

柴达木盆地古近系下干柴沟组上段碎屑锆石 U-Pb 测年及盆山耦合探讨

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内容提要:柴达木盆地被祁连山、阿尔金山及昆仑山所环绕,盆地古近系下干柴沟组(E_3^2)地层独特的岩性和沉积格局指示了复杂盆山体系和源区多样成因。本文选取了盆地内部不同构造带 5 口钻井下干柴沟组的中粗砂岩样品,利用碎屑锆石 U-Pb 定年等分析方法对柴达木盆地进行了构造、物源系统分析。研究结果表明,位于祁连山前的 XX-1 井样品下干柴沟组锆石年龄介于 2692~156 Ma 之间,主要峰值年龄为 448 Ma 和 249 Ma, L6-1 井样品锆石年龄介于 2693~220 Ma 之间,主要峰值年龄为 499 Ma 和 415 Ma;位于盆地西部沉降中心内部的 YIT-1 井样品下干柴沟组锆石年龄介于 2796~266 Ma 之间,主要峰值年龄为 423 Ma 和 255 Ma;阿尔金山前的 N-105 井样品下干柴沟组锆石年龄介于 2481~242 Ma 之间,主要峰值年龄为 422 Ma 和 259 Ma, N-109 井样品锆石年龄介于 2638~228 Ma 之间,主要峰值年龄为 444 Ma 和 246 Ma。通过与主要源区年龄对比可知,盆地不同构造带下干柴沟组的物源差异较大,靠近祁连山前的 XX-1 井、L6-1 井的物源主要来自于祁连山内部;位于阿尔金山前相邻的 N-105、N-109 井物源主体来自于阿尔金山内部,但 N-109 井存在祁连山物源贡献;柴西坳陷内部 YIT-1 井物源受祁连山及东昆仑共同控制。物源分析结果表明祁连山在古近纪已大规模隆升,并且作为青藏高原北部边界为柴达木盆地持续提供物源;阿尔金山及昆仑山在下干柴沟组沉积时期已经形成雏形,但并未大规模隆升,造成了山前带复杂的物源体系。

关键词:柴达木盆地;下干柴沟组;碎屑锆石;U-Pb 年龄;物源分析

柴达木盆地位于青藏高原东北缘,是青藏高原上大型陆相中新生代盆地(付锁堂等, 2016),其形成发育与特提斯构造域构造演化、特别是喜马拉雅运动有直接的联系(刘池洋等, 2020)。同时盆地被祁连山、阿尔金山及昆仑山所环绕,3 条造山带构造演化各异(吕宝凤等, 2011):阿尔金山为大型陆内左行走滑断裂带,祁连山以逆冲为主,东昆仑造山带则兼具逆冲、走滑双重特征。因此,不同造山带的构造演化对柴达木盆地构造面貌控制作用迥异(Alison et al., 2013; Cheng Feng et al., 2015a, 2015b; Ji Junliang et al., 2017)。特殊的盆山背景造成盆地

沉积充填极具独特性,古近系下干柴沟组上段(E_3^2)沉积时期(42.8~35.5 Ma)(潘家伟等, 2015),在柴达木盆地西南部发育咸化湖盆沉积,在其他地区表现为一套粗粒碎屑沉积。目前对 E_3^2 沉积时期的盆山关系存在以下科学问题:① 东昆仑造山带在该时期是否开始大规模隆升? 一种观点认为在新生代早期(50~35 Ma)东昆仑造山带由于印度-欧亚大陆碰撞的远程效应,经历了强烈的构造变形及隆升剥露过程,形成了青藏高原北部重要的边界,控制着柴西坳陷整体构造格局的形成演化(Yin An et al., 2008; 付玲等, 2012; Mao Liguang et al., 2014; 霍斐

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斐等,2019);而另一种观点认为青藏高原的隆升经历了自南向北的扩展过程,东昆仑地区大规模的快速隆升始于渐新世晚期—中新世早期,古地磁年龄框架和物源分析结果显示东昆仑山构造隆升发生在 25 Ma (Wang Weitao et al., 2017),黑云母和钾长石 $^{40}\text{Ar}/^{39}\text{Ar}$ 年龄及相关热史模拟支持东昆仑山在 30 Ma 快速剥露 (Mock C et al., 1999),昆仑山垭口地貌学研究表明东昆仑山强烈构造隆升在第四纪才发生 (吴珍汉等, 2001),在 E_3^2 沉积时期东昆仑山并不是现今的盆地边界,盆地西南缘整体处于相对平静构造期,形成了大型湖盆坳陷,昆仑山前的昆北、东柴山地区广泛发育细粒沉积物是东昆仑山晚期隆升的直接证据 (刘玉华等, 2010; 马达德等, 2015)。

② 阿尔金山在该时期是否大规模活动,为盆地提供物源? 一种观点认为阿尔金山在渐新世开始大规模右行走滑运动,阿尔金山与昆仑山的结合部位形成了大型走滑拉分盆地 (葛肖虹等, 1998; Yin An et al., 2002; Yue Yongjun et al., 2004, 2005),盆地内部为 E_3^2 沉积时期柴达木盆地西部的湖盆中心,沉积了一套以页岩、膏岩、碳酸盐岩夹少量细砂岩—粉砂岩的近千米的半深湖—深湖相沉积建造;从牛鼻子梁、七个泉等构造的古近系岩石粒度及沉积体系分析 (张金明等, 2021; 张世铭等, 2022),该时期阿尔金山为盆地提供物源。第二种观点认为阿尔金山启动较晚,在渐新世末期 (36 Ma) 才开始大规模活动 (杨经绥等, 2008; 刘永顺等, 2010; 吴磊等, 2012; 张建新等, 2015),而早期为一水下隆起,深层 (新近系底部—基底) 发育一系列北西向逆冲断裂,中新世后,阿尔金山断裂才大规模走滑活动,处于阿尔金山与东昆仑山结合部位的茫崖凹陷内部主要构造带浅层 (第四系—新近系底部) 为一系列滑脱逆冲构造叠加走滑构造样式,形成了深、浅两套构造层 (易立, 2020)。

③ E_3^2 沉积时期位于祁连山前的盆地北缘地区主要是偏氧化色的粗碎屑沉积,而柴西地区整体为干旱、咸化背景下的湖相沉积,祁连山如何控制盆地的构造—沉积格局? 由此可见 E_3^2 沉积时期是盆地一个关键构造沉积变革期,开展其构造演化的研究可以破译柴达木盆地盆山作用关系及时空演化,而基于精细的物源分析是探讨盆山关系的重要纽带,因此碎屑锆石的 U-Pb 年龄变化可以反映物源区的构造隆升与沉降史。本次研究选取了柴达木盆地内山前凹陷 5 口钻井 E_3^2 的砂岩样品,利用激光剥蚀—电感耦合等离子体—质谱法 (LA-ICP-MS) 开展了碎屑锆石 U-Pb 定年研究,结合周缘山系主要年龄

分析了柴达木盆地 E_3^2 的沉积物源信息,建立了祁连山、东昆仑山及阿尔金山 E_3^2 沉积时期的古地貌面貌,探讨了周缘山系与盆地构造演化作用关系,为新生代区域盆山耦合关系的研究提供沉积物源方面的证据。

1 区域地质背景

柴达木盆地在大地构造位置上属于特提斯构造域的东部,紧邻新生代印度和欧亚两大汇聚板块的过渡地带 (许志琴等, 2022)。盆地位于青藏高原的东北部,在前侏罗纪地块基础上发育起来的中新生代陆内叠合—改造型盆地,南界为东昆仑造山带与巴颜喀拉地块相邻,北界为祁连山—宗务隆山断裂,东以鄂拉山断裂为界,西以阿尔金造山带为界,形成“三山夹一盆”的楔状构造格局 (Yin An et al., 2008)。柴达木盆地由古生代褶皱基底和元古宙结晶基底的双重基底构成 (陈宣华等, 2011; Cheng Feng et al., 2017),盆地内部可划分出 11 个二级构造单元 (陈琰等, 2019) (图 1)。

1.1 盆地周缘造山带构造演化背景

祁连山构造带位于柴达木地块北部,由多条北西—南东走向的山脉组成,其西端与阿尔金造山带相接,东部与秦岭造山带相连。该造山带由南往北依次划分为南祁连、中祁连与北祁连等构造单元 (Yan Zhen et al., 2019)。祁连山造山带记录了新元古代—中生代期间发生的多期大陆裂解、洋盆形成、陆陆碰撞的造山过程 (Guo Zhaojie et al., 2009; Song Shuguang et al., 2012)。新元古代—早古生代,柴达木北缘地区大陆开始裂解,形成早古生代“秦祁昆海”,该时期洋盆也发生俯冲消减,形成了一系列的岛弧火山岩及岩浆岩 (姜高磊等, 2014);晚奥陶世,北祁连洋闭合消亡形成北祁连造山带,柴北缘地块向与祁连微板块之间的欧龙布鲁克微陆块下俯冲消亡,柴达木地块发生陆壳深俯冲并形成了超高压变质带 (汤良杰等, 1999)。志留纪末—泥盆纪初期,造山作用结束,柴达木地块与欧龙布鲁克地块已拼合成一个整体。石炭纪在柴达木古陆南北两侧边缘强烈裂陷,祁连山内部的宗务隆海槽及阿尼玛卿海槽与盆地为碳酸盐岩台地及潮坪环境 (汤良杰等, 1999)。二叠纪—三叠纪时期,祁连地区海水退缩,构造活动相对较弱,同时也伴随着小规模岩浆运动 (彭渊等, 2016)。三叠纪末期古特提斯洋闭合,祁连山发生强烈隆升。印支期构造事件之后,柴达木地区处于印支造山期后的应力松弛状态,在近南北向

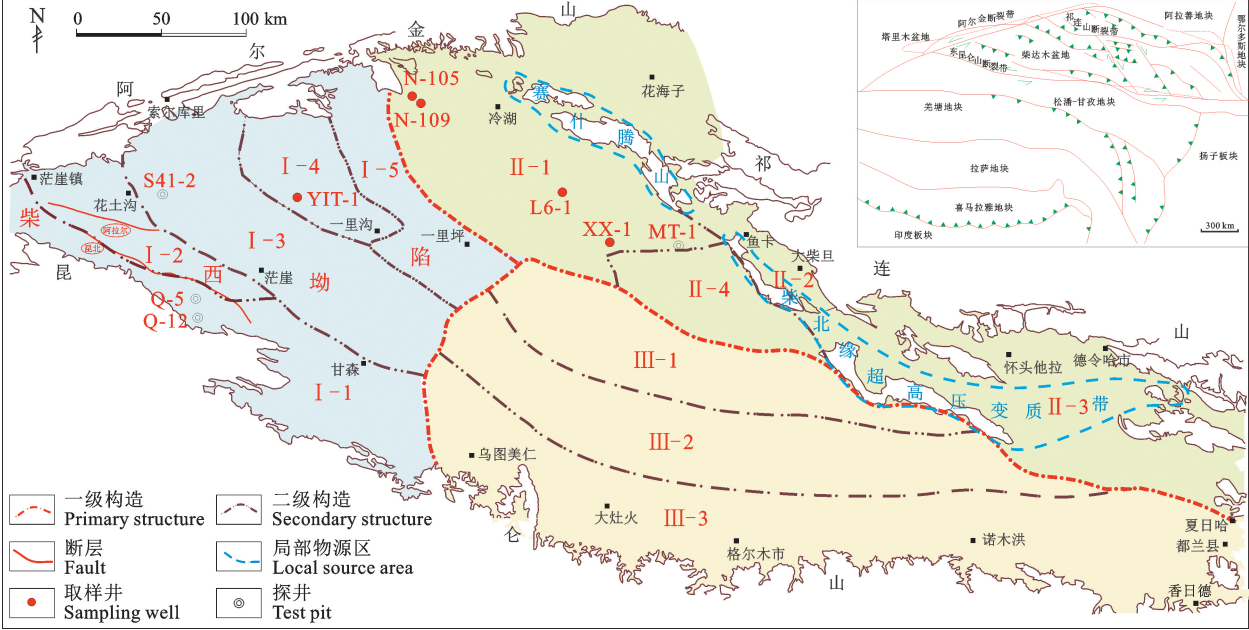


图 1 柴达木盆地构造分区及采样位置

Fig. 1 Tectonic division of the Qaidam basin and sampling location

I-1—昆北断阶; I-2—尕斯断陷; I-3—茫崖凹陷; I-4—大风山凸起; I-5—一里坪凹陷; II-1—赛昆断陷; II-2—大柴旦断陷; II-3—德令哈断陷; II-4—马海大红沟凸起; III-1—三湖北斜坡; III-2—三湖中央凹陷; III-3—三湖南斜坡

I-1—Kunbei fault stage; I-2—Gasi fault depression; I-3—Mangya depression; I-4—Dafengshan uplift; I-5—Yiliping depression; II-1—Saikun fault depression; II-2—Dachaidan fault depression; II-3—Delingha fault depression; II-4—Mahai Dahonggou uplift; III-1—Sanhubei slopes; III-2—Sanhu central depression; III-3—Sanhunan slope

松弛伸展构造应力场作用下,柴达木盆地开始接受沉积(Zhao Junfeng et al., 2020)。

阿尔金造山带夹于柴达木盆地和塔里木盆地之间,由多个形成于不同时期的构造单元组成(刘永顺等, 2009; 张建新等, 2015)。阿北地块广泛出露由米兰群、TTG 片麻岩和古元古代侵入岩等构成的阿克塔什塔格杂岩,代表太古宙—古元古代陆核和结晶基底。阿中地块主要由中元古界阿尔金岩群及中—上元古界浅变质沉积岩系组成,反映中元古代稳定大陆边缘的沉积环境(刘永顺等, 2009)。另外,在阿尔金地区南北各分布一条代表“古阿尔金洋”洋壳的新元古代末期—早古生代蛇绿混杂岩带,因此南阿尔金高压—超高压变质带也被认为是古洋闭合后,陆壳俯冲碰撞造山的产物(杨经绥等, 2008; 刘良等, 2015)。侏罗纪以来,阿尔金造山带具有脉冲性的多期活动特点,特别是在新生代的大规模左旋走滑和逆冲活动,在控制柴西地区新生代沉积的同时,也破坏了侏罗系—白垩系的原始沉积面貌(Zhao Xudong et al., 2020)。

东昆仑造山带夹于柴达木盆地和巴彦喀拉山—松潘甘孜地块之间,其次级构造单元北祁漫塔格构

造带与柴达木盆地西部中—新生代沉积-构造演化紧密相关(Pan Guitang et al., 2012)。北祁漫塔格构造带基底为太古宇—古元古界深变质岩系金水口岩群;上覆不整合中元古界—早古生界万宝沟群和纳赤台群,并不同程度发育晚古生代浅海沉积。南侧为祁漫塔格—香格里拉蛇绿混杂岩带,是早古生代祁漫塔格洋向北俯冲消减的产物,岩浆活动时间约为 486~423 Ma(Dong Yunpeng et al., 2018)。二叠纪—三叠纪由于古特提斯洋俯冲-闭合,东昆仑—祁漫塔格山开始大规模隆升,柴达木盆地和可可西里盆地因此被分隔(Wang Yadong et al., 2018)。之后又经历了中侏罗世末、晚白垩世、中新世等多期隆升事件,控制并改造了柴达木盆地西南部的中—新生代沉积地层(Cheng Feng et al., 2014; Zhao Xudong et al., 2020)。

1.2 柴达木盆地 E₃ 沉积时期构造沉积格局

目前对柴达木盆地新生代地层年龄框架主要存在两种年代模型:即传统的观点认为柴达木盆地新生代初始沉积时间为 53.5 Ma(Yin An et al., 2008; Ji Junliang et al., 2017),而最近几项古地磁研究则表明柴达木盆地新生界底界年龄为 30~25

Ma(Wang Weitao et al. ,2017,2022;Nie Junsheng et al. ,2020)。然而,考虑到新的年龄框架的争议剖面均位于柴达木盆地东部地区(即红沟、红山一带),而本文所涉研究区主要位于或靠近盆地西部地区。Chang Hong et al. (2015)通过对柴达木盆地西部的花土沟开展精细的古地磁工作,研究表明下干柴沟组上覆的上干柴沟组初始沉积年龄大于 30 Ma。因此,本文仍延续使用传统的新生代地层年龄框架,即下干柴沟组上段(E_3^2)沉积时代为 42.8~35.5 Ma。

渐新世 E_3^2 沉积时期的柴达木盆地与中喜马拉雅运动相对应(侯增谦等,2006),柴达木盆地构造演化整体可以概况为:阿尔金山、祁连山、昆仑山各异、挤压与弱伸展共存。由于印度板块的持续北移和陆内俯冲,在其与欧亚板块的持续聚敛作用下,青藏高原内部多个刚性块体有序的向北推挤,陆续挤压形成盆-山相间的复杂构造格局(王伟涛等,2014);处于柴达木地块与阿拉善地块之间的祁连山再次活化,快速隆升、逆冲、走滑、断陷断裂活动强烈(Yu Jingxing et al. ,2019),在祁连山发育连片的河三角

