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东昆仑东段下三叠统洪水川组砾岩源区研究:来自砾岩特征及锆石U-Pb年龄的证据

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提要:东昆仑东段下三叠统洪水川组主要分布于东昆南断裂带和东昆中断裂带之间的红水川—托索河一带。笔者分别对出露于宝日禾日俄地区和可可沙地区洪水川组底部层位砾岩的砾石成分、磨圆度和粒度进行综合统计对比分析。结果显示:可可沙地区砾石成分主要为灰岩和变质岩,宝日禾日俄地区砾石成分主要为花岗岩和变质岩。从宝日禾日俄地区花岗岩砾石中获得的LA-ICP-Ma锆石U-Pb年龄为(464.9±9.3) Ma(MSWD=2.9)。砾石特征表明可可沙地区物源来自可可沙地区下伏地层哈拉郭勒组,而宝日禾日俄地区物源主要为早古生代岩浆岩,表明洪水川组底部层位物源主要为加里东期弧岩浆岩,而晚滇西—印支期弧岩浆岩并未提供沉积物质。结合前人资料认为,布青山—阿尼玛卿古特提斯洋于晚二叠世开始向北俯冲,洪水川组为一套弧前盆地的沉积产物,早三叠世早期布青山—阿尼玛卿古特提斯洋处于向北俯冲初始阶段。

关 键 词:东昆仑东段;洪水川组;砾岩;锆石U-Pb年龄;布青山—阿尼玛卿古特提斯洋

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Conglomerate source and source area property of Lower Triassic Hongshuichuan Formation in the East Kunlun Mountains: Evidence from conglomerate characteristics and U-Pb dating

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Abstract: The lower Hongshuichuan Formation is mainly distributed around Tuosuo River between Middle Kunlun orogen and South Kunlun orogen in eastern Kunlun Mountains. In this paper, the authors made a comparative study of the conglomerate of Lower Hongshuichuan Formation distributed in Baoriherie area and Kekesha area in components, psephicity and granularity of gravel. The results show that the main components of the gravel are limestone and metamorphic rock in Kekesha area. The main components of gravel in Baoriherie area are granite and metamorphic rock. LA−ICP−MS zircon U−Pb dating of granite yielded magmatic crystallization age of (464.9±9.3) Ma (MSWD=2.9) from Baoriherie area. The characteristics of gravel show that the source of the Kekesha area is Halaguole Formation in Qingshuiquan area, whereas the source of the Baoriherie area is Caledonian magmatic rock. These data indicate that the source of Lower Hongshuichuan Formation is Caledonian magmatic rock rather than arc granite of late Hercynian—Indosinian period. Combined with previous data, the authors hold that the Buqingshan—A`nimaqing Ocean began the northward subduction in late Permian, and the Hongshuichuan Formation was a set of sedimentary products in the fore−arc basin. It is held that Buqingshan−A`nimaqing Ocean began its subduction in early Triassic.

Key words: East Kunlun; Hongshuichuan Formation; conglomerate; Buqingshan—A’nimaqing Ocean

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1 引 言

对于沉积盆地砾岩的研究一直以来都是国内外地质学家关注的重点(何培元等,1982; 王凤林等,2003; 刘运明等,2007;章泽军等,1995; 申顺喜等,1995;黄培华等,1994; Mc Lane et al.,1995; 温泉波等,2008; 崔秉荃等,1991; 韩建恩等,2005; 朱大岗等,2002; 郑德文等,2006; 林秀斌等,2009; 李勇等,2006; 黎兵等,2007; Aileen et al.,2002; Dario et al.,2010; 梅惠等,2011)。砾岩层携带的信息,一方面能够为盆地物源分析、确定沉积环境、恢复盆地古地理提供重要线索(Krumbein et al.,1934; 赵学钦等,2012; Boggs et al.,1969);另一方面能够反映构造隆升过程及砾石剥蚀搬运历史(Frostick et al.,1980; Schleyer et al.,1987; Wolcott et al.,1988; Sun et al.,2002;刘聃等,2012; 傅开道等,2006)。

东昆仑造山带是横亘于中国“中央造山系”的重要组成部分,位于中央造山系中西段。近些年来的研究结果(潘裕生等,1996; 殷鸿福等,1997;解玉月等,1998;王国灿等,1999,2004; 朱云海等,1999; 王秉璋等,2000; 姜春发等,2000; 杨经绥等,2003; 龙晓平等,2004; 李怀坤等,2006; 许志琴等,2006; 莫宣学等,2007; 陈能松等,2007; 陈能松等,2008; 张亚峰等,2010; 陈守建等,2010; 陈有炘等,2011; 刘战庆等,2011a,2011b; 李瑞保等, 2012,2015;陈有炘等,2015)显示,东昆仑造山带是一多旋回的复合大陆造山带,至少经历了新元古代—早古生代和晚古生代—早中生代两期洋陆构造旋回。大部分学者认为早古生代东昆仑洋从早中寒武世以来发生了复杂的俯冲作用,而于晚奥陶世开始碰撞造山,至志留纪晚期完成碰撞造山过程,以晚志留—早泥盆世牦牛山组磨拉石建造标志原特提斯构造旋回的结束和古特提斯构造旋回的开始。晚古生代以来,晚二叠世格曲组角度不整合于晚石炭统浩特洛哇组及下伏地层之上,代表布青山—阿尼玛卿古特提斯洋向北俯冲的开始(李瑞保等,2012)。而基于二叠纪以来的多数岩浆岩资料显示(张刚等,2012; 王学良等,2015; 孙雨等, 2009; Xia et al.,2015),东昆仑东段于晚二叠世已进入俯冲造山阶段,而于晚三叠世进入后碰撞造山阶段。

