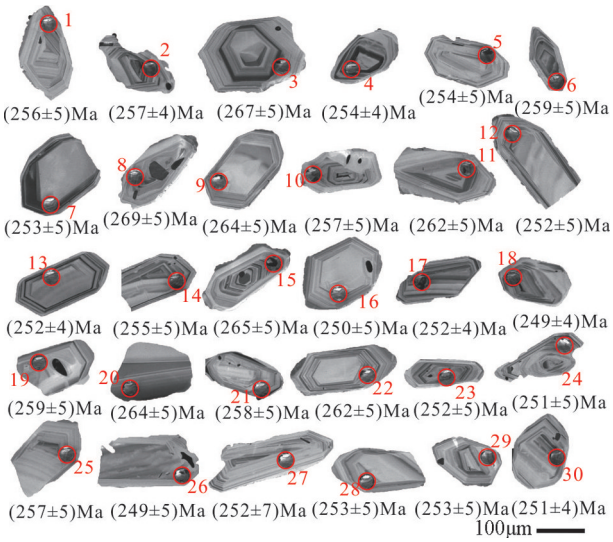

图5 幸福之路组中段凝灰岩的锆石阴极发光图像和$^{206}Pb/^{238}U$年龄

Fig.5 CL images of the tuffs in the middle part of Xingfuzhilu Formation in Xingfuzhilu, Bairin Right Banner, Inner Mongolia (using the age of $^{206}Pb/^{238}U$)

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

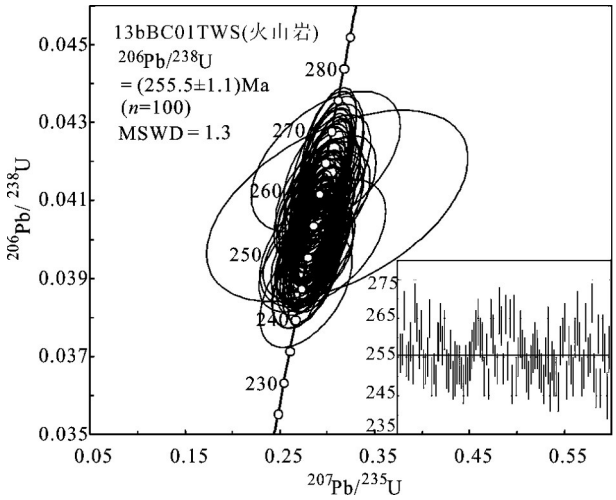

图6 幸福之路组中段岩屑晶屑凝灰岩样品(13BC01TWS)的锆石U-Pb谐和图

Fig.6 Zircon U-Pb concordant diagram of the tuffs from the middle part of Xingfuzhilu Formation

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(Anderson,2002)。

4 测试结果

对查干布拉格凝灰岩样品13BC01TWS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5)可以看出样品中锆石晶形完好,主要为长柱状,内部结构清晰,发育典型的振荡型环带,具有较高的Th/U比值(0.28~0.78),反映了岩浆成因锆石的特点(表1)。

样品测定了100颗锆石的100个点,测试点都位于谐和线上(图6),均为谐和年龄(谐和度都高于90%),100个点的$^{206}Pb/^{238}U$加权平均年龄为(255.5±1.1)Ma,MSWD = 1.3,代表岩浆结晶年龄,即样品为晚二叠世火山活动的产物,测年地层的时代应为晚二叠世。

5 讨 论

5.1 幸福之路组的时代及二叠—三叠系界线

朱儒峰等(1992)基于1∶5万区域地质填图成果,根据双壳、植物化石及岩性组合特征、岩相变化等综合分析,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。分为三个岩性段:下段为杂色砾岩,平行不整合于晚二叠世林西组之上;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。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。和政军等(1997,1998)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(2013b,2014)对幸福之路三段建组剖面的孢粉、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,并对幸福之路组二段和三段的对比关系提出疑问。张海华等(2015)测得幸福之路三段建组剖面下部的一个凝灰岩样品的年龄为(254.3±2.6)Ma,结合已有的火山岩测年资料及火山岩上部的化石资料,提出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,幸福之路组的时代为晚二叠世—早三叠世,大兴安岭地区上二叠统与下三叠统为连续沉积。郑月娟等(2015)对侵入到幸福之路组二段红层中的闪长玢岩做了同位素测年研究,结果为(247.7±2.0)Ma,相当于早三叠世最晚期—中三叠世最早期,从同位素测年的角度限定了该地层的沉积上限,其结果与生物地层学的研究结果基本一致。本次工作在幸福之路组二段中下部红色砂岩中发现凝灰岩夹层(剖面第18层),测得的锆石U−Pb年龄为(255.5±1.1)Ma,在凝灰岩夹层之上幸福之路组原二段上部及原三段多个层位发现孢粉化石,计17属20种,主要属种有*Baculatisporites* sp., *Cyclogranisporites* sp. *Alisporites cacheutensis*, *Al. indarraensis*, *Al. parvus*, *Al.* sp., *Klausipollenites* sp., *Lueckisporites virkkiae*, *Paleoconiferae* sp., *Piceites* sp., *Piceaepollenites* sp., *Pinuspollenites* sp., *Platysaccus* sp., *Pristinuspollenites* sp., *Protoconiferus* sp., *Protopinus* sp., *Pseudopicea* sp., *Psophosphaera* sp., *Quadraeculina* sp., *Sulcatisporites rhombicus*,时代为晚二叠世晚期—早三叠世初期,另外发现少量叶肢介化石,时代为晚二叠世(张德军等,2019)。综合同位素测年和孢粉化石资料,推测原划为早三叠世的幸福之路组二、三段的时代应为晚二叠世—早三叠世,大兴安岭地区二叠—三叠系界线在幸福之路组内部,二者为整合接触。