洲、扇三角洲沉积建造, E_3^2 以浅灰色粉砂岩、细砂岩、棕色—棕红色泥岩为主,夹少量偏氧化色的泥质粉砂岩、泥质砂岩,偶见含砾砂岩,中细粒砂岩叠置连片(图 2)。而盆地的西南部则处于走滑转换应变场中,主要原因是阿尔金断裂为一条具有走滑调节性质的大型板内断裂,虽然前人对此时阿尔金山及东昆仑山的面貌及是否隆升存在争议,但是多数学者认为此时柴达木盆地西南部进入走滑拉分的弱断陷阶段,主要原因是 NEE 向阿尔金断裂新生代的第一幕走滑运动的左行走滑,叠加 NWW 向东昆仑断裂的左行走滑使得柴达木盆地向东逃逸、伸展(张克信等,2013;张岳桥等,2016;李海兵等,2021),在盆地内形成了 2 个主要的沉降中心:柴西英雄岭-茫崖凹陷和一里坪凹陷。盆地西南部 E_3^2 沉积受区域构造演化控制,干柴沟组上段(E_3^2)主要为一套湿润气候条件下深湖—半深湖、三角洲前缘-前三角洲的沉积体系,岩性以灰色—深灰色、黑色的粉砂岩、碳酸盐岩、膏盐岩为主;即便在靠近东昆仑山前地区同样为深湖相的暗色泥岩沉积,只在非常靠近阿尔金山

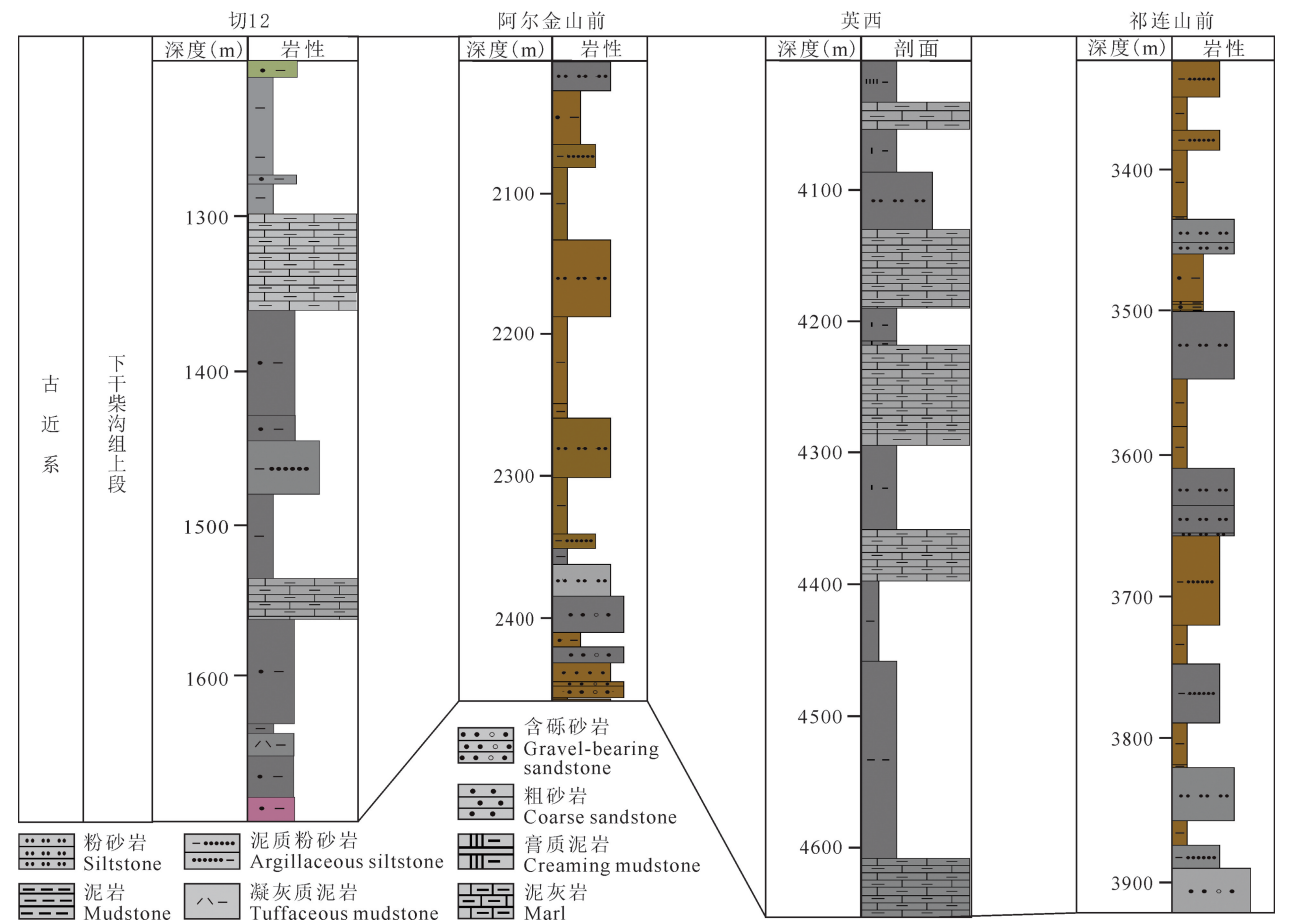


图 2 柴达木盆地不同构造带 E_3^2 岩性柱状图

Fig. 2 Lithology column of E_3^2 in different tectonic belts of Qaidam basin

前的冲断带为棕红色、灰色—深灰色粗砂岩-砂岩的粗碎屑沉积。

2 样品采集及测试

结合柴达木盆地三山环绕的地质背景,本文选取了阿尔金山前的牛东、柴西地区的南翼山、祁连山前的冷湖地区典型探井的 5 件 E_3^2 砂岩样品,进行了碎屑锆石 U-Pb 的年龄测试,井位位置见图 1,样品以中、粗粒砂岩为主,具体信息见表 1。L6-1 井样品为棕灰色岩屑细砂岩,粒径主要介于 0.1~0.2 mm,分选中等,磨圆度以棱角一次棱角状为主,矿物成分以石英、长石为主,岩屑以变质岩为主,见少量碳酸盐岩、板岩及个别酸性喷出岩碎屑等,填隙物主要为方解石、少量硬石膏及泥级矿物(图 3a、b)。N-109 井样品为浅灰色含砾粗砂岩,岩石成分以石英、长石为主,石英表面较为干净,长石高岭土化和绢云母化,岩屑主要为石英岩、千枚岩、碳酸盐岩等,填隙物为方解石及黏土矿物(图 3c、d)。XX-1 井样品为棕灰色含砾岩屑粗砂岩,石英具波状消光,且普遍具次生加大,长石为高岭土化、绢云母化,岩屑见石英岩、板岩、二长岩、长英岩等。填隙物为方解石。孔隙较发育,多为原生粒间孔、粒间溶蚀孔(图 3e、

f)。YIT-1 井样品为棕灰色含砾长石中砂岩,长石高岭土化及绢云母化,石英表面干净,见少量岩屑,岩屑见花岗岩、石英岩、碳酸盐岩等,填隙物由方解石及硬石膏组成,见粒间孔、粒间溶孔(图 3g、h)。N-105 井样品为棕红色岩屑粗砂岩,颗粒分选差,石英表面干净,长石高岭土化和绢云母化,岩屑主要为碳酸盐岩、花岗岩、砂岩和石英岩碎屑,见零星绿帘石,填隙物由方解石和泥级矿物组成(图 3i、j)。

锆石的制靶、阴极发光图像拍摄及锆石 U-Pb 同位素测试分析均在西北大学大陆动力学国家重点实验室完成。测试流程包括:① 样品分析,对样品进行机械性粉碎至 80 目,利用矿物介电分选仪进行磁选,然后经重液分选,最后通过双目镜挑选无裂痕、晶型完好、干净锆石颗粒。② 样品抛光、制靶,先

表 1 柴达木盆地 E_3^2 样品信息表

Table 1 Sample information of E_3^2 in the Qaidam basin				
井位 (样品号)	深度 (m)	构造区域	岩性	锆石 (颗)
L6-1	3681.80	祁连山前冷湖地区	棕灰色细砂岩	1000
XX-1	4111.38	祁连山前南八仙地区	棕灰色含砾粗砂岩	3000
N-105	1102.18	阿尔金山前牛东地区	棕红色含砾粗砂岩	2000
N-109	2281.48	阿尔金山前牛东地区	浅灰色含砾粗砂岩	1000
YIT-1	3955.95	盆地西部大风山地区	浅灰色中砂岩	3000

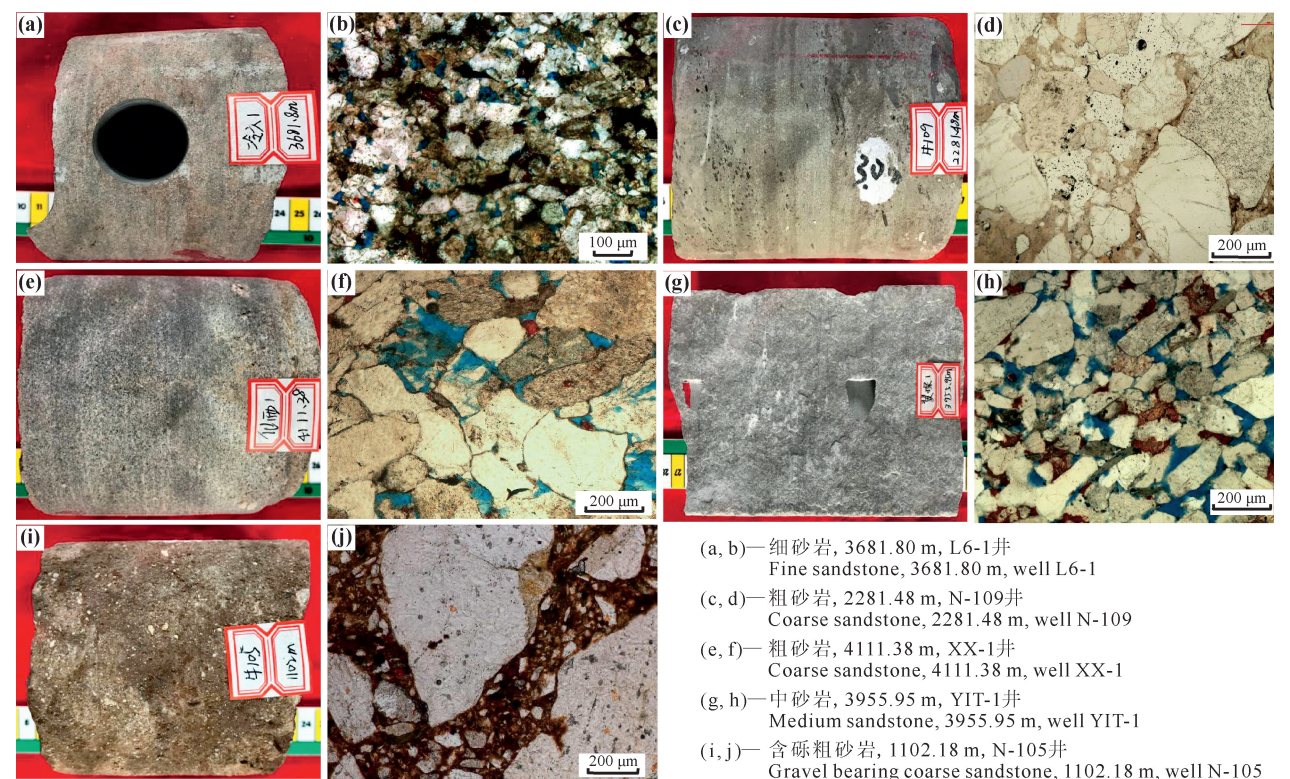


图 3 柴达木盆地典型钻井 E_3^2 岩芯样品照片和铸体薄片照片(单偏光)

Fig. 3 E_3^2 core samples and casting thin sections (plane-polarized photomicrograph) from typical wells in the Qaidam basin

用无色透明的环氧树脂固定,之后将锆石抛光使其内部结构剖面充分暴露,然后进行锆石颗粒的反射光、透射光、阴极发光照相(CL),通过透射光图象可以观察锆石内部是否有包裹体,通过反射光图象可以观察锆石是否有裂开,以选定最合适的锆石颗粒和激光剥蚀位置,CL 图像用于观察锆石内部结构。

③ 测试前处理,用 3%(v/v) 的 HNO₃ 清洗样品表面,以除去样品表面的污染。

④ 样品测试,将制好的靶置于剥蚀池中,高能量的激光使样品被轰击部分剥蚀并高温蒸发,由于样品放在密封的样品室,样品室有一个进气孔,一个出气孔,蒸发的样品被不断流通的气体(He、Ar 气等) 运送,通过管道带至等离子炬管中电离,再通过透镜系统由四极杆质谱进行同位素的测量。在测试过程中,首先使用美国研发人工合成的硅酸盐玻璃标准参考物质 NIST SRM610 使激光剥蚀系统达到最佳工作状态,并采用 91500 国际标准锆石作为外标进行校正,每测定 6 个样品点测定一次标样。光剥蚀等离子质谱为德国 MicroLas 公司生产的 GeoLas200M。数据处理采用 GLITTER4.0 程序,谐和图的绘制和年龄计算采用 Isoplot 4.15 版本软件。

3 分析结果

本次采集的碎屑锆石绝大部分为无色透明,部

分具棕红色,外形多为棱角状,是近物源的表现。代表性锆石阴极发光图像(图 4)显示,可以分辨出两种锆石类型。一种是岩浆锆石,占总样品数量的 70%,多呈长柱状,结晶环带较发育,CL 图像显示比较清晰的韵律振荡环带结构,说明研究区被测锆石为典型的岩浆结晶锆石,因此所获得的年龄能够代表岩体的结晶年龄。另一种是变质岩锆石,变质锆石的母岩有两种类型,即沉积岩与火成岩。沉积岩为母岩的变质锆石,其锆石外形浑圆、磨蚀明显;火成岩为母岩的变质锆石,其锆石由暗色核部和亮色宽边两部分组成,反映源区经历了多期构造热事件。

5 个砂岩样品锆石 U-Pb 同位素分析结果见附表 1,其中大于 1000 Ma 的点采用²⁰⁷Pb/²⁰⁶Pb 年龄,而小于 1000 Ma 的点则采用²⁰⁶Pb/²³⁸U 年龄。从 U-Pb 年龄谐和图(图 5)可以看出,大部分都落在谐和线上或者谐和线附近,表明大部分锆石没有明显的 Pb 丢失,没受到明显后期热事件的影响。XX-1 样品测试 120 颗锆石,共获得 106 个有效数据点,锆石年龄介于 2691.9~155.8 Ma 之间,主要峰值年龄为 448 Ma 和 249.2 Ma,次要峰值年龄为 1952 Ma、1810 Ma 和 847 Ma(图 5a)。YIT-1 样品测试 116 颗锆石,样品共获得 84 个有效数据点,锆石年龄介于 2795.8~266.1 Ma 之间,主要峰值年龄为



图 4 柴达木盆地 E₃ 砂岩样品典型锆石 CL 图像

Fig. 4 Typical zircon CL images of E₃ sandstone samples from Qaidam basin

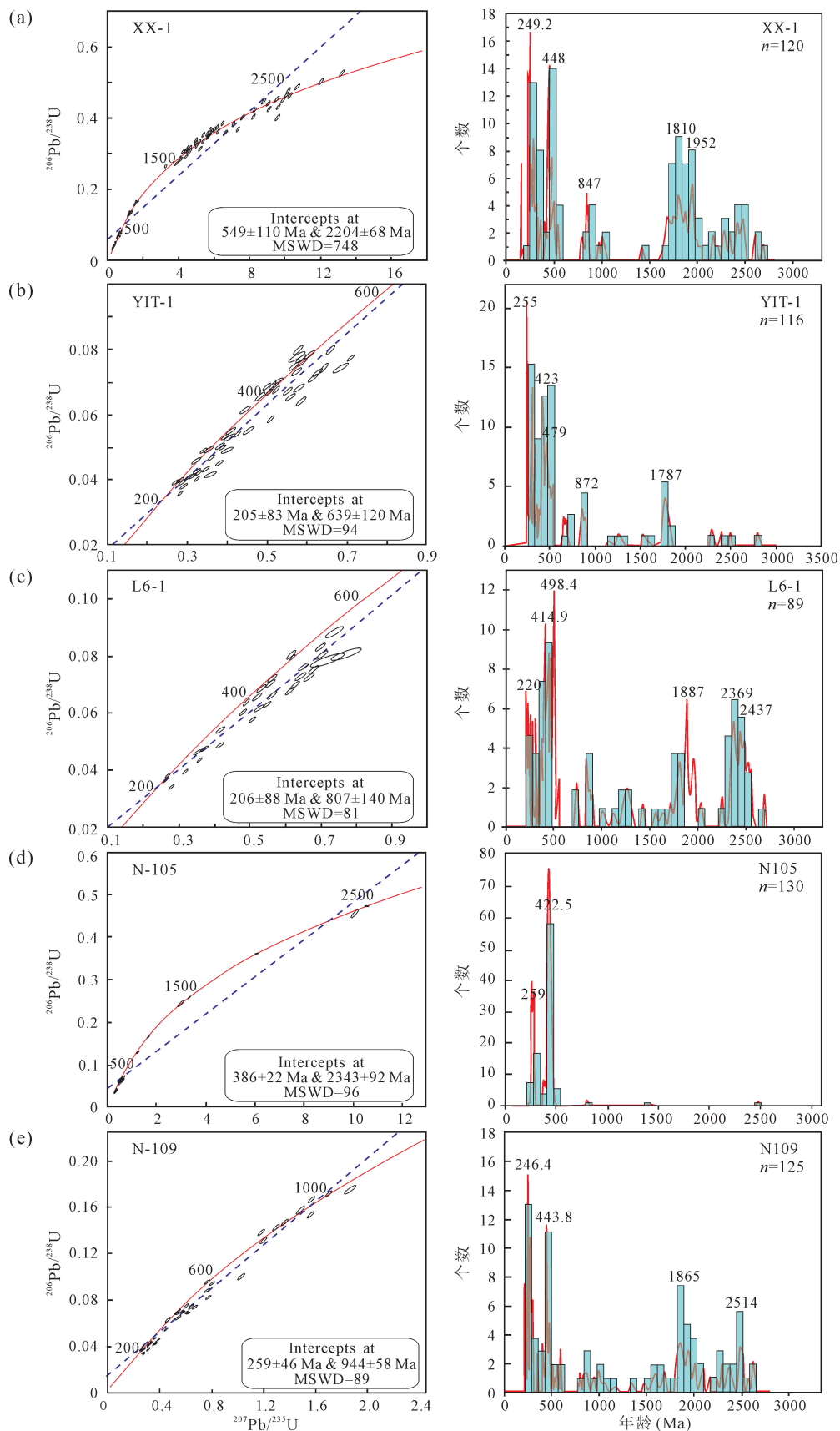


图 5 柴达木盆地 E₃ 砂岩样品碎屑锆石 U-Pb 年龄谐和图和直方图

Fig. 5 Detrital zircon U-Pb age concordant and histogram of E₃ sandstone samples from Qaidam basin

423 Ma 和 255 Ma, 次要峰值年龄为 1787 Ma、872 Ma 和 479 Ma(图 5b)。L6-1 样品共测试 123 颗锆石, 该样品共获得 89 个有效数据点, 锆石年龄介于 2692.8~220.2 Ma 之间, 主要峰值年龄为 498.4 Ma 和 414.9 Ma, 次要峰值年龄为 2437 Ma、2369 Ma、1887 Ma 和 220 Ma(图 5c)。N-105 样品共测试 130 颗锆石, 该样品共获得 102 个有效数据点, 锆石年龄介于 2481.5~241.9 Ma 之间, 主要峰值年龄为 422.5 Ma 和 259 Ma(图 5d)。N-109 样品共测试 125 颗锆石, 该样品共获得 90 个有效数据点, 锆石年龄介于 2637.9~228.3 Ma 之间, 主要峰值年龄为 443.8 Ma 和 246.4 Ma, 次要峰值年龄为 2514 Ma 和 1865 Ma(图 5e)。

4 碎屑物源分析

4.1 潜在物源区

前人分析表明, 柴达木盆地存在 3 个潜在物源区, 分别是东昆仑-祁曼塔格地块、阿尔金山、祁连造山带(曾旭等, 2019; Zhao Junfeng et al., 2020; Zhao Xudong et al., 2020)(图 6)。

祁连造山带位于柴达木盆地以北。祁连造山带岩体年龄跨度较大, 以早古生代(472~440 Ma)年龄群为主, 主峰年龄为 462 Ma, 其次为一些更古老的元古宙年龄群, 包括 1000~800 Ma(峰值年龄 924 Ma)、2000~1800 Ma(峰值年龄 1855 Ma)和 2500~2300 Ma(峰值年龄 2432 Ma)(Wang Fei et al., 2016; Lu Haijian et al., 2019; Nie Junsheng et al., 2020; Song Bowen et al., 2020; Wang Lin et al., 2020)。祁连造山带内部发育大量与晚奥陶世—早泥盆世(460~400 Ma)柴达木地块与阿拉善地块碰撞相关的侵入岩, 同时广泛分布于北祁连造山带高压变质岩带和柴达木北缘超高压变质岩带。前人锆石 U-Pb 定年结果表明柴达木北缘超高压变质岩带指示了大洋俯冲作用(490~460 Ma)、大陆俯冲作用(435~420 Ma)和超高压变质岩折返过程中退变质作用(410~400 Ma)。2000~1800 Ma 和 2500~2300 Ma 年龄群主要分布在柴北缘东北部的欧龙布鲁克的变质基底中(张建新等, 2021; 肖安成等, 2021)。1000~800 Ma 年龄群广泛分布在祁连造山带中的微陆块(如中祁连地块)中, 被认为与新元古代罗迪尼亚超大陆汇集和随后的裂解作用有关(Song Shuguang et al., 2012; Peng Yinbiao et al., 2019)。在新元古代, 塔里木—华北板块南缘发生大洋板块俯冲, 1000 Ma 的锆石可能与其造成的

大陆型岩浆作用有关; 在新元古代晚期(约 820~775 Ma), 祁连洋盆沿着塔里木洋关闭的古缝合带在柴达木地块与华北板块之间打开(Song Shuguang et al., 2012; 许志琴等, 2016; Peng Yinbiao et al., 2019)。

东昆仑-祁曼塔格地块发育中生代早期(320~248 Ma, 峰值年龄 251 Ma)、早古生代(530~380 Ma, 峰值年龄 451 Ma)和新元古代(850~756 Ma, 峰值年龄 840 Ma)3 期年龄岩体(陈国超等, 2013; 赵菲菲等, 2017; 苏联国等, 2019)。晚古生代—三叠纪东昆仑造山带为活动大陆边缘岩浆弧, 发生了以花岗质为主的岩浆事件, 该期岩浆事件在东昆仑造山带中部发育最为广泛(倪晋宇, 2010)。在早古生代时期由于祁曼塔格弧后盆地的打开, 东昆仑造山带经历了柴达木地块裂解—拼合的过程, 整体处于岛弧构造环境。古生代(474~390 Ma)的花岗岩是东昆仑洋俯冲和祁曼塔格弧后盆地关闭的响应。新元古代的岩体表明东昆仑造山带中部曾卷入 Rodinia 超大陆的聚合事件中(李瑞保等, 2012)。

阿尔金造山带的岩体主要有 2 个年龄峰值, 分别是 1918 Ma 和 433 Ma, 其中 433 Ma 代表阿尔金山地区主要花岗岩活动时期(潘家伟等, 2015; Wang Lin et al., 2020), 早古生代时期阿尔金板块与塔里木板块碰撞, 早古生代柴达木盆地及周缘整体上进入洋盆裂解-闭合、陆内俯冲碰撞、造山后碰撞的构造演化阶段, 山间断陷或山前凹陷的局部地区沉积有上泥盆统磨拉石建造, 反映了阿尔金造山带强烈的收敛俯冲-板块汇聚作用(陈正乐等, 2004), 故 433 Ma 的年龄峰值在阿尔金山前广泛分布。1918 Ma 峰值主要反映了 Columbia 超大陆的聚合事件, 该时期, 阿尔金山周缘的塔里木板块、柴达木地块均经历了此期构造热事件, 该年龄在敦煌—库鲁克塔格地区、塔西南区、柴北缘的欧龙布鲁克地块十分常见(叶雨晖等, 2021)。

4.2 柴达木盆地 E₃² 沉积时期碎屑物源分析

对比柴达木盆地 5 个 E₃² 样品的锆石 U-Pb 年龄(图 5)与周缘造山带碎屑锆石 U-Pb 年龄(图 6), 分析柴达木盆地 E₃² 的沉积物源。

样品 L6-1 与 XX-1 具有 5 个峰值年龄, 分别为 2500 Ma、1800~1650 Ma、950~750 Ma、500~435 Ma 和 249.2~220 Ma。500~435 Ma 年龄峰值, 对应了与祁连洋闭合期间的大洋俯冲作用及其伴生的岩浆弧有关的早古生代年龄群, 且锆石 CL 图像显示主要为岩浆岩锆石, 表明该期碎屑锆石是祁连造

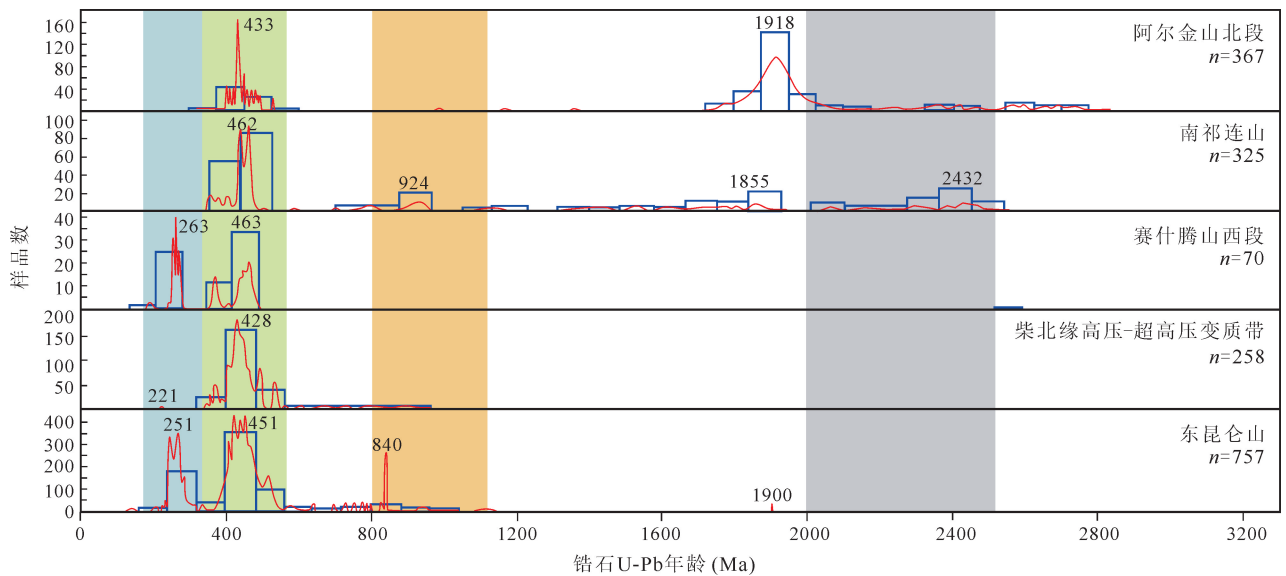


图 6 柴达木盆地周缘造山带碎屑锆石 U-Pb 年龄分布(据曾旭等,2019;Zhao Junfeng et al. ,2020;Zhao Xudong et al. ,2020)
Fig. 6 U-Pb ages distribution of detrital zircons in the orogenic belt around Qaidam basin (after Zeng Xu et al. ,2019;
Zhao Junfeng et al. ,2020;Zhao Xudong et al. ,2020)

山带内部主要产物,L6-1 井同时出现了 414 Ma 年龄峰值,其可能受到柴达木北缘超高压变质岩带年龄的影响,同时值得注意的是,两块样品在 249.2~220 Ma 年龄范围内也出现了差异,L6-1 井的 220 Ma 峰值也与柴达木北缘超高压变质岩带年龄更为相近,从构造位置看,柴达木北缘超高压变质带更为靠近 L6-1 井。XX-1 井的 249.2 Ma 的年龄峰值来自赛事腾山西段的少量二叠纪火成岩岩体,该岩体主体年龄值为 260±5 Ma 左右(高万里等,2019;图 6),或南祁连山-赛事腾山山前由于断层逆冲出露的侏罗纪—白垩纪地层(Zhao Junfeng et al. ,2020)。需要说明的是,盆地西部的阿尔金山也出露少量 300~200 Ma 的火成岩体(董增产等,2014;Zhao Xudong et al. ,2020),但样品 L6-1、XX-1 所在位置与阿尔金山之间隔以一里坪凹陷和赛昆断陷(图 1)。换言之,阿尔金山南段物质很难跨越湖盆中心搬运至柴达木盆地的东北部。850 Ma 年龄峰值主要来自于在南祁连山内部的微地块中。1800~1650 Ma 和 2500 Ma 碎屑锆石虽然是华北板块基底的特征性锆石年龄组分,但由于祁连山及秦岭造山带的阻隔,华北板块物质很难直接到达柴达木盆地内部。因此,我们推测这些元古宙碎屑锆石可能再旋回来自祁连山造山带内的古老基底物质,或者柴北缘构造带以及欧龙布鲁克地块的前寒武纪结晶基底。

N-109 井和 N-105 井虽然同处于阿尔金山前

带,但是其样品的年龄谱特征差别较大(图 5),两个样品具有 280~260 Ma 和 440~420 Ma 年龄峰值,但 N-105 井样品中缺乏 1865 Ma 与 2514 Ma 年龄峰值的样品。如上所述,280~260 Ma 年龄峰值可能来自北侧的赛什腾山,也可能来自西部的阿尔金山,但已有资料数据尚难以确定其具体源区,因此二者都可能作为 N-109 井和 N-105 井的潜在源区。在新元古代—早古生代时期,阿尔金造山带中的阿中地块与柴达木地块之间的“南阿尔金洋盆”,在早古生代经历了洋—陆转换过程,469~445 Ma 和 411~404 Ma 为岩浆活动的高峰期,因此两个样品发育 440~420 Ma 锆石 U-Pb 年龄峰值。1900 Ma 与 2400 Ma 年龄峰值的样品主要是来自于中阿尔金地块的中元古代深变质的阿尔金岩群或北部敦煌地块的元古宙—太古宙基底(Feng Wei et al. ,2022)。前人的研究表明,阿尔金岩群年龄主要集中于 1990~1850 Ma,但是阿尔金岩群本身可能为不同时代、不同性质岩石组成,受后期断裂影响,遭受了不同程度的剥蚀。N-105 井更加靠近阿尔金山前,而 N-109 井更加靠近盆地内部,因此,N-105 井碎屑组分可能受近源的阿尔金山影响更大,N-109 井由于靠近盆地内部,则出现了 1865 Ma 与 2514 Ma 等代表南祁连山的年龄峰值。但由于目前采样密度小,以及源-汇体系的复杂性,这一认识仅为初步推论,未来尚需更加精细的研究加以证实。综上所述,N-109 井和 N-105 井的物源受阿尔金山及南

祁连共同控制,但是阿尔金山对该区的物源影响更大。同时也间接表明,祁连山在此时可能已经开始隆升,物源影响范围较远。

YIT-1 井的样品年龄谱中具有 840 Ma 年龄峰值,受 Rodinia 超大陆裂解事件的影响,东昆仑山广泛分布着 800 Ma 年龄的花岗岩,同时锆石 CL 图像表明 YIT-1 样品中 900~700 Ma 年龄段的锆石均为岩浆成因,这指示了 840 Ma 年龄样品的东昆仑山物源成因。但碎屑锆石 U-Pb 年龄研究表明东昆仑山缺乏 >1000 Ma 的年龄样品(图 6),Zhao Junfeng (2020) 研究表明柴西侏罗纪地层的物源也主要来自于东昆仑山,同样缺乏 >1000 Ma 的年龄样品。对比样品的锆石 U-Pb 年龄与柴达木盆地周缘造山带碎屑锆石 U-Pb 年龄,我们推测 1800 Ma 的年龄样品应来自于阿尔金岩群。YIT-1 井的物源受东昆仑山及阿尔金山双重控制。

5 柴达木盆地古近系盆山关系探讨

渐新世 E_3^2 沉积时期处于中喜马拉雅运动时期(侯增谦等,2006)。由于印度板块的持续北移和陆内俯冲,在其与欧亚板块的持续聚敛作用下,青藏高原内部多个刚性块体有序地向北碰撞,陆续拼合挤压形成盆-山相间的复杂构造格局(王伟涛等,2014)。处于柴达木地块与华北板块结合部位的柴达木盆地北部的祁连山再次活化,快速隆升、逆冲、走滑、断陷断裂活动强烈(Yu Jingxing et al., 2019)。YIT-1 物源分析表明此时东昆仑山已经作为柴达木盆地重要的沉积物来源,暗示山体开始剧烈的构造活动,这也与低温热年代学揭示的结果一致(Li Chaopeng et al., 2021; Wu Chen et al., 2021)。东昆仑山前大部分地区仍发育粗碎屑沉积物, E_3^2 与上覆地层呈角度不整合接触(易立,2020),均是造山带对盆地的构造-沉积响应。青藏高原的演化过程中,本身具有多块断、多因素的特征,由于基底、壳幔结构、先存断裂的差异,往往会导致隆凹相间构造-沉积格局,因此,在青藏高原隆升构造背景下,依然发育可可西里、羌塘、柴达木等大中型盆地。东昆仑山隆升将北部的古柴达木盆地与南部的羌塘北和巴颜喀拉地体已经隔开(Wu Chen et al., 2016, 2021),因此盆地北部 N-105、N-109、L6-1 等样品中并未见到任何东昆仑山或者羌塘基底的锆石特征。但是柴西 E_3^2 沉积时期发育多个沉降中心,特别是东昆仑山前一东柴山地区,呈隆凹相间的构造格局,凹陷内细粒沉积物分布广泛,且发育于温

暖潮湿的环境当中。在盆山耦合过程中,大规模的山体抬升,往往伴随着盆地内沉积地层中发育的多层生长地层,柴达木盆地阿尔金山前、祁连山前的地震剖面中,在新生代地层中,均可以见到生长地层发育(潘家伟等,2015; Luo Liang et al., 2022)。而在昆山山前的地震剖面中, E_3^2 — N_2^1 地层内未见到明显的生长地层发育(倪祥龙等,2019),表明当时东昆仑山脉构造抬升有限。因此,可可西里、索木库里与柴西南盆地形成了一个统一的凹陷,3 个盆地此时的沉积环境极为相似(Cheng Feng et al., 2014),与此时的柴达木盆地内部各异的沉积环境形成鲜明的对比(图 7)。