需要特别说明的是,幸福之路组建组时下部的砾岩段没有确切的时代依据,只是根据地层的野外产出状态建立。朱俊宾等(2017)对划为幸福之路组下部的砾岩层段进行碎屑锆石测年研究,认为幸福之路组时代为早—中三叠世。本次工作通过剖面实测,发现砾岩段产状平缓,为18~34°,划为其下部林西组的砂岩产状更为平缓,为17~20°,二者均倾向东南,微角度不整合接触;对原划为林西组的砂岩做了碎屑锆石测年,测得的最年轻的峰值年龄为249 Ma,最小峰值区间年龄段年龄的加权平均值为(248.8±6.4) Ma(笔者未发表数据),与最小峰值年龄吻合,且发现原幸福之路组下段砾岩中有中段的红色泥岩砾石(图7a),据此推断该砂岩(原划为林西组)及上覆的砾岩的时代不早于中三叠世,而不是前人所划定的晚二叠世—早三叠世,其层位应位于二段红层之上(另文发表)。另外如上文所述,幸福之路组二段、三段的关系还需进一步加强研究。

5.2 大兴安岭地区晚二叠世—早三叠世沉积环境演化

二叠纪—三叠纪处于地质历史上气候变化剧烈的时期,晚石炭世占据冈瓦纳大陆的冰川到早二叠世萨克马尔中期结束(Shi et al.,2010),但直至中二叠世沃德期仍处于冰室气候环境。从中二叠世卡匹敦期开始,气候快速升温转为温室气候,至二叠—三叠纪之交达到顶峰,导致大宗绝灭(Raup, 1979; Maxwell et al., 1992; Labandeira et al.,1993; Jin et al., 2000; Nereo Preto et al.,2010),结束了古生代历史。晚二叠世和早三叠世之交全球许多地区发生了由温暖、潮湿的海洋性气候向干燥、炎热的大陆性气候的转变(南君亚等,1998;殷鸿福等,2013;Tian et al.,2014),晚二叠—早三叠世,我国很多地区也处于干燥炎热的气候环境下,并发育许多成因类似的炎热干燥的古气候标志(颜佳新等,2002;杨兵等,2014)。在中国华南一些海相地层主要是以发育鲕粒灰岩、含铜砂岩、厚层白云岩、海洋蒸发岩为特征(颜佳新等,2002),而北方陆相地层则是以红层的持续发育为特征(屈迅等,2002;李强等,2002;颜佳新等,2002)。

华北地区晚二叠世晚期—早三叠世发育了一套代表干旱环境的红层沉积,地层自下而上为上石

盒子组、孙家沟组(石千峰组)、刘家沟组、和尚沟组。上石盒子组以黄绿、紫红等杂色泥页岩和砂岩为主,孙家沟组、刘家沟组、和尚沟组以紫色、砖红色泥岩、砂岩为主,见泥灰岩夹层且泥岩中含钙质结核(金玉玕等,2000)。李守军等(2014)对山西二叠系山西组、石盒子组的孢粉化石进行分析研究,认为山西组、石盒子组下部沉积时期为温暖半潮湿气候,石盒子组上部沉积时期为干旱气候。孙家沟组(石千峰组)沉积时期正是华北晚古生代植物群演化历史上重大的转替点,这与气候逐渐干旱有关(王自强等,1986;王仁农,1997。在中国南方,二叠—三叠纪之交,热带大羽羊齿植物群也被半干旱—潮坪的石松类植物群替代(殷鸿福等,2013)。王自强等(1997)认为华北晚二叠世红层沉积是半干旱—干旱气候环境下的产物,其砂岩极不稳定,为暂时性河道沉积,层面上富有干裂纹、波痕和同生泥砾结构,化学成分上富含蒸发岩成分,所产裸子植物化石角质层结构也出现了干旱性状特征,如表皮细胞强角质化、皮下组织发育、保卫细胞深陷,叶表面密被茸毛和乳突等。除了植物化石证据外,沉积学及地球化学的研究也证实晚二叠世末期—早三叠世华北地区处于干旱气候(张翔等,2008;张旻旻等,2015)。