阿尔金山地区中、新元古界分布广泛,厚度巨大,构成了阿尔金山脉的主体,经过吕梁旋回,地壳刚性显著增强,从中元古代开始进入了一个新的相对稳定的演化阶段。但对于阿尔金断裂喜马拉雅运动的构造演化阶段,主要存在两种观点:① 阿尔金断裂有两阶段构造演化模式,第一阶段以左行走滑运动为主,属于埋藏沉积期(Gao Shibao et al., 2022),渐新世一早中新世时期受印度板块的挤压,盆地向东侧向迁移,阿尔金断裂作为区域调节性质断裂,第二阶段为中中新世以来,青藏高原北部地区整体的地壳缩短、加厚,特别是大部分走滑调节分量传递至垂向上的运动,阿尔金山发生构造隆升(Jolivet et al., 2003; Yin An et al., 2008; 霍斐斐, 2019; Gao Shibao et al., 2022);② 36~15 Ma 时期阿尔金山构造隆升,15 Ma 至今,阿尔金断裂左行走滑移动(吴磊等,2012)。阿尔金断裂在渐新世一早中新世时期受印度板块的挤压发生左行走滑,这一认识得到多数学者的认可,构造、沉积、地震资料及年代学资料较为丰富(表 2)。本文通过对阿尔金山前带的 N-105、N-109 及 YIT-1 井的碎屑锆石 U-Pb 年龄分析表明,渐新世(40~30 Ma)以来阿尔金山极有可能已经发生阶段性隆升,并且控制了山前带的构造-沉积格局。这 3 口井的碎屑锆石 U-Pb 年龄存在一定的差异,这是由于阿尔金山断裂带强烈的走滑作用,致使隆升过程中为多断块式隆升,形成了一系列的走滑拉分凹陷及隆起,向两侧盆地提供碎屑物质,造成锆石年龄宏观上相对统一,却又差异较大。阿尔金山古近系的隆升致使柴达木盆地整体向北压缩,在南阿尔金山中段的临海套以南形成了一个大型凹陷(茫崖凹陷),该凹陷发育了一套以石膏、暗色泥页岩、灰岩、泥粉晶白云岩为主的咸化湖盆沉积建造,气候整体为干旱寒冷,蒸发作用强,长

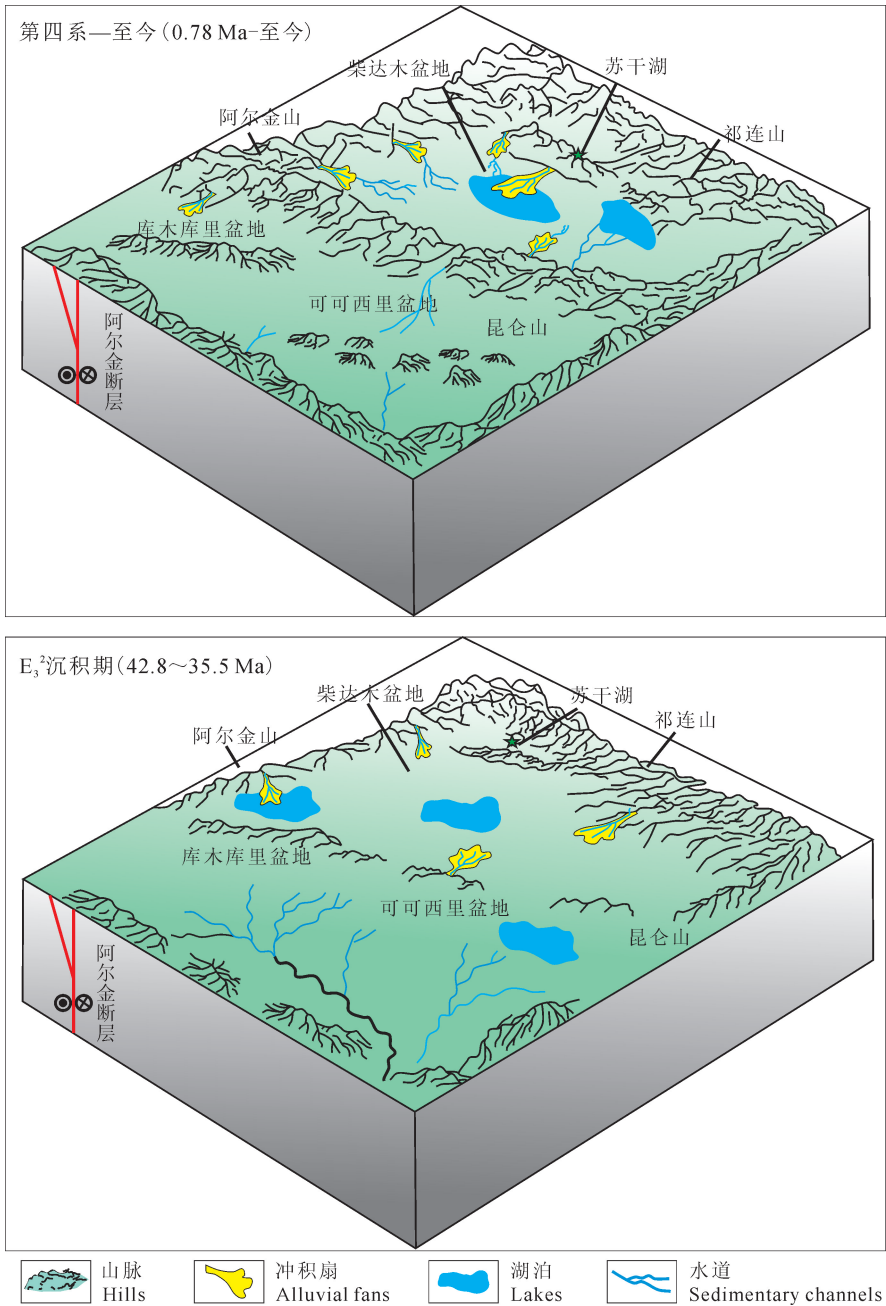


图 7 柴达木盆地周缘造山带 E_3^2 沉积期以来地貌演化
Fig. 7 Geomorphic evolution of the Qaidam basin since E_3^2

期处于半咸化—咸化环境,同时受周缘三角洲沉积体系充足的陆源输入和补给的影响,导致区内矿物成分复杂多样、横向变化较大(李林林等,2015)。该凹陷的边界正是位于 YIT-1 井以南地区,在东昆仑山物源波及范围内。阿尔金山及东昆仑山有限、分块式的隆升使得茫崖凹陷既处在了一个相对安静的构造环境,发育了大量的细粒沉积物,陆源碎屑波及强度小,范围有限;同时大规模的隆升启动,使得其又处于高海拔环境中,干旱且强烈蒸发(图 7)。

由于华北板块和阿拉善地块刚性块体的阻挡作

用,祁连山作为青藏高原向北东扩展的前锋部位,在新生代早期受到印度-欧亚板块的碰撞的远程效应,发生十分强烈的变形-造山活动,构造样式以强烈的冲断为主。一些学者认为南祁连山最初的抬升时间是始新世(Yin An et al. ,2008;Qi Bangshen et al. ,2016;Cheng Feng et al. ,2019),而另一些学者则认为南祁连山初始隆升时间是中新世中晚期(Wang Weitao et al. ,2017; Pang Jianzhan et al. ,2019;Yu Jingxing et al. ,2019;Nie Junsheng et al. ,2020)。此次发现 N-109 井已经受到祁连山物源体系的影

响,可见祁连山在渐新世已经开始大规模隆升,并提供物源,加之 L6-1 与 XX-1 井年龄存在部分差异,表明山前的地貌受隆升影响也存在了一定差异。同

时, E_3^2 沉积时期,祁连山前河流-三角洲体系十分发育,湖泊沉积体系也较为发育,并且向南波及范围较远(图 7)。

表 2 柴达木盆地及周缘造山带隆升挤压时间统计

Table 2 Uplift and compression time statistics of Qaidam basin and its surrounding orogenic belts

构造区域	隆升挤压时限(Ma)	研究方法	参考文献
盆地北缘	22~17	热年代学	Jolivet et al. ,2003
盆地整体	15	沉积学	Fang Xiaomin et al. ,2007
盆地西部	22	古地磁	张涛等,2012
盆地整体	中新世以来	地层学、沉积学	关平等,2013
东昆仑	30	构造热代学	Mock et al. ,1999
盆地整体	42.8~40.5、2.8	构造形变研究	Wang Tao et al. ,2006
周缘山系	31	构造热年代学	王非等,2002
南缘昆仑山西段	33.5~11.3	构造热年代学	吴珍汉等,2007
盆地及周缘	≤24~29	构造演化分析	Yin An et al. ,2002
东昆仑	30~20	综合分析	王成善等,2009
北缘-盆内	32	地震资料解释	Luo Liang et al. ,2022

6 结论

(1)综合柴达木盆地内山前凹陷典型钻井 E_3^2 砂岩样品锆石 U-Pb 定年研究,结合周缘山系主要锆石 U-Pb 年龄,明确了柴达木盆地 E_3^2 的沉积物源信息,对祁连山、东昆仑山及阿尔金山 E_3^2 沉积时期的古地貌进行了约束。柴达木盆地内祁连山、东昆仑山及阿尔金山前 E_3^2 碎屑锆石 U-Pb 年龄跨度较大,以早寒武世一早泥盆世和早三叠世两个年龄群为主。祁连山前 L6-1 井与 XX-1 井 E_3^2 锆石 U-Pb 主要峰值年龄为 249 Ma 和 415~499 Ma,盆地西部沉降中心 YIT-1 井 E_3^2 锆石 U-Pb 主要峰值年龄为 255 Ma 和 423 Ma,阿尔金山前 E_3^2 锆石 U-Pb 主要峰值年龄为 259 Ma 和 422 Ma。

(2)通过与周缘山系主要物源年龄对比,柴达木盆地不同构造带 E_3^2 的物源差异较大,祁连山前的冷湖地区的物源主要来自于祁连山内部;阿尔金山前牛东地区的物源主体来自于阿尔金山内部,但盆地西北部存在祁连山物源贡献;柴西坳陷内部的物源受祁连山及东昆仑山的共同控制。

(3)祁连山在古近纪末期已大规模隆升,并且作为青藏高原北部边界为柴达木盆地持续提供物源;阿尔金山及昆仑山在 E_3^2 沉积时期已经形成雏形,但并未大规模隆升,造成了山前带复杂的物源体系。祁连山、东昆仑山及阿尔金山迥异的构造演化特征造成了现今柴达木盆地 E_3^2 沉积时期特殊的沉积面貌。

附件: 本文附件(附表 1)详见 http://www.geojournals.cn/dzxb/dzxb/article/abstract/202401094?st=article_issue

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Detrital zircon U-Pb dating of the Paleogene lower Ganchaigou Formation in the Qaidam basin and discussion of basin-mountain coupling

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Abstract

The Qaidam basin is surrounded by the Qilian Mountains, Altun Mountains and Kunlun Mountains. The unique lithology and sedimentary pattern of the Paleogene lower Ganchaigou Formation (E_3^2) in the basin indicate the complex basin mountain system and the diverse genesis of the source area. In this paper, the structure and provenance of the Qaidam basin are systematically analyzed by using detrital zircon U-Pb dating and other analytical methods. The results show that the E_3^2 zircon ages of the samples from well XX-1 in the front of the Qilian Mountains range from 2692 Ma to 156 Ma, and the main peak ages were 448 Ma and 249 Ma. The E_3^2 zircon ages of samples from the well L6-1 ranged from 2693 Ma to 220 Ma, with the main peak ages of 499 Ma and 415 Ma. The E_3^2 zircon ages of samples from the well YIT-1 located in the Western subsidence center of the basin ranged from 2796 Ma to 266 Ma, with the main peak ages of 423 Ma and 255 Ma. The E_3^2 zircon ages of samples from the well N-105 in front of the Altun Mountains ranged from 2481 Ma to 242 Ma, and the main peak ages were 422 Ma and 259 Ma. The E_3^2 zircon ages of samples from the well N-109 ranged from 2638 Ma to 228 Ma, and the main peak ages were 444 Ma and 246 Ma. Compared with the ages of the main source areas, the provenance of E_3^2 in different structural zones of the basin is different. The provenance of E_3^2 in wells XX-1 and L6-1 near the front of the Qilian Mountains mainly comes from the interior of the Qilian Mountains. The main source of wells N-105 and N-109 located in front of the Altyn Tagh Mountains is from the interior of the Altyn Tagh Mountains, but well N-109 has the contribution of the Qilian Mountains. The source of the well YIT-1 in the Chaixi depression is jointly controlled by the Qilian Mountains and the East Kunlun Mountains. The results of provenance analysis show that the Qilian Mountain has been uplifted on a large scale in the Paleogene, and as the northern boundary of the Qinghai-Tibet Plateau, it continues to provide provenance for the Qaidam basin. The Altun Mountains and Kunlun Mountains had taken shape in the E_3^2 period, but did not rise on a large scale, resulting in a complex provenance system in the piedmont zone.

Key words: Qaidam basin; lower Ganchaigou Formation; detrital zircon; U-Pb age; provenance analysis

附表 1 柴达木盆地 E₃ 探井碎屑锆石 U-Pb 同位素分析与年龄结果

Appendix 1 U-Pb isotope analysis and age results of detrital zircons from E₃ exploration wells in the Qaidam basin

测点	Th/U	同位素比值						年龄 (Ma)					
		²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ
样品 L6-1, 3681. 80 m													
001	0. 6	0. 06848	0. 00050	0. 14578	0. 00171	1. 37696	0. 01059	883. 2	15. 08	877. 2	9. 63	879. 1	4. 52
002	1. 3	0. 05080	0. 00089	0. 03876	0. 00049	0. 27159	0. 00464	231. 8	40. 03	245. 1	3. 05	244. 0	3. 70
003	0. 1	0. 06560	0. 00086	0. 07028	0. 00087	0. 63599	0. 00821	793. 8	27. 41	437. 8	5. 22	499. 8	5. 09
005	0. 6	0. 05778	0. 00080	0. 04018	0. 00049	0. 32022	0. 00432	521. 1	30. 22	253. 9	3. 05	282. 1	3. 32
006	0. 2	0. 07068	0. 00091	0. 15065	0. 00186	1. 46880	0. 01857	948. 0	26. 09	904. 6	10. 43	917. 6	7. 64
007	0. 4	0. 16550	0. 00096	0. 48267	0. 00557	11. 02037	0. 07005	2512. 6	9. 70	2538. 9	24. 24	2524. 9	5. 92
008	0. 6	0. 12019	0. 00179	0. 31010	0. 00425	5. 14176	0. 07485	1959. 0	26. 34	1741. 2	20. 93	1843. 0	12. 37
009	0. 5	0. 06197	0. 00118	0. 06226	0. 00081	0. 53228	0. 00979	673. 0	40. 31	389. 4	4. 92	433. 3	6. 48
010	0. 3	0. 08361	0. 00117	0. 23946	0. 00305	2. 76211	0. 03790	1283. 3	27. 06	1383. 9	15. 88	1345. 4	10. 23
011	0. 5	0. 11575	0. 00082	0. 35138	0. 00408	5. 61142	0. 04179	1891. 6	12. 74	1941. 2	19. 47	1917. 9	6. 42
012	1. 0	0. 16933	0. 00190	0. 49353	0. 00651	11. 52957	0. 13093	2551. 1	18. 64	2585. 9	28. 12	2567. 0	10. 61
013	0. 5	0. 09676	0. 00119	0. 23820	0. 00295	3. 17956	0. 03840	1562. 5	22. 90	1377. 3	15. 37	1452. 2	9. 33
017	0. 7	0. 06392	0. 00115	0. 08081	0. 00103	0. 71247	0. 01238	739. 0	37. 70	500. 9	6. 12	546. 2	7. 34
018	0. 9	0. 16693	0. 00132	0. 46579	0. 00548	10. 72500	0. 08738	2527. 1	13. 20	2465. 1	24. 12	2499. 6	7. 57
019	0. 7	0. 06184	0. 00085	0. 06668	0. 00079	0. 56872	0. 00763	668. 6	29. 27	416. 1	4. 78	457. 2	4. 94
021	0. 2	0. 11579	0. 00071	0. 32507	0. 00361	5. 19074	0. 03340	1892. 1	10. 96	1814. 5	17. 55	1851. 1	5. 48
023	0. 4	0. 07746	0. 00094	0. 17804	0. 00211	1. 90166	0. 02266	1133. 1	24. 04	1056. 2	11. 54	1081. 7	7. 93
024	0. 6	0. 05891	0. 00082	0. 04424	0. 00052	0. 35939	0. 00485	563. 8	30. 07	279. 1	3. 20	311. 8	3. 62
025	0. 8	0. 16430	0. 00226	0. 45240	0. 00623	10. 24547	0. 14021	2500. 4	23. 00	2405. 9	27. 64	2457. 2	12. 66
026	0. 7	0. 06818	0. 00452	0. 07992	0. 00207	0. 75098	0. 04743	873. 9	131. 57	495. 7	12. 33	568. 8	27. 51
029	0. 8	0. 15092	0. 00123	0. 39916	0. 00455	8. 30082	0. 06825	2356. 4	13. 86	2165. 2	20. 99	2264. 4	7. 45
030	0. 4	0. 15217	0. 00130	0. 41269	0. 00475	8. 65207	0. 07438	2370. 4	14. 51	2227. 2	21. 69	2302. 0	7. 82
031	0. 3	0. 07141	0. 00063	0. 14025	0. 00161	1. 38145	0. 01238	969. 3	18. 18	846. 1	9. 09	881. 1	5. 28
034	0. 6	0. 06326	0. 00096	0. 06344	0. 00077	0. 55348	0. 00817	716. 9	32. 00	396. 5	4. 68	447. 3	5. 34
036	0. 6	0. 16143	0. 00182	0. 44943	0. 00580	10. 00612	0. 11337	2470. 6	18. 90	2392. 7	25. 82	2435. 3	10. 46
037	0. 9	0. 15398	0. 00133	0. 43150	0. 00515	9. 16332	0. 08075	2390. 6	14. 58	2312. 5	23. 21	2354. 5	8. 07
038	0. 7	0. 11084	0. 00112	0. 30151	0. 00362	4. 60909	0. 04656	1813. 2	18. 26	1698. 8	17. 91	1750. 9	8. 43
039	0. 4	0. 06149	0. 00094	0. 08343	0. 00102	0. 70752	0. 01054	656. 3	32. 53	516. 6	6. 05	543. 3	6. 27
040	0. 8	0. 08210	0. 00107	0. 21488	0. 00263	2. 43287	0. 03102	1247. 8	25. 22	1254. 7	13. 97	1252. 4	9. 17
041	0. 5	0. 05660	0. 00092	0. 06926	0. 00084	0. 54069	0. 00851	475. 4	35. 78	431. 7	5. 09	438. 9	5. 61
042	0. 8	0. 05703	0. 00085	0. 07245	0. 00087	0. 56984	0. 00828	492. 3	32. 87	450. 9	5. 24	457. 9	5. 36
043	0. 9	0. 06744	0. 00061	0. 14177	0. 00162	1. 31857	0. 01194	851. 5	18. 58	854. 7	9. 15	853. 9	5. 23
044	0. 7	0. 06119	0. 00150	0. 08842	0. 00123	0. 74612	0. 01753	645. 8	51. 66	546. 2	7. 28	566. 0	10. 19
045	0. 4	0. 16920	0. 00106	0. 48194	0. 00546	11. 24550	0. 07494	2549. 8	10. 43	2535. 7	23. 76	2543. 7	6. 21
046	0. 8	0. 06860	0. 00129	0. 08049	0. 00104	0. 76154	0. 01380	886. 8	38. 50	499. 1	6. 21	574. 9	7. 95
048	0. 7	0. 05577	0. 00122	0. 05470	0. 00071	0. 42076	0. 00885	443. 1	47. 53	343. 3	4. 37	356. 6	6. 33
050	0. 8	0. 05784	0. 00068	0. 06638	0. 00077	0. 52945	0. 00617	523. 4	25. 98	414. 3	4. 66	431. 4	4. 09
051	0. 5	0. 05731	0. 00049	0. 06600	0. 00075	0. 52161	0. 00454	503. 2	19. 16	412. 0	4. 51	426. 2	3. 03
053	0. 0	0. 11458	0. 00069	0. 31865	0. 00356	5. 03467	0. 03239	1873. 3	10. 87	1783. 2	17. 42	1825. 2	5. 45
054	0. 3	0. 11137	0. 00178	0. 30048	0. 00408	4. 61477	0. 07167	1822. 0	28. 65	1693. 7	20. 24	1751. 9	12. 96
055	0. 6	0. 05780	0. 00102	0. 07099	0. 00088	0. 56582	0. 00970	522. 1	38. 60	442. 1	5. 32	455. 3	6. 29
056	0. 4	0. 05524	0. 00113	0. 04688	0. 00060	0. 35711	0. 00701	421. 9	44. 25	295. 3	3. 68	310. 1	5. 25
057	0. 8	0. 05852	0. 00084	0. 03475	0. 00041	0. 28039	0. 00390	549. 2	30. 97	220. 2	2. 57	251. 0	3. 09
058	0. 6	0. 05592	0. 00055	0. 06428	0. 00073	0. 49566	0. 00485	448. 9	21. 28	401. 6	4. 43	408. 8	3. 30
059	0. 6	0. 05177	0. 00084	0. 03719	0. 00045	0. 26551	0. 00420	275. 4	36. 89	235. 4	2. 78	239. 1	3. 37
060	0. 5	0. 15706	0. 00111	0. 43464	0. 00498	9. 41290	0. 06915	2424. 3	11. 91	2326. 6	22. 39	2379. 1	6. 74
061	0. 6	0. 05603	0. 00088	0. 08073	0. 00103	0. 62608	0. 00960	453. 2	34. 15	500. 5	6. 12	493. 6	5. 99
063	0. 7	0. 15115	0. 00267	0. 44884	0. 00717	9. 38717	0. 16403	2359. 0	29. 87	2390. 1	31. 91	2376. 6	16. 03
064	1. 0	0. 08387	0. 00103	0. 23981	0. 00304	2. 78262	0. 03397	1289. 5	23. 82	1385. 7	15. 79	1350. 9	9. 12
065	0. 5	0. 15482	0. 00137	0. 46036	0. 00576	9. 85866	0. 08998	2399. 9	14. 93	2441. 1	25. 44	2421. 7	8. 41
066	0. 7	0. 15387	0. 00170	0. 41862	0. 00551	8. 90804	0. 09905	2389. 3	18. 69	2254. 2	25. 06	2328. 6	10. 15

续附表 1

测点	Th/U	同位素比值						年龄 (Ma)					
		²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ
		样品 L6-1,3681.80 m											
067	0.7	0.10556	0.00089	0.29993	0.00361	4.37725	0.03795	1724.1	15.44	1691.0	17.90	1708.1	7.17
068	0.7	0.05658	0.00096	0.04819	0.00061	0.37691	0.00621	474.4	37.53	303.4	3.76	324.8	4.58
069	0.7	0.16317	0.00095	0.48015	0.00559	10.82855	0.06923	2488.8	9.76	2527.9	24.35	2508.5	5.94
070	0.7	0.10104	0.00130	0.28734	0.00372	4.01192	0.05101	1643.2	23.75	1628.2	18.61	1636.6	10.33
071	0.8	0.15754	0.00106	0.45645	0.00539	9.93563	0.07134	2429.4	11.37	2423.9	23.87	2428.8	6.62
072	0.7	0.06589	0.00091	0.06840	0.00084	0.62262	0.00833	802.9	28.53	426.5	5.08	491.5	5.21
073	0.6	0.06909	0.00107	0.07945	0.00100	0.75782	0.01135	901.3	31.65	492.8	5.98	572.8	6.55
074	0.9	0.11496	0.00168	0.31430	0.00426	4.98758	0.07128	1879.2	26.11	1761.8	20.89	1817.2	12.09
075	0.6	0.10920	0.00235	0.28557	0.00450	4.30392	0.08939	1786.0	38.81	1619.4	22.55	1694.1	17.11
076	0.7	0.18440	0.00116	0.50663	0.00588	12.89193	0.08716	2692.8	10.40	2642.2	25.17	2671.8	6.37
077	0.3	0.06501	0.00051	0.12414	0.00142	1.11350	0.00892	774.6	16.41	754.4	8.17	759.9	4.29
080	0.5	0.06450	0.00109	0.07320	0.00092	0.65106	0.01057	758.1	35.15	455.4	5.54	509.1	6.50
081	0.7	0.06877	0.00108	0.07047	0.00088	0.66821	0.01009	892.0	32.07	439.0	5.28	519.6	6.14
082	0.5	0.11795	0.00186	0.35094	0.00490	5.70617	0.08811	1925.4	28.02	1939.1	23.38	1932.3	13.34
083	0.3	0.06178	0.00129	0.04959	0.00065	0.42220	0.00841	666.4	43.95	312.0	4.01	357.6	6.01
084	0.7	0.15175	0.00132	0.42243	0.00508	8.83375	0.07815	2365.7	14.80	2271.5	23.01	2321.0	8.07
085	0.5	0.15870	0.00104	0.45032	0.00512	9.84252	0.06730	2441.9	11.04	2396.7	22.78	2420.1	6.30
086	0.4	0.12515	0.00096	0.35395	0.00408	6.09975	0.04785	2030.9	13.58	1953.5	19.41	1990.2	6.84
087	0.8	0.06602	0.00105	0.07587	0.00093	0.68966	0.01057	807.1	32.98	471.4	5.60	532.6	6.35
088	1.3	0.08206	0.00108	0.18366	0.00224	2.07460	0.02660	1246.9	25.64	1086.9	12.21	1140.5	8.78
089	0.9	0.16148	0.00105	0.47527	0.00537	10.56328	0.07131	2471.2	10.89	2506.6	23.47	2485.5	6.26
090	0.7	0.06259	0.00092	0.07658	0.00092	0.65960	0.00935	694.2	30.99	475.7	5.51	514.4	5.72
092	0.5	0.09019	0.00073	0.21303	0.00240	2.64279	0.02140	1429.4	15.37	1244.9	12.76	1312.6	5.97
093	1.1	0.11620	0.00105	0.32626	0.00379	5.21431	0.04691	1898.6	16.16	1820.3	18.44	1855.0	7.67
094	0.2	0.05701	0.00099	0.07671	0.00095	0.60317	0.01010	491.5	37.96	476.5	5.68	479.2	6.40
095	0.5	0.05704	0.00047	0.08000	0.00090	0.62921	0.00520	492.3	18.16	496.1	5.35	495.6	3.24
096	0.8	0.06373	0.00089	0.05845	0.00070	0.51366	0.00693	732.5	29.27	366.2	4.24	420.9	4.65
097	0.8	0.16074	0.00119	0.42556	0.00493	9.43325	0.07222	2463.4	12.50	2285.7	22.32	2381.1	7.03
098	0.5	0.15874	0.00144	0.45186	0.00547	9.89138	0.09099	2442.2	15.25	2403.5	24.30	2424.7	8.48
100	0.4	0.15060	0.00105	0.43671	0.00501	9.06999	0.06582	2352.8	11.87	2335.9	22.48	2345.1	6.64
101	0.6	0.06705	0.00116	0.07315	0.00092	0.67635	0.01125	839.2	35.64	455.1	5.54	524.6	6.81
102	0.6	0.07332	0.00077	0.16952	0.00198	1.71399	0.01776	1022.7	21.06	1009.5	10.90	1013.8	6.65
104	1.0	0.14252	0.00092	0.40613	0.00461	7.98253	0.05394	2258.1	11.05	2197.2	21.12	2229.1	6.10
106	1.0	0.11534	0.00076	0.31521	0.00357	5.01370	0.03454	1885.2	11.84	1766.3	17.48	1821.6	5.83
107	0.5	0.10955	0.00135	0.28546	0.00358	4.31279	0.05217	1792.0	22.31	1618.8	17.97	1695.8	9.97
111	0.4	0.06899	0.00081	0.12090	0.00143	1.15035	0.01318	898.5	23.90	735.7	8.23	777.4	6.22
112	0.6	0.11032	0.00114	0.31997	0.00388	4.86783	0.04996	1804.6	18.60	1789.6	18.93	1796.7	8.65
113	0.6	0.11986	0.00101	0.32565	0.00383	5.38287	0.04602	1954.1	14.99	1817.3	18.61	1882.1	7.32
114	0.5	0.12007	0.00086	0.33485	0.00385	5.54445	0.04129	1957.2	12.80	1861.8	18.60	1907.5	6.41
118	0.5	0.05789	0.00082	0.06068	0.00073	0.48443	0.00669	525.3	31.08	379.8	4.44	401.1	4.57
样品 XX-1,4111.38 m													
001	0.6	0.16098	0.00167	10.85527	0.11466	0.48886	0.00622	2466.0	17.44	2510.8	9.82	2565.7	26.92
002	0.7	0.10877	0.00250	4.67099	0.10374	0.31134	0.00504	1778.8	41.32	1762.1	18.58	1747.3	24.77
003	0.5	0.05709	0.00092	0.56666	0.00884	0.07196	0.00088	494.3	35.18	455.9	5.73	448.0	5.32
004	0.5	0.05410	0.00098	0.32704	0.00576	0.04382	0.00055	375.0	40.47	287.3	4.40	276.5	3.38
005	1.0	0.13527	0.00166	6.73825	0.08172	0.36112	0.00468	2167.5	21.23	2077.7	10.72	1987.5	22.16
006	0.5	0.18429	0.00132	13.40615	0.10089	0.52738	0.00619	2691.9	11.75	2708.7	7.11	2730.4	26.11
007	0.8	0.05951	0.00119	0.43250	0.00829	0.05269	0.00068	585.7	42.66	365.0	5.88	331.0	4.17
008	0.2	0.06836	0.00095	0.68840	0.00931	0.07301	0.00089	879.4	28.59	531.8	5.60	454.3	5.32
009	0.3	0.05586	0.00130	0.52329	0.01169	0.06791	0.00091	446.6	50.51	427.3	7.79	423.6	5.52
010	0.4	0.12294	0.00088	6.57137	0.04917	0.38752	0.00447	1999.4	12.69	2055.5	6.59	2111.3	20.75
011	0.6	0.05818	0.00097	0.31568	0.00509	0.03934	0.00049	536.1	36.66	278.6	3.93	248.7	3.01

地 质 学 报													
http://www.geojournals.cn/dzxb/ch/index.aspx													
2024 年													
续附表 1													
测点	Th/U	同位素比值						年龄 (Ma)					
		²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ
样品 XX-1,4111.38 m													
012	0.8	0.11284	0.00116	5.15022	0.05292	0.33090	0.00402	1845.7	18.48	1844.4	8.74	1842.8	19.47
013	0.6	0.05961	0.00135	0.63720	0.01385	0.07751	0.00105	589.3	48.27	500.6	8.59	481.2	6.25
014	0.9	0.15433	0.00147	9.70608	0.09395	0.45601	0.00562	2394.4	16.10	2407.3	8.91	2421.9	24.89
015	0.5	0.17463	0.00150	9.72282	0.08512	0.40368	0.00487	2602.5	14.28	2408.9	8.06	2186.0	22.38
017	0.4	0.05881	0.00086	0.57967	0.00822	0.07147	0.00086	560.0	31.43	464.3	5.28	445.0	5.20
020	0.4	0.05657	0.00121	0.36546	0.00755	0.04685	0.00061	473.9	47.34	316.3	5.61	295.1	3.78
021	0.4	0.13517	0.00095	7.18729	0.05285	0.38555	0.00444	2166.2	12.25	2134.9	6.55	2102.2	20.66
022	0.3	0.07349	0.00065	1.72421	0.01527	0.17012	0.00196	1027.5	17.67	1017.6	5.69	1012.8	10.79
024	0.6	0.06898	0.00130	0.76347	0.01385	0.08025	0.00105	898.1	38.53	576.0	7.97	497.6	6.24
025	0.4	0.05448	0.00102	0.54097	0.00984	0.07200	0.00091	391.0	41.41	439.1	6.49	448.2	5.47
026	0.6	0.13842	0.00116	7.71871	0.06604	0.40435	0.00479	2207.5	14.46	2198.8	7.69	2189.0	22.00
027	0.7	0.08964	0.00069	3.31756	0.02618	0.26835	0.00307	1417.9	14.62	1485.2	6.16	1532.4	15.63
028	0.8	0.10986	0.00121	5.08164	0.05583	0.33542	0.00413	1797.0	19.97	1833.0	9.32	1864.6	19.93
029	0.5	0.05231	0.00108	0.25858	0.00513	0.03584	0.00046	298.9	46.21	233.5	4.14	227.0	2.85
031	2.2	0.11910	0.00118	5.96095	0.05922	0.36293	0.00440	1942.8	17.59	1970.2	8.64	1996.1	20.80
032	0.5	0.05275	0.00097	0.30052	0.00536	0.04131	0.00052	317.9	41.33	266.8	4.19	261.0	3.19
033	0.2	0.11762	0.00072	5.94072	0.03866	0.36626	0.00413	1920.4	10.94	1967.2	5.66	2011.8	19.51
035	0.7	0.11357	0.00188	5.12652	0.08264	0.32734	0.00459	1857.3	29.56	1840.5	13.70	1825.5	22.28
036	0.5	0.10714	0.00138	4.71708	0.05992	0.31926	0.00408	1751.4	23.36	1770.3	10.64	1786.1	19.91
039	1.9	0.16081	0.00103	10.06182	0.06795	0.45375	0.00518	2464.2	10.74	2440.5	6.24	2411.9	22.97
040	0.5	0.05585	0.00073	0.54944	0.00702	0.07135	0.00084	445.9	28.35	444.6	4.60	444.3	5.08
041	3.0	0.06876	0.00130	1.34465	0.02452	0.14182	0.00187	891.5	38.53	865.2	10.62	855.0	10.55
043	0.5	0.10747	0.00069	5.05362	0.03416	0.34102	0.00386	1756.9	11.63	1828.4	5.73	1891.6	18.54
044	0.4	0.12011	0.00106	5.79982	0.05162	0.35017	0.00414	1957.9	15.63	1946.4	7.71	1935.4	19.78
045	0.7	0.05601	0.00072	0.55372	0.00697	0.07169	0.00085	452.6	27.95	447.4	4.56	446.3	5.09
046	0.6	0.06647	0.00112	1.22371	0.02001	0.13352	0.00169	821.1	34.87	811.5	9.14	807.9	9.64
047	0.8	0.05372	0.00175	0.33474	0.01043	0.04519	0.00069	359.2	71.55	293.2	7.93	284.9	4.23
048	0.6	0.05463	0.00104	0.31618	0.00579	0.04197	0.00053	397.1	41.71	279.0	4.47	265.1	3.27
049	0.4	0.06993	0.00073	1.56502	0.01619	0.16231	0.00190	926.2	21.30	956.5	6.41	969.6	10.52
050	0.5	0.05174	0.00079	0.28403	0.00423	0.03981	0.00048	273.8	34.71	253.9	3.34	251.7	2.96
051	0.8	0.05299	0.00151	0.32640	0.00890	0.04467	0.00064	328.3	63.22	286.8	6.81	281.7	3.93
052	0.6	0.05277	0.00128	0.27038	0.00629	0.03716	0.00050	318.9	54.02	243.0	5.03	235.2	3.10
053	0.7	0.11882	0.00080	5.70838	0.04004	0.34841	0.00396	1938.6	11.99	1932.6	6.06	1927.0	18.95
054	0.7	0.11741	0.00135	5.46628	0.06227	0.33764	0.00422	1917.2	20.50	1895.3	9.78	1875.3	20.34
057	1.2	0.12125	0.00129	5.30170	0.05601	0.31713	0.00389	1974.6	18.88	1869.1	9.02	1775.7	19.04
058	0.5	0.06044	0.00105	0.64413	0.01077	0.07729	0.00097	619.5	36.95	504.9	6.65	479.9	5.79
059	0.4	0.11544	0.00070	5.69920	0.03666	0.35805	0.00403	1886.8	10.89	1931.2	5.56	1972.9	19.12
060	0.8	0.11017	0.00176	4.49219	0.06992	0.29574	0.00405	1802.1	28.86	1729.5	12.93	1670.1	20.15
061	0.6	0.11494	0.00073	5.83841	0.03900	0.36840	0.00416	1879.0	11.40	1952.1	5.79	2021.9	19.61
062	0.5	0.05825	0.00086	0.55951	0.00801	0.06966	0.00084	538.6	32.56	451.2	5.21	434.1	5.07
063	0.5	0.14576	0.00091	7.45771	0.04912	0.37109	0.00420	2296.7	10.72	2167.9	5.90	2034.5	19.76
064	1.2	0.06469	0.00077	0.78402	0.00913	0.08790	0.00103	764.4	24.88	587.8	5.19	543.1	6.13
065	0.9	0.10910	0.00095	5.09002	0.04485	0.33837	0.00397	1784.4	15.83	1834.4	7.48	1878.8	19.12
066	0.5	0.15025	0.00101	9.19960	0.06459	0.44409	0.00509	2348.7	11.42	2358.1	6.43	2368.9	22.71
067	0.8	0.11012	0.00065	4.81941	0.03003	0.31744	0.00355	1801.3	10.63	1788.3	5.24	1777.2	17.39
069	0.5	0.06494	0.00105	0.58383	0.00910	0.06521	0.00081	772.4	33.73	466.9	5.84	407.2	4.89
070	0.9	0.16258	0.00098	10.43701	0.06672	0.46561	0.00526	2482.7	10.09	2474.3	5.92	2464.3	23.16
071	0.4	0.06539	0.00093	0.73092	0.01006	0.08107	0.00098	787.0	29.57	557.1	5.90	502.5	5.85
072	1.5	0.10314	0.00113	4.10502	0.04458	0.28866	0.00351	1681.4	20.15	1655.3	8.87	1634.9	17.56
073	0.5	0.05386	0.00118	0.29223	0.00617	0.03936	0.00051	364.9	48.85	260.3	4.85	248.8	3.18
074	0.4	0.14386	0.00100	8.40560	0.06098	0.42378	0.00487	2274.2	11.98	2275.8	6.58	2277.6	22.06
075	0.4	0.06732	0.00068	1.29763	0.01292	0.13981	0.00162	847.6	20.76	844.7	5.71	843.6	9.15