新疆北部准噶尔盆地上二叠统—下三叠统自下而上为泉子街组、梧桐沟组、锅底坑组、韭菜园组、烧房沟组。根据多门类生物化石组合及古地磁研究,二叠系—三叠系界线位于锅底坑组内部,锅底坑组上部属于下三叠统,锅底坑组中下部为上二叠统(中国地质科学院地质研究所等,1986;程政武等,1997;彭元桥等,2001;屈迅等,2002;李永安等,2003,2004;候静鹏,2004;欧阳舒等,2004;庞其清等,2004;柳益群等,2006)。泉子街组、梧桐沟组为灰黑色碎屑岩沉积,喜湿的安加拉蕨类植物化石丰富(吴绍祖等,2000),但梧桐沟组上部开始出现反映干旱气候的钙结层和钙结核,锅底坑组、韭菜沟组则为红层沉积同时伴有钙结层和钙结核(李强等,2002;李永安等,2003),喜湿的安加拉型植物稀少。屈迅等(2002)提出准噶尔南缘—吐鲁番盆地晚二叠世—中三叠世早期地层中发现的二齿兽类化石生活在河流—浅水湖泊的古地理环境中,伴随的古气候条件为热带—亚热带气候,该时期准噶尔主要处于干旱条件下,晚二叠世晚期至早三叠世基本为"红层",并认为这个时期是欧亚大陆"红层"分布最广的时期之一,中国华北、中欧、北美都有类似的特征,是古气候在沉积物上的反映是热带—亚热带气候的一种标志。

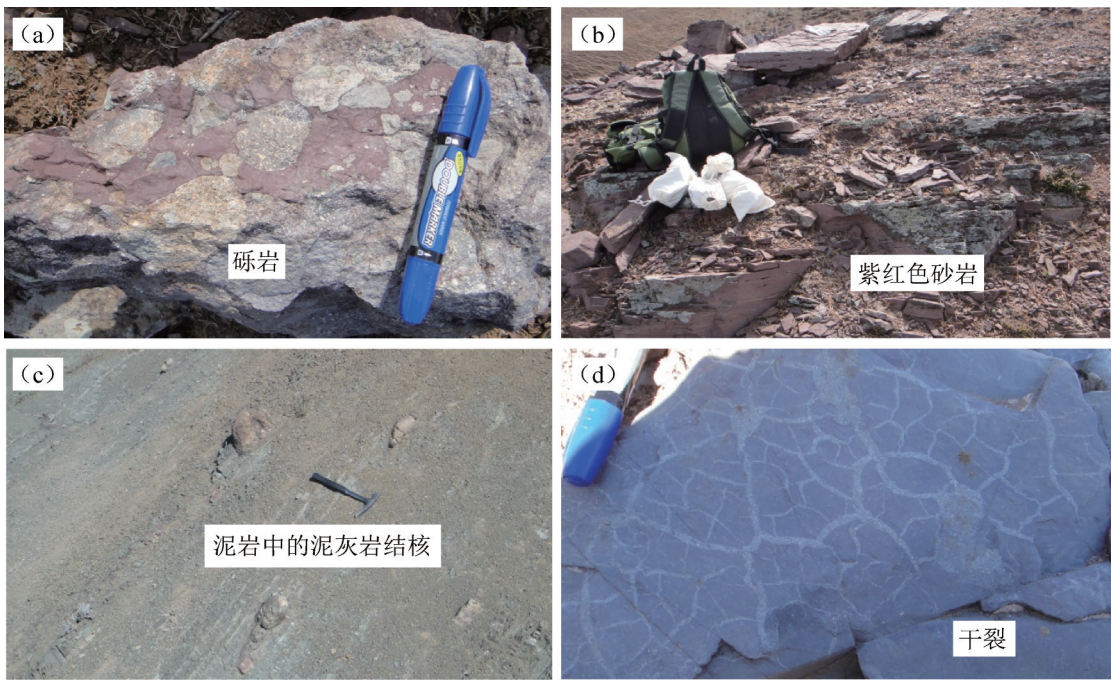

图7 幸福之路组野外照片

Fig.7 Field photographs for the Xingfuzhilu Formation

大兴安岭南部上二叠统—下三叠统自下而上为林西组、幸福之路组,晚二叠世林西组以灰黑、灰绿色砂板岩为主,含双壳、叶肢介、介形虫、植物、孢粉化石。发育于上部的孢粉化石可与准噶尔盆地的梧桐沟组及锅底坑组中下部大致对比,时代为晚二叠世晚期(郑月娟等,2013a;杨兵等,2014);植物化石分布广,喜湿的安加拉蕨类植物化石丰富,一些植物的叶子或小羽片比较大,叶脉普遍较为细密,反映雨水稀少,水分不充分,气候上是温暖少雨的温带区(黄本宏,1993)。幸福之路组以红层做为划分标志,中部为紫红色砂岩(图7b)、粉砂岩夹砂砾岩,上部为红杂色细碎屑岩,见大量泥灰岩夹层及钙质结核(图7c),另见到大量干裂现象(图7d),反映了炎热、干燥及强氧化条件的气候环境。如上文所述,前人根据叶肢介、介形虫、双壳及少量植物化石将其划为早三叠世。笔者通过孢粉、叶肢介化石及火山岩同位素测年的综合研究,将其时代修正为晚二叠世晚期—早三叠世早期,其中孢粉化石与新疆准噶尔盆地梧桐沟组、锅底坑组、韭菜园组孢粉化石关系密切,对其生态分析也显示幸福之路组沉积时期为干旱-半干旱的气候环境(张德军等,2019)。

广泛发育于中国北方晚二叠世晚期—早三叠世的红层沉积代表干旱—半干旱的气候环境,已被大多数学者认可。但对红层及干旱气候的成因却有不同看法。例如,有学者认为全球二叠纪—三叠纪古气候的演化实际上是巨型季风气候体制的形成、鼎盛和崩溃的演化过程。二叠纪为巨型季风气候体制的形成时期,早、中三叠世为巨型季风气候体制发育的鼎盛时期。在季风气候体制发育的鼎盛时期,联合古大陆东侧的赤道地区变得及其干燥,而正处于该区的扬子板块和华北板块均处于干燥炎热的气候环境,并发育许多成因类似的炎热干燥的古气候标志(颜佳新等,2002)。李明武等(2007)认为从石炭纪和早二叠世湿润气候、含煤的沉积相变化到晚二叠世和早三叠世干旱气候的红层沉积,可能是由于华北地块向北漂移经过干旱的亚热带纬度区的结果。李强(2002)认为影响古气候的有地外和地内两种因素,并从地内的角度探讨了准噶尔地区石炭纪—三叠纪古气候的重要事件:对于准噶尔来说,石炭纪至三叠纪是一个漫长的地质历史时期,经历了约150 Ma,更重要的是准噶尔在这期间古地理和古构造的变迁,从一个广阔的海盆逐渐上升为陆地,先后与西伯利亚古板块和塔里木古板块碰撞造山,而这些变迁对古气候来说都有直接和明显的影响。鉴于西伯利亚大火山岩省的$^{40}Ar/^{39}Ar$年龄在252 Ma(Reichow et al., 2002),与二叠—三叠纪界线年龄一致,一些学者认为是因为火山爆发导致大气突变、气候干旱,生物绝灭(Kamo et al., 2003; Saunders, 2009)。殷鸿福等(2013)认为古、中生代之交生物大灭绝和气候变化是地球各圈层相互作用的产物。

当然,古环境、古气候的影响因素可能是多方面,并且各方面因素是互相作用、互相影响的,但无论何种因素为主,在晚二叠世—早三叠世期间华北板块与西伯利亚板块已经拼合,古亚洲洋消失(王玉净等,1997;尚庆华,2004;孙德有等,2004;李锦轶等,2007;黄宝春等,2008;侯方辉等,2014),大兴安岭地区与相邻的华北及新疆准噶尔地区处于相近的纬度,古气候、古环境演化特点相同。

6 结　论

(1)幸福之路组二、三段的时代为晚二叠世—早三叠世,大兴安岭地区二叠—三叠系界线位于幸福之路组二、三段内部,火山岩锆石U-Pb定年为(255.5±1.1)Ma,二者为整合接触。

(2)大兴安岭地区晚二叠世—早三叠世气候由温暖少雨转为炎热干旱,晚二叠世晚期(幸福之路组二段下部)就已出现反映干旱气候的红层沉积,与相邻华北(孙家沟组)及新疆北部准噶尔等地区(锅底坑组)二叠纪晚期即已出现的与干旱事件相关的陆相红层一致,说明晚二叠世—早三叠世气候干热事件波及到大兴安岭地区。

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注释

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