续附表 1

测点	Th/U	同位素比值						年龄 (Ma)					
		²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ
		样品 XX-1,4111.38 m											
076	0.9	0.14896	0.00088	8.34820	0.05263	0.40648	0.00458	2334.0	10.15	2269.6	5.72	2198.8	20.97
077	0.6	0.12044	0.00074	6.25248	0.04071	0.37652	0.00424	1962.8	10.97	2011.8	5.70	2060.0	19.86
078	0.5	0.05966	0.00092	0.20117	0.00298	0.02446	0.00030	591.1	32.96	186.1	2.52	155.8	1.86
079	0.6	0.05933	0.00223	0.35609	0.01274	0.04353	0.00072	579.2	79.49	309.3	9.54	274.7	4.48
081	0.6	0.05423	0.00105	0.31782	0.00590	0.04251	0.00054	380.4	42.75	280.2	4.55	268.4	3.32
082	0.6	0.11109	0.00085	4.73180	0.03681	0.30895	0.00355	1817.3	13.79	1772.9	6.52	1735.5	17.48
083	1.2	0.10418	0.00126	4.51201	0.05369	0.31414	0.00392	1699.9	22.07	1733.2	9.89	1761.0	19.22
084	0.7	0.04970	0.00126	0.25309	0.00619	0.03694	0.00050	181.0	58.20	229.1	5.02	233.8	3.10
085	0.4	0.05734	0.00109	0.59787	0.01093	0.07563	0.00096	504.1	41.63	475.9	6.94	470.0	5.76
086	0.5	0.06289	0.00105	0.40771	0.00656	0.04702	0.00058	704.6	35.26	347.2	4.73	296.2	3.59
087	0.8	0.16336	0.00125	9.77256	0.07666	0.43390	0.00509	2490.8	12.81	2413.6	7.23	2323.3	22.86
088	0.8	0.10967	0.00112	5.05303	0.05160	0.33420	0.00404	1793.9	18.58	1828.3	8.66	1858.7	19.50
089	0.5	0.05757	0.00057	0.57991	0.00566	0.07306	0.00083	513.2	21.29	464.4	3.64	454.6	5.01
090	1.2	0.06016	0.00116	0.41506	0.00767	0.05004	0.00064	609.5	41.12	352.5	5.50	314.8	3.93
091	0.4	0.05706	0.00076	0.67367	0.00879	0.08563	0.00101	493.3	29.58	522.9	5.33	529.7	6.03
092	0.5	0.05336	0.00122	0.28190	0.00620	0.03832	0.00051	343.9	51.03	252.2	4.91	242.4	3.14
093	0.5	0.11411	0.00105	5.12232	0.04704	0.32560	0.00385	1865.8	16.46	1839.8	7.80	1817.0	18.73
094	0.3	0.15920	0.00102	10.26002	0.06924	0.46745	0.00532	2447.2	10.82	2458.5	6.24	2472.4	23.38
095	2.0	0.11292	0.00114	5.23875	0.05256	0.33650	0.00406	1847.0	18.11	1858.9	8.55	1869.8	19.56
096	0.5	0.05480	0.00124	0.43092	0.00935	0.05704	0.00076	403.9	49.43	363.8	6.63	357.6	4.61
097	0.7	0.05937	0.00150	0.39788	0.00963	0.04861	0.00068	580.8	54.10	340.1	6.99	306.0	4.17
098	0.6	0.05926	0.00120	0.56386	0.01094	0.06902	0.00090	576.7	43.30	454.0	7.10	430.2	5.40
099	0.4	0.15660	0.00090	10.35212	0.06372	0.47948	0.00538	2419.3	9.76	2466.8	5.70	2525.0	23.45
100	1.3	0.11853	0.00112	5.83445	0.05527	0.35703	0.00427	1934.2	16.83	1951.5	8.21	1968.1	20.27
101	0.6	0.10535	0.00163	4.16379	0.06267	0.28668	0.00385	1720.4	28.21	1666.9	12.32	1624.9	19.29
102	0.6	0.17589	0.00117	12.20839	0.08506	0.50344	0.00578	2614.5	11.01	2620.6	6.54	2628.6	24.80
103	0.5	0.05548	0.00094	0.28273	0.00465	0.03697	0.00045	431.3	37.02	252.8	3.68	234.0	2.80
105	0.5	0.04998	0.00084	0.27188	0.00440	0.03946	0.00048	193.9	38.39	244.2	3.51	249.5	2.97
106	1.0	0.15703	0.00108	9.24146	0.06587	0.42688	0.00490	2423.9	11.61	2362.2	6.53	2291.6	22.13
107	1.3	0.06347	0.00069	1.22301	0.01306	0.13977	0.00162	724.0	22.81	811.2	5.96	843.3	9.18
108	0.2	0.06439	0.00060	1.15051	0.01063	0.12959	0.00148	754.6	19.48	777.5	5.02	785.5	8.45
109	0.3	0.12522	0.00096	6.30360	0.04926	0.36514	0.00422	2031.9	13.50	2019.0	6.85	2006.5	19.91
110	0.8	0.11866	0.00085	5.96381	0.04379	0.36456	0.00416	1936.1	12.72	1970.6	6.39	2003.7	19.66
111	0.5	0.06064	0.00088	0.64384	0.00902	0.07702	0.00093	626.3	30.88	504.7	5.57	478.3	5.55
112	0.6	0.11990	0.00076	6.11379	0.04060	0.36986	0.00417	1954.7	11.31	1992.2	5.80	2028.7	19.60
113	0.9	0.10374	0.00115	4.56575	0.05007	0.31923	0.00390	1692.1	20.31	1743.0	9.14	1786.0	19.04
114	0.4	0.05256	0.00160	0.33195	0.00969	0.04581	0.00067	309.7	67.79	291.0	7.39	288.8	4.16
115	0.7	0.10135	0.00140	4.33846	0.05857	0.31049	0.00401	1649.0	25.35	1700.7	11.14	1743.1	19.70
116	0.5	0.06909	0.00064	1.61515	0.01500	0.16956	0.00194	901.5	19.12	976.1	5.82	1009.7	10.72
117	1.2	0.10329	0.00167	3.92873	0.06168	0.27590	0.00375	1684.0	29.63	1619.6	12.71	1570.7	18.92
118	1.0	0.11152	0.00084	5.47665	0.04199	0.35622	0.00408	1824.3	13.54	1896.9	6.58	1964.2	19.39
119	1.3	0.07083	0.00124	1.35964	0.02300	0.13923	0.00180	952.5	35.35	871.7	9.90	840.3	10.18
120	0.9	0.14425	0.00156	8.94600	0.09726	0.44983	0.00570	2278.9	18.54	2332.5	9.93	2394.5	25.34
样品 N-105.1102.18 m													
001	0.6	0.05483	0.00101	0.06753	0.00085	0.51045	0.00910	405.1	40.43	421.3	5.12	418.7	6.11
002	1.9	0.05149	0.00141	0.03975	0.00056	0.28221	0.00743	262.8	61.70	251.3	3.45	252.4	5.89
004	0.6	0.05494	0.00112	0.06737	0.00087	0.51031	0.01001	409.9	44.55	420.3	5.25	418.7	6.73
005	0.8	0.05006	0.00307	0.04132	0.00089	0.28520	0.01683	197.6	136.74	261.0	5.51	254.8	13.30
006	0.9	0.05680	0.00187	0.06780	0.00106	0.53093	0.01671	483.0	71.62	422.9	6.39	432.4	11.08
007	0.7	0.05246	0.00082	0.04060	0.00049	0.29369	0.00447	305.5	35.27	256.6	3.04	261.5	3.51
008	0.6	0.05515	0.00080	0.07148	0.00086	0.54353	0.00772	418.2	32.02	445.1	5.17	440.8	5.08
009	0.7	0.05932	0.00230	0.06429	0.00110	0.52580	0.01952	578.8	82.15	401.6	6.65	429.0	12.99

地 质 学 报													
http://www.geojournals.cn/dzxb/ch/index.aspx													
2024 年													
续附表 1													
测点	Th/U	同位素比值						年龄 (Ma)					
		²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ
样品 N-105.1102.18 m													
010	0.6	0.05488	0.00057	0.06770	0.00078	0.51225	0.00526	407.2	22.75	422.3	4.71	420.0	3.53
011	1.2	0.05971	0.00129	0.04358	0.00058	0.35875	0.00744	593.3	45.85	275.0	3.56	311.3	5.56
012	1.2	0.05124	0.00094	0.04193	0.00052	0.29625	0.00526	251.7	41.62	264.8	3.23	263.5	4.12
013	1.0	0.05775	0.00237	0.06742	0.00120	0.53685	0.02103	519.9	87.79	420.6	7.27	436.3	13.89
014	0.1	0.05471	0.00075	0.07024	0.00084	0.52990	0.00712	400.1	30.29	437.6	5.06	431.7	4.73
015	0.5	0.05950	0.00058	0.05905	0.00068	0.48457	0.00471	585.5	21.01	369.9	4.15	401.2	3.22
016	0.6	0.05417	0.00157	0.04440	0.00064	0.33170	0.00924	377.9	63.81	280.1	3.96	290.9	7.05
017	0.5	0.05769	0.00083	0.06802	0.00082	0.54109	0.00761	517.6	31.64	424.2	4.97	439.1	5.01
018	0.1	0.05444	0.00053	0.06790	0.00078	0.50976	0.00496	389.1	21.69	423.5	4.73	418.3	3.34
019	0.5	0.05426	0.00084	0.07206	0.00088	0.53927	0.00818	381.7	34.64	448.6	5.29	437.9	5.40
020	0.7	0.05847	0.00151	0.06633	0.00094	0.53490	0.01324	547.4	55.34	414.0	5.67	435.1	8.76
021	0.7	0.05788	0.00138	0.04124	0.00056	0.32922	0.00752	524.8	51.61	260.5	3.47	289.0	5.74
022	0.3	0.05772	0.00058	0.06620	0.00077	0.52707	0.00532	519.1	21.64	413.2	4.65	429.9	3.54
023	0.4	0.05630	0.00107	0.07159	0.00092	0.55589	0.01022	463.4	41.85	445.7	5.51	448.8	6.67
024	0.6	0.05534	0.00068	0.06905	0.00082	0.52708	0.00638	425.9	27.08	430.4	4.93	429.9	4.24
025	0.8	0.05481	0.00186	0.04025	0.00062	0.30424	0.00988	404.5	73.43	254.4	3.87	269.7	7.69
026	0.3	0.05907	0.00184	0.06955	0.00107	0.56652	0.01687	569.6	66.28	433.4	6.45	455.8	10.94
027	0.5	0.05487	0.00065	0.06658	0.00078	0.50383	0.00592	407.0	26.21	415.5	4.74	414.3	4.00
028	0.6	0.06297	0.00095	0.07265	0.00089	0.63088	0.00926	707.2	31.87	452.1	5.37	496.6	5.76
029	0.6	0.06429	0.00271	0.07164	0.00134	0.63517	0.02547	751.2	86.56	446.0	8.06	499.3	15.82
031	0.6	0.05914	0.00061	0.06001	0.00070	0.48936	0.00499	572.1	22.12	375.7	4.24	404.5	3.40
032	0.3	0.05482	0.00061	0.07202	0.00084	0.54447	0.00603	404.8	24.60	448.3	5.06	441.4	3.96
033	0.0	0.05446	0.00060	0.06761	0.00079	0.50778	0.00550	390.2	24.34	421.7	4.76	417.0	3.71
034	0.4	0.05533	0.00045	0.06576	0.00075	0.50183	0.00413	425.5	17.82	410.6	4.53	412.9	2.79
035	0.6	0.05705	0.00165	0.06883	0.00102	0.54151	0.01502	493.0	63.09	429.1	6.13	439.4	9.89
036	0.8	0.05940	0.00149	0.04295	0.00060	0.35182	0.00842	581.6	53.41	271.1	3.70	306.1	6.32
037	0.9	0.05794	0.00240	0.06964	0.00125	0.55646	0.02199	527.2	88.47	434.0	7.53	449.2	14.35
038	0.4	0.05407	0.00072	0.06876	0.00082	0.51272	0.00672	374.0	30.02	428.7	4.94	420.3	4.51
039	0.5	0.05379	0.00165	0.04306	0.00064	0.31941	0.00942	362.1	67.78	271.8	3.95	281.5	7.25
040	0.4	0.06147	0.00133	0.06789	0.00091	0.57549	0.01198	655.7	45.88	423.4	5.50	461.6	7.72
041	0.7	0.05716	0.00090	0.06987	0.00086	0.55068	0.00841	497.0	34.42	435.3	5.17	445.4	5.51
042	0.4	0.05487	0.00061	0.06958	0.00081	0.52648	0.00576	406.7	24.33	433.6	4.88	429.5	3.83
045	0.6	0.05633	0.00078	0.06921	0.00083	0.53758	0.00723	464.5	30.46	431.4	5.00	436.8	4.77
046	0.7	0.06404	0.00208	0.06329	0.00101	0.55890	0.01731	743.0	67.32	395.6	6.13	450.8	11.27
047	0.4	0.05470	0.00055	0.06707	0.00077	0.50588	0.00506	400.1	22.01	418.5	4.67	415.7	3.41
048	0.7	0.05162	0.00143	0.04185	0.00059	0.29790	0.00792	268.5	62.15	264.3	3.64	264.8	6.19
049	0.6	0.06131	0.00232	0.07062	0.00121	0.59713	0.02158	650.3	79.29	439.9	7.31	475.4	13.72
050	0.5	0.05332	0.00060	0.06724	0.00078	0.49443	0.00545	342.5	25.00	419.5	4.72	407.9	3.71
052	0.4	0.06180	0.00068	0.06547	0.00076	0.55793	0.00603	667.1	23.35	408.8	4.62	450.2	3.93
054	0.3	0.05549	0.00064	0.06711	0.00078	0.51354	0.00581	431.7	25.32	418.7	4.73	420.8	3.89
055	0.8	0.05130	0.00139	0.04344	0.00061	0.30737	0.00802	254.4	61.21	274.1	3.76	272.1	6.23
056	1.2	0.05234	0.00190	0.04381	0.00070	0.31627	0.01097	300.5	80.41	276.4	4.33	279.0	8.47
057	0.6	0.05122	0.00152	0.04087	0.00059	0.28866	0.00822	250.5	66.82	258.2	3.67	257.5	6.48
058	0.4	0.05392	0.00057	0.06609	0.00076	0.49144	0.00515	367.6	23.80	412.5	4.61	405.9	3.51
059	1.0	0.05709	0.00234	0.06654	0.00118	0.52393	0.02053	494.6	88.43	415.3	7.11	427.8	13.68
060	0.7	0.06422	0.00242	0.06769	0.00113	0.59946	0.02161	748.9	77.50	422.2	6.81	476.9	13.72
061	0.4	0.05287	0.00218	0.04101	0.00070	0.29900	0.01183	323.1	91.11	259.1	4.34	265.6	9.25
062	0.6	0.04947	0.00122	0.04092	0.00055	0.27916	0.00664	170.1	56.65	258.5	3.41	250.0	5.27
064	1.1	0.06057	0.00252	0.06771	0.00124	0.56555	0.02247	624.0	87.41	422.3	7.48	455.1	14.57
065	0.7	0.05408	0.00133	0.04129	0.00056	0.30792	0.00727	374.2	54.27	260.8	3.49	272.6	5.64
066	0.3	0.05543	0.00053	0.06540	0.00075	0.49991	0.00478	429.2	21.04	408.4	4.57	411.6	3.23
068	0.2	0.05673	0.00086	0.06196	0.00076	0.48468	0.00711	480.2	33.35	387.5	4.60	401.3	4.86

续附表 1

测点	Th/U	同位素比值						年龄 (Ma)					
		²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ
样品 N-105,1102.18 m													
069	0.7	0.05560	0.00188	0.04071	0.00064	0.31221	0.01013	436.3	73.59	257.3	3.94	275.9	7.84
070	0.9	0.05698	0.00242	0.06850	0.00121	0.53826	0.02197	490.2	91.62	427.1	7.27	437.3	14.50
072	0.8	0.05482	0.00120	0.03824	0.00051	0.28907	0.00607	404.7	47.79	241.9	3.14	257.8	4.78
073	0.4	0.05566	0.00077	0.07343	0.00090	0.56369	0.00767	438.7	30.16	456.8	5.38	453.9	4.98
074	0.4	0.05629	0.00052	0.06743	0.00079	0.52348	0.00492	463.1	20.58	420.7	4.76	427.5	3.28
075	1.2	0.05958	0.00148	0.07010	0.00099	0.57600	0.01376	588.2	53.08	436.8	5.99	461.9	8.87
076	0.4	0.05646	0.00076	0.06669	0.00081	0.51928	0.00685	469.7	29.70	416.2	4.91	424.7	4.58
077	0.6	0.05473	0.00051	0.06809	0.00080	0.51399	0.00487	401.4	20.66	424.6	4.82	421.1	3.26
078	0.4	0.05700	0.00076	0.07467	0.00091	0.58703	0.00765	490.9	29.36	464.3	5.46	469.0	4.89
079	0.4	0.05641	0.00068	0.07768	0.00094	0.60433	0.00725	467.8	26.81	482.2	5.61	480.0	4.59
081	0.7	0.05561	0.00192	0.04335	0.00069	0.33249	0.01097	436.7	74.85	273.5	4.28	291.5	8.36
082	0.7	0.06583	0.00314	0.06829	0.00141	0.61996	0.02809	800.9	96.85	425.8	8.48	489.8	17.61
083	0.5	0.05393	0.00078	0.07298	0.00090	0.54285	0.00774	368.1	31.99	454.1	5.44	440.3	5.09
084	0.6	0.05834	0.00080	0.06839	0.00085	0.55024	0.00744	541.7	30.56	426.4	5.10	445.2	4.87
085	0.8	0.05452	0.00179	0.07175	0.00112	0.53956	0.01704	392.7	71.20	446.7	6.76	438.1	11.24
086	0.3	0.05644	0.00050	0.06820	0.00081	0.53087	0.00478	468.9	19.49	425.3	4.89	432.4	3.17
087	0.2	0.05514	0.00058	0.07195	0.00087	0.54724	0.00582	417.9	23.32	447.9	5.22	443.2	3.82
088	0.4	0.05297	0.00162	0.04632	0.00070	0.33842	0.00994	327.3	67.88	291.9	4.31	296.0	7.54
089	0.9	0.05430	0.00134	0.04243	0.00060	0.31777	0.00758	383.5	54.53	267.9	3.70	280.2	5.84
090	0.3	0.05408	0.00086	0.07285	0.00092	0.54339	0.00843	374.1	35.35	453.3	5.55	440.7	5.54
092	0.6	0.06520	0.00111	0.07575	0.00097	0.68114	0.01119	780.9	35.29	470.7	5.81	527.5	6.76
093	0.2	0.06841	0.00086	0.13306	0.00162	1.25530	0.01554	880.9	25.76	805.3	9.23	825.8	7.00
094	0.6	0.05890	0.00206	0.07036	0.00115	0.57150	0.01920	563.4	74.57	438.3	6.92	459.0	12.40
096	0.2	0.06331	0.00096	0.07179	0.00089	0.62678	0.00924	718.5	31.87	446.9	5.37	494.1	5.77
097	0.7	0.05703	0.00080	0.07321	0.00089	0.57578	0.00792	491.9	31.03	455.5	5.36	461.7	5.10
098	0.4	0.05714	0.00112	0.07541	0.00098	0.59428	0.01128	496.5	42.54	468.7	5.89	473.6	7.18
099	0.8	0.05604	0.00189	0.07207	0.00114	0.55695	0.01806	453.5	73.20	448.6	6.85	449.5	11.78
100	0.6	0.05543	0.00062	0.07147	0.00084	0.54629	0.00604	429.2	24.51	445.0	5.08	442.6	3.97
102	1.1	0.08910	0.00139	0.24579	0.00326	3.02008	0.04608	1406.2	29.58	1416.7	16.85	1412.7	11.64
103	0.6	0.06000	0.00155	0.07037	0.00101	0.58224	0.01443	603.5	54.93	438.4	6.07	465.9	9.26
104	0.3	0.05713	0.00078	0.06675	0.00081	0.52589	0.00704	496.0	30.05	416.5	4.88	429.1	4.68
105	0.6	0.05396	0.00144	0.04469	0.00063	0.33252	0.00852	369.0	58.86	281.8	3.90	291.5	6.49
106	0.4	0.05777	0.00075	0.06987	0.00084	0.55668	0.00710	520.9	28.45	435.4	5.06	449.4	4.63
109	0.1	0.06082	0.00072	0.06070	0.00072	0.50911	0.00591	632.8	25.18	379.9	4.38	417.8	3.98
110	0.5	0.05668	0.00069	0.07022	0.00083	0.54888	0.00658	478.4	26.90	437.5	5.03	444.3	4.31
111	0.9	0.05369	0.00132	0.04272	0.00058	0.31626	0.00747	358.0	54.52	269.6	3.60	279.0	5.77
112	1.0	0.05394	0.00152	0.06962	0.00101	0.51783	0.01408	368.3	62.24	433.9	6.08	423.7	9.42
113	0.5	0.05666	0.00059	0.07004	0.00082	0.54728	0.00568	477.8	23.02	436.4	4.93	443.2	3.73
114	1.0	0.16247	0.00134	0.45647	0.00551	10.22687	0.08746	2481.5	13.87	2424.0	24.39	2455.5	7.91
115	0.9	0.05273	0.00104	0.04501	0.00058	0.32731	0.00626	317.2	44.22	283.8	3.55	287.5	4.79
116	0.8	0.06085	0.00169	0.04334	0.00063	0.36366	0.00969	634.0	58.83	273.5	3.89	314.9	7.21
119	0.8	0.05860	0.00087	0.07010	0.00086	0.56646	0.00816	552.3	31.94	436.8	5.15	455.7	5.29
120	0.4	0.05500	0.00063	0.06915	0.00081	0.52449	0.00597	412.3	25.22	431.0	4.90	428.1	3.97
样品 N-109,2281.48 m													
001	0.6	0.16098	0.00167	10.85527	0.11466	0.48886	0.00622	2466.0	17.44	2510.8	9.82	2565.7	26.92
003	0.7	0.10877	0.00250	4.67099	0.10374	0.31134	0.00504	1778.8	41.32	1762.1	18.58	1747.3	24.77
004	0.5	0.05709	0.00092	0.56666	0.00884	0.07196	0.00088	494.3	35.18	455.9	5.73	448.0	5.32
005	0.5	0.05410	0.00098	0.32704	0.00576	0.04382	0.00055	375.0	40.47	287.3	4.40	276.5	3.38
006	1.0	0.13527	0.00166	6.73825	0.08172	0.36112	0.00468	2167.5	21.23	2077.7	10.72	1987.5	22.16
007	0.5	0.18429	0.00132	13.40615	0.10089	0.52738	0.00619	2691.9	11.75	2708.7	7.11	2730.4	26.11
010	0.8	0.05951	0.00119	0.43250	0.00829	0.05269	0.00068	585.7	42.66	365.0	5.88	331.0	4.17
012	0.2	0.06836	0.00095	0.68840	0.00931	0.07301	0.00089	879.4	28.59	531.8	5.60	454.3	5.32

地 质 学 报													
http://www.geojournals.cn/dzxb/ch/index.aspx													
2024 年													
续附表 1													
测点	Th/U	同位素比值						年龄 (Ma)					
		²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ
样品 N-109.2281.48 m													
013	0.3	0.05586	0.00130	0.52329	0.01169	0.06791	0.00091	446.6	50.51	427.3	7.79	423.6	5.52
014	0.4	0.12294	0.00088	6.57137	0.04917	0.38752	0.00447	1999.4	12.69	2055.5	6.59	2111.3	20.75
015	0.6	0.05818	0.00097	0.31568	0.00509	0.03934	0.00049	536.1	36.66	278.6	3.93	248.7	3.01
016	0.8	0.11284	0.00116	5.15022	0.05292	0.33090	0.00402	1845.7	18.48	1844.4	8.74	1842.8	19.47
017	0.6	0.05961	0.00135	0.63720	0.01385	0.07751	0.00105	589.3	48.27	500.6	8.59	481.2	6.25
018	0.9	0.15433	0.00147	9.70608	0.09395	0.45601	0.00562	2394.4	16.10	2407.3	8.91	2421.9	24.89
019	0.5	0.17463	0.00150	9.72282	0.08512	0.40368	0.00487	2602.5	14.28	2408.9	8.06	2186.0	22.38
020	0.4	0.05881	0.00086	0.57967	0.00822	0.07147	0.00086	560.0	31.43	464.3	5.28	445.0	5.20
021	0.4	0.05657	0.00121	0.36546	0.00755	0.04685	0.00061	473.9	47.34	316.3	5.61	295.1	3.78
022	0.4	0.13517	0.00095	7.18729	0.05285	0.38555	0.00444	2166.2	12.25	2134.9	6.55	2102.2	20.66
023	0.3	0.07349	0.00065	1.72421	0.01527	0.17012	0.00196	1027.5	17.67	1017.6	5.69	1012.8	10.79
024	0.6	0.06898	0.00130	0.76347	0.01385	0.08025	0.00105	898.1	38.53	576.0	7.97	497.6	6.24
025	0.4	0.05448	0.00102	0.54097	0.00984	0.07200	0.00091	391.0	41.41	439.1	6.49	448.2	5.47
027	0.6	0.13842	0.00116	7.71871	0.06604	0.40435	0.00479	2207.5	14.46	2198.8	7.69	2189.0	22.00
029	0.7	0.08964	0.00069	3.31756	0.02618	0.26835	0.00307	1417.9	14.62	1485.2	6.16	1532.4	15.63
030	0.8	0.10986	0.00121	5.08164	0.05583	0.33542	0.00413	1797.0	19.97	1833.0	9.32	1864.6	19.93
031	0.5	0.05231	0.00108	0.25858	0.00513	0.03584	0.00046	298.9	46.21	233.5	4.14	227.0	2.85
033	2.2	0.11910	0.00118	5.96095	0.05922	0.36293	0.00440	1942.8	17.59	1970.2	8.64	1996.1	20.80
034	0.5	0.05275	0.00097	0.30052	0.00536	0.04131	0.00052	317.9	41.33	266.8	4.19	261.0	3.19
035	0.2	0.11762	0.00072	5.94072	0.03866	0.36626	0.00413	1920.4	10.94	1967.2	5.66	2011.8	19.51
036	0.7	0.11357	0.00188	5.12652	0.08264	0.32734	0.00459	1857.3	29.56	1840.5	13.70	1825.5	22.28
037	0.5	0.10714	0.00138	4.71708	0.05992	0.31926	0.00408	1751.4	23.36	1770.3	10.64	1786.1	19.91
038	1.9	0.16081	0.00103	10.06182	0.06795	0.45375	0.00518	2464.2	10.74	2440.5	6.24	2411.9	22.97
039	0.5	0.05585	0.00073	0.54944	0.00702	0.07135	0.00084	445.9	28.35	444.6	4.60	444.3	5.08
040	3.0	0.06876	0.00130	1.34465	0.02452	0.14182	0.00187	891.5	38.53	865.2	10.62	855.0	10.55
041	0.5	0.10747	0.00069	5.05362	0.03416	0.34102	0.00386	1756.9	11.63	1828.4	5.73	1891.6	18.54
043	0.4	0.12011	0.00106	5.79982	0.05162	0.35017	0.00414	1957.9	15.63	1946.4	7.71	1935.4	19.78
045	0.7	0.05601	0.00072	0.55372	0.00697	0.07169	0.00085	452.6	27.95	447.4	4.56	446.3	5.09
046	0.6	0.06647	0.00112	1.22371	0.02001	0.13352	0.00169	821.1	34.87	811.5	9.14	807.9	9.64
047	0.8	0.05372	0.00175	0.33474	0.01043	0.04519	0.00069	359.2	71.55	293.2	7.93	284.9	4.23
050	0.6	0.05463	0.00104	0.31618	0.00579	0.04197	0.00053	397.1	41.71	279.0	4.47	265.1	3.27
051	0.4	0.06993	0.00073	1.56502	0.01619	0.16231	0.00190	926.2	21.30	956.5	6.41	969.6	10.52
052	0.5	0.05174	0.00079	0.28403	0.00423	0.03981	0.00048	273.8	34.71	253.9	3.34	251.7	2.96
054	0.8	0.05299	0.00151	0.32640	0.00890	0.04467	0.00064	328.3	63.22	286.8	6.81	281.7	3.93
057	0.6	0.05277	0.00128	0.27038	0.00629	0.03716	0.00050	318.9	54.02	243.0	5.03	235.2	3.10
059	0.7	0.11882	0.00080	5.70838	0.04004	0.34841	0.00396	1938.6	11.99	1932.6	6.06	1927.0	18.95
060	0.7	0.11741	0.00135	5.46628	0.06227	0.33764	0.00422	1917.2	20.50	1895.3	9.78	1875.3	20.34
061	1.2	0.12125	0.00129	5.30170	0.05601	0.31713	0.00389	1974.6	18.88	1869.1	9.02	1775.7	19.04
064	0.5	0.06044	0.00105	0.64413	0.01077	0.07729	0.00097	619.5	36.95	504.9	6.65	479.9	5.79
065	0.4	0.11544	0.00070	5.69920	0.03666	0.35805	0.00403	1886.8	10.89	1931.2	5.56	1972.9	19.12
066	0.8	0.11017	0.00176	4.49219	0.06992	0.29574	0.00405	1802.1	28.86	1729.5	12.93	1670.1	20.15
067	0.6	0.11494	0.00073	5.83841	0.03900	0.36840	0.00416	1879.0	11.40	1952.1	5.79	2021.9	19.61
068	0.5	0.05825	0.00086	0.55951	0.00801	0.06966	0.00084	538.6	32.56	451.2	5.21	434.1	5.07
069	0.5	0.14576	0.00091	7.45771	0.04912	0.37109	0.00420	2296.7	10.72	2167.9	5.90	2034.5	19.76
070	1.2	0.06469	0.00077	0.78402	0.00913	0.08790	0.00103	764.4	24.88	587.8	5.19	543.1	6.13
071	0.9	0.10910	0.00095	5.09002	0.04485	0.33837	0.00397	1784.4	15.83	1834.4	7.48	1878.8	19.12
072	0.5	0.15025	0.00101	9.19960	0.06459	0.44409	0.00509	2348.7	11.42	2358.1	6.43	2368.9	22.71
073	0.8	0.11012	0.00065	4.81941	0.03003	0.31744	0.00355	1801.3	10.63	1788.3	5.24	1777.2	17.39
074	0.5	0.06494	0.00105	0.58383	0.00910	0.06521	0.00081	772.4	33.73	466.9	5.84	407.2	4.89
076	0.9	0.16258	0.00098	10.43701	0.06672	0.46561	0.00526	2482.7	10.09	2474.3	5.92	2464.3	23.16
078	0.4	0.06539	0.00093	0.73092	0.01006	0.08107	0.00098	787.0	29.57	557.1	5.90	502.5	5.85
081	1.5	0.10314	0.00113	4.10502	0.04458	0.28866	0.00351	1681.4	20.15	1655.3	8.87	1634.9	17.56

续附表 1

测点	Th/U	同位素比值						年龄 (Ma)					
		²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ
		样品 N-109,2281.48 m											
082	0.5	0.05386	0.00118	0.29223	0.00617	0.03936	0.00051	364.9	48.85	260.3	4.85	248.8	3.18
083	0.4	0.14386	0.00100	8.40560	0.06098	0.42378	0.00487	2274.2	11.98	2275.8	6.58	2277.6	22.06
084	0.4	0.06732	0.00068	1.29763	0.01292	0.13981	0.00162	847.6	20.76	844.7	5.71	843.6	9.15
085	0.9	0.14896	0.00088	8.34820	0.05263	0.40648	0.00458	2334.0	10.15	2269.6	5.72	2198.8	20.97
088	0.6	0.12044	0.00074	6.25248	0.04071	0.37652	0.00424	1962.8	10.97	2011.8	5.70	2060.0	19.86
089	0.5	0.05966	0.00092	0.20117	0.00298	0.02446	0.00030	591.1	32.96	186.1	2.52	155.8	1.86
090	0.6	0.05933	0.00223	0.35609	0.01274	0.04353	0.00072	579.2	79.49	309.3	9.54	274.7	4.48
091	0.6	0.05423	0.00105	0.31782	0.00590	0.04251	0.00054	380.4	42.75	280.2	4.55	268.4	3.32
092	0.6	0.11109	0.00085	4.73180	0.03681	0.30895	0.00355	1817.3	13.79	1772.9	6.52	1735.5	17.48
094	1.2	0.10418	0.00126	4.51201	0.05369	0.31414	0.00392	1699.9	22.07	1733.2	9.89	1761.0	19.22
095	0.7	0.04970	0.00126	0.25309	0.00619	0.03694	0.00050	181.0	58.20	229.1	5.02	233.8	3.10
096	0.4	0.05734	0.00109	0.59787	0.01093	0.07563	0.00096	504.1	41.63	475.9	6.94	470.0	5.76
097	0.5	0.06289	0.00105	0.40771	0.00656	0.04702	0.00058	704.6	35.26	347.2	4.73	296.2	3.59
098	0.8	0.16336	0.00125	9.77256	0.07666	0.43390	0.00509	2490.8	12.81	2413.6	7.23	2323.3	22.86
099	0.8	0.10967	0.00112	5.05303	0.05160	0.33420	0.00404	1793.9	18.58	1828.3	8.66	1858.7	19.50
100	0.5	0.05757	0.00057	0.57991	0.00566	0.07306	0.00083	513.2	21.29	464.4	3.64	454.6	5.01
101	1.2	0.06016	0.00116	0.41506	0.00767	0.05004	0.00064	609.5	41.12	352.5	5.50	314.8	3.93
103	0.4	0.05706	0.00076	0.67367	0.00879	0.08563	0.00101	493.3	29.58	522.9	5.33	529.7	6.03
104	0.5	0.05336	0.00122	0.28190	0.00620	0.03832	0.00051	343.9	51.03	252.2	4.91	242.4	3.14
106	0.5	0.11411	0.00105	5.12232	0.04704	0.32560	0.00385	1865.8	16.46	1839.8	7.80	1817.0	18.73
108	0.3	0.15920	0.00102	10.26002	0.06924	0.46745	0.00532	2447.2	10.82	2458.5	6.24	2472.4	23.38
110	2.0	0.11292	0.00114	5.23875	0.05256	0.33650	0.00406	1847.0	18.11	1858.9	8.55	1869.8	19.56
111	0.5	0.05480	0.00124	0.43092	0.00935	0.05704	0.00076	403.9	49.43	363.8	6.63	357.6	4.61
112	0.7	0.05937	0.00150	0.39788	0.00963	0.04861	0.00068	580.8	54.10	340.1	6.99	306.0	4.17
114	0.6	0.05926	0.00120	0.56386	0.01094	0.06902	0.00090	576.7	43.30	454.0	7.10	430.2	5.40
116	0.4	0.15660	0.00090	10.35212	0.06372	0.47948	0.00538	2419.3	9.76	2466.8	5.70	2525.0	23.45
117	1.3	0.11853	0.00112	5.83445	0.05527	0.35703	0.00427	1934.2	16.83	1951.5	8.21	1968.1	20.27
118	0.6	0.10535	0.00163	4.16379	0.06267	0.28668	0.00385	1720.4	28.21	1666.9	12.32	1624.9	19.29
119	0.6	0.17589	0.00117	12.20839	0.08506	0.50344	0.00578	2614.5	11.01	2620.6	6.54	2628.6	24.80
120	0.5	0.05548	0.00094	0.28273	0.00465	0.03697	0.00045	431.3	37.02	252.8	3.68	234.0	2.80
样品 YIT-1,3955.95 m													
001	0.8	0.10585	0.00253	4.61400	0.10690	0.31618	0.00524	1729.1	43.22	1751.8	19.34	1771.1	25.67
002	1.2	0.05280	0.00109	0.45049	0.00902	0.06189	0.00080	320.1	46.31	377.6	6.31	387.1	4.85
003	0.7	0.05310	0.00068	0.29492	0.00371	0.04029	0.00047	333.1	28.76	262.4	2.91	254.6	2.93
005	0.4	0.05730	0.00081	0.43120	0.00590	0.05458	0.00065	502.8	30.64	364.0	4.19	342.6	3.99
006	0.5	0.09515	0.00077	2.94335	0.02426	0.22438	0.00259	1531.1	15.25	1393.1	6.25	1305.0	13.62
007	0.4	0.05610	0.00179	0.41613	0.01278	0.05380	0.00080	456.0	69.33	353.3	9.17	337.8	4.88
008	0.5	0.05529	0.00077	0.59167	0.00806	0.07762	0.00093	423.7	30.68	471.9	5.14	481.9	5.55
009	0.1	0.07161	0.00054	1.47207	0.01144	0.14912	0.00169	974.8	15.42	919.0	4.70	896.0	9.49
010	0.3	0.06306	0.00103	0.63170	0.00998	0.07266	0.00090	710.3	34.42	497.2	6.21	452.2	5.43
014	0.5	0.05511	0.00088	0.51604	0.00798	0.06793	0.00083	416.5	34.96	422.5	5.34	423.7	5.01
016	0.4	0.05737	0.00094	0.57940	0.00919	0.07326	0.00090	505.2	35.40	464.1	5.91	455.8	5.42
017	0.5	0.10977	0.00135	4.36536	0.05271	0.28848	0.00363	1795.5	22.25	1705.8	9.97	1633.9	18.16
018	0.3	0.05179	0.00137	0.35688	0.00907	0.04998	0.00069	276.2	59.38	309.9	6.79	314.4	4.26
019	0.3	0.06048	0.00081	0.66754	0.00871	0.08007	0.00096	620.7	28.64	519.2	5.31	496.5	5.71
020	0.4	0.05362	0.00064	0.49125	0.00581	0.06645	0.00078	355.2	26.90	405.8	3.95	414.7	4.69
021	0.3	0.07083	0.00053	1.34896	0.01037	0.13816	0.00156	952.4	15.32	867.1	4.48	834.2	8.86
022	0.5	0.08374	0.00120	2.25972	0.03151	0.19575	0.00247	1286.3	27.74	1199.8	9.82	1152.5	13.30
023	0.5	0.05645	0.00063	0.52817	0.00577	0.06787	0.00079	469.5	24.53	430.6	3.84	423.3	4.75
024	0.7	0.05777	0.00069	0.67067	0.00786	0.08421	0.00099	520.8	26.18	521.1	4.78	521.2	5.87
025	0.9	0.05307	0.00158	0.29109	0.00831	0.03979	0.00058	331.9	66.23	259.4	6.53	251.5	3.60
026	0.6	0.05105	0.00104	0.28266	0.00555	0.04017	0.00051	243.0	46.28	252.8	4.40	253.9	3.17

地 质 学 报													
http://www.geojournals.cn/dzxb/ch/index.aspx													
2024 年													
续附表 1													
测点	Th/U	同位素比值						年龄 (Ma)					
		²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ
样品 YIT-1.3955.95 m													
027	0.7	0.05478	0.00142	0.52789	0.01312	0.06991	0.00098	403.1	56.11	430.4	8.72	435.6	5.89
028	0.4	0.19631	0.00141	13.03691	0.09754	0.48172	0.00565	2795.8	11.70	2682.3	7.06	2534.8	24.58
029	0.6	0.07864	0.00118	2.46871	0.03622	0.22771	0.00290	1163.2	29.53	1262.9	10.60	1322.5	15.23
031	0.4	0.06738	0.00136	0.69297	0.01340	0.07460	0.00099	849.5	41.48	534.6	8.04	463.8	5.93
032	0.3	0.06923	0.00074	1.36877	0.01440	0.14343	0.00168	905.5	21.79	875.6	6.17	864.0	9.45
033	0.6	0.05759	0.00085	0.34844	0.00500	0.04389	0.00053	514.0	32.53	303.5	3.76	276.9	3.26
036	0.4	0.05410	0.00137	0.40082	0.00977	0.05375	0.00074	374.9	56.05	342.2	7.09	337.5	4.54
037	0.3	0.06889	0.00056	1.37036	0.01127	0.14430	0.00164	895.4	16.70	876.3	4.83	868.9	9.24
038	0.1	0.10994	0.00084	4.80325	0.03737	0.31692	0.00365	1798.4	13.79	1785.5	6.54	1774.7	17.85
039	0.9	0.11061	0.00099	5.27810	0.04769	0.34614	0.00409	1809.5	16.19	1865.3	7.71	1916.2	19.58
040	0.4	0.07136	0.00201	1.45256	0.03908	0.14767	0.00231	967.6	56.32	910.9	16.18	887.9	12.99
041	0.4	0.05678	0.00065	0.65333	0.00738	0.08346	0.00097	482.4	25.41	510.5	4.53	516.8	5.78
043	0.3	0.14555	0.00081	7.77723	0.04627	0.38761	0.00434	2294.3	9.48	2205.6	5.35	2111.7	20.14
047	0.4	0.05427	0.00124	0.41623	0.00913	0.05563	0.00074	382.3	50.32	353.3	6.54	349.0	4.52
049	0.6	0.06620	0.00128	1.07737	0.02007	0.11806	0.00155	812.6	39.98	742.3	9.81	719.4	8.96
050	0.8	0.05517	0.00110	0.29434	0.00566	0.03870	0.00049	418.8	43.46	262.0	4.44	244.8	3.07
051	0.7	0.06664	0.00109	0.59206	0.00933	0.06445	0.00080	826.6	33.88	472.2	5.95	402.6	4.87
053	0.6	0.05322	0.00064	0.50407	0.00594	0.06871	0.00080	338.1	26.87	414.5	4.01	428.4	4.83
055	0.6	0.08274	0.00094	2.64395	0.02971	0.23180	0.00278	1263.1	21.98	1313.0	8.28	1343.9	14.57
056	0.3	0.10929	0.00073	4.49396	0.03130	0.29829	0.00338	1787.5	12.22	1729.9	5.78	1682.8	16.78
057	0.4	0.05529	0.00098	0.57296	0.00985	0.07517	0.00094	423.7	38.62	459.9	6.36	467.2	5.63
059	0.5	0.06204	0.00163	0.36201	0.00907	0.04233	0.00060	675.6	55.29	313.7	6.76	267.2	3.73
060	0.4	0.05511	0.00063	0.50601	0.00569	0.06661	0.00077	416.5	25.16	415.8	3.83	415.7	4.67
062	0.7	0.04931	0.00089	0.27077	0.00474	0.03983	0.00049	162.7	41.75	243.3	3.79	251.8	3.04
063	0.4	0.05549	0.00084	0.53158	0.00781	0.06949	0.00084	431.8	32.88	432.9	5.17	433.1	5.06
064	0.6	0.05654	0.00102	0.59592	0.01035	0.07645	0.00096	473.0	39.72	474.6	6.59	474.9	5.75
065	0.5	0.05744	0.00082	0.64987	0.00906	0.08206	0.00099	508.2	31.02	508.4	5.58	508.4	5.87
066	0.2	0.10816	0.00070	4.84334	0.03283	0.32481	0.00367	1768.7	11.86	1792.5	5.70	1813.2	17.84
068	0.7	0.06248	0.00094	0.56586	0.00819	0.06570	0.00080	690.5	31.68	455.3	5.31	410.2	4.83
069	0.9	0.05377	0.00118	0.30768	0.00650	0.04151	0.00054	361.2	48.96	272.4	5.05	262.2	3.36
070	0.5	0.05155	0.00081	0.28828	0.00437	0.04057	0.00049	265.3	35.49	257.2	3.44	256.4	3.02
071	0.5	0.06115	0.00123	0.38665	0.00742	0.04587	0.00059	644.4	42.50	331.9	5.43	289.1	3.66
072	0.2	0.10866	0.00062	4.42408	0.02686	0.29535	0.00329	1776.9	10.41	1716.9	5.03	1668.2	16.39
074	0.3	0.05584	0.00081	0.36362	0.00511	0.04723	0.00056	445.7	31.55	314.9	3.81	297.5	3.47
075	1.1	0.16361	0.00118	9.89667	0.07373	0.43876	0.00509	2493.3	12.10	2425.2	6.87	2345.1	22.83
077	0.6	0.05734	0.00099	0.34556	0.00575	0.04371	0.00054	504.2	37.33	301.4	4.34	275.8	3.34
078	0.6	0.05600	0.00094	0.32702	0.00532	0.04236	0.00052	451.9	36.73	287.3	4.07	267.5	3.22
079	0.5	0.05913	0.00163	0.40405	0.01062	0.04957	0.00072	571.8	58.85	344.6	7.68	311.9	4.41
080	0.5	0.05995	0.00080	0.55908	0.00725	0.06765	0.00080	601.7	28.63	450.9	4.72	422.0	4.85
081	0.2	0.05464	0.00089	0.31357	0.00493	0.04163	0.00051	397.4	35.77	276.9	3.81	262.9	3.13
082	0.1	0.11200	0.00080	4.39008	0.03195	0.28432	0.00323	1832.1	12.84	1710.5	6.02	1613.1	16.23
084	0.5	0.05635	0.00075	0.28361	0.00368	0.03651	0.00043	465.4	29.57	253.5	2.91	231.1	2.68
085	0.4	0.07165	0.00087	0.84322	0.00994	0.08536	0.00101	976.1	24.59	620.9	5.48	528.0	6.00
086	0.5	0.06716	0.00072	0.71789	0.00757	0.07753	0.00090	842.9	22.30	549.4	4.48	481.4	5.38
087	0.9	0.05530	0.00139	0.38841	0.00937	0.05094	0.00069	424.3	54.58	333.2	6.85	320.3	4.26
088	0.3	0.05808	0.00071	0.32725	0.00391	0.04087	0.00048	532.2	27.16	287.5	2.99	258.2	2.95
093	0.4	0.06325	0.00075	0.51453	0.00597	0.05900	0.00069	716.8	25.13	421.5	4.00	369.5	4.20
095	0.3	0.06316	0.00055	0.64917	0.00561	0.07454	0.00084	713.8	18.32	508.0	3.45	463.5	5.06
097	0.2	0.09747	0.00111	3.82604	0.04281	0.28472	0.00347	1576.2	21.13	1598.2	9.01	1615.1	17.41
098	0.5	0.07072	0.00067	1.07932	0.01011	0.11070	0.00127	949.2	19.30	743.3	4.94	676.8	7.37
099	0.5	0.05305	0.00089	0.58436	0.00953	0.07989	0.00098	330.9	37.64	467.3	6.11	495.5	5.86
101	0.8	0.15502	0.00108	9.92102	0.07194	0.46419	0.00535	2402.0	11.84	2427.5	6.69	2458.0	23.56

续附表 1

测点	Th/U	同位素比值						年龄 (Ma)					
		²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U	1σ	²⁰⁶ Pb/ ²³⁸ U	1σ
		样品 YIT-1,3955.95 m											
103	0.5	0.06316	0.00073	0.62045	0.00696	0.07125	0.00083	713.5	24.28	490.1	4.36	443.7	4.99
105	0.6	0.05978	0.00110	0.45800	0.00808	0.05557	0.00070	595.0	39.84	382.9	5.63	348.6	4.29
107	1.1	0.05490	0.00107	0.32547	0.00609	0.04300	0.00054	408.0	42.72	286.1	4.67	271.4	3.37
108	0.6	0.05425	0.00146	0.58249	0.01507	0.07788	0.00111	381.2	59.35	466.1	9.67	483.4	6.64
112	0.1	0.06630	0.00049	0.98385	0.00740	0.10763	0.00121	815.7	15.46	695.6	3.79	659.0	7.02
113	0.5	0.05663	0.00093	0.39418	0.00625	0.05048	0.00062	476.5	36.34	337.4	4.55	317.5	3.79
114	0.6	0.05007	0.00077	0.34250	0.00514	0.04961	0.00059	198.4	35.53	299.1	3.89	312.1	3.65
115	0.3	0.05350	0.00082	0.48693	0.00719	0.06601	0.00079	349.8	34.07	402.8	4.91	412.1	4.80
117	0.4	0.06207	0.00116	0.58701	0.01051	0.06858	0.00088	676.7	39.46	469.0	6.72	427.6	5.29
119	0.4	0.05068	0.00132	0.32431	0.00808	0.04641	0.00064	226.1	58.96	285.2	6.20	292.5	3.93
120	0.8	0.05650	0.00111	0.61028	0.01151	0.07833	0.00100	471.5	43.22	483.7	7.26	486.1	6.01