分布于东昆南构造带南坡地区红水川—托索河地区的下三叠统洪水川组是东昆仑造山带进入碰撞造山之前最晚期洋陆转换的沉积物。其沉积厚度大且相对连续的特征,成为众多学者研究东昆仑造山带构造演化的重点(殷鸿福等,2003; 徐强等,1998; 田军等,2001; 李利平等, 2002; 蔡雄飞等,2008; 闫臻等,2008; 杨忠智,2012; 刘图杰,2015;岳远刚,2014)。前人对托索河地区洪水川组的研究,仅限于砂岩碎屑骨架、砂岩地球化学,但未对洪水川组底部砾岩层进行详细调查与研究,并缺少与可可沙地区洪水川组砾岩层的对比研究。且洪水川组沉积序列中仅底部具有砾石沉积,对于其底部砾石沉积特征的研究能够直接反映其早期物源特征,可为研究洪水川组早期源区性质提供直接证据。笔者通过统计对比宝日禾日俄地区洪水川组(南带)和可可沙地区洪水川组(北带)底部层位砾石的特征,并结合南带砾岩中花岗岩砾石LA-ICP-MS锆石U-Pb同位素年龄,确定盆地沉积物质来源及源区构造属性,进而为东昆仑造山带早三叠世早期的构造演化提供地质证据。

2 区域地质概况

东昆仑造山带位于中央造山系中西段,青藏高原东北部,东与西秦岭造山带被共和盆地相隔,西与西昆仑造山带为邻,以阿尔金左行走滑断裂相隔,南邻布青山—阿尼玛卿构造混杂岩带。结合前人研究结果(朱云海等,1999; 姜春发等,2000; 殷鸿福等,2003; 许志琴等,2007; 朱云海等,2002; 姜春发等,2002),笔者将东昆仑造山带以东昆中断裂带和东昆南断裂带为界,分为东昆北构造带、东昆南构造带和布青山—阿尼玛卿构造带。本文研究区位于东昆南构造带,主要由古—中元古代中深变质岩系、新元古代—早古生代浅变质岩系、石炭—三叠纪沉积地层和早古生代可可沙岩体组成。其中变质岩系主要分布于研究区北部地区。可可沙岩体主要分布于研究区中北部,主要为寒武纪石英闪长岩和奥陶纪花岗闪长岩。

研究区内发育的下三叠统洪水川组(T_1h),被一近东西向断层分开(图1)。断层南侧宝日禾日俄地区洪水川组(后文称为南带),沉积厚度较大,岩石组合较为齐全,岩层倾向300°~350°,倾角10°~60°,变形相对较弱。其底部与下伏地层上二叠统格曲组(P_2g)呈断层接触(区域上为平行不整合接触),顶部与上覆地层中三叠统闹仓坚沟组(T_2n)呈整合接触。断层北侧可可沙地区洪水川组(后文称为北带),岩性变化较大,厚度较小,变形强烈。其东侧与新元古界万宝沟岩群(Pt_3W)呈不整合接触,北侧与古元古界白沙河岩组(Pt_1b)或早古生代可可沙岩体呈角度不整合或断层接触。

南带洪水川组主体为粗碎屑岩、碎屑岩夹碳酸盐岩沉积组合,并进一步划分为6个岩段,由底至顶分别为红绿相间碎屑岩组合、浅灰-灰绿色碎屑岩组合、灰黑-深灰色薄层灰岩组合、灰色-灰黑色灰岩与细碎屑岩组合、深水浊积岩组合和细碎屑岩组合。其中第二段下部为一套浅灰绿色中厚层状含砾粗粒长石砂岩、灰绿色厚层状含细砾中粗粒长石砂岩夹灰色薄层状长石石英细砂岩、浅灰—灰色厚层块状砾岩,局部夹细砾岩、灰黑色薄层粉砂质泥岩夹浅灰绿色中薄层状中粗粒长石石英砂岩;该段中部为一套灰绿色中层状细粒钙质长石石英砂岩、浅灰绿色中层状细粒钙质长石石英砂岩、浅灰—灰白色薄层状泥晶灰岩、紫红色中层状铁质胶结含砾中粗粒长石石英砂岩、浅灰色厚层—巨厚层状含砾中粗粒长石石英砂岩;该段上部为一套浅灰色薄层状细粒长石石英砂岩夹灰绿色中厚层状含细粒中粗粒长石砂岩、浅灰色薄层粉砂质页岩夹灰绿色中层状中细粒长石石英砂岩。

北带洪水川组主体也为粗碎屑岩、碎屑岩夹碳酸盐岩沉积组合,并进一步划分为3个岩段,分别为a段粗碎屑岩组合,b段灰岩组合和c段细碎屑岩组合。其中a段主要为灰色—浅灰色中层状复成分砾岩、含砾粗粒长石砂岩夹有少量钙质粉砂岩及细粒砂岩,局部地段夹有少量灰白色中薄层状白云质灰岩。

3 砾石统计分析

3.1 统计方法

在野外对洪水川组砾石出露的不同层位选取测点,分别选取1 m×1 m的区域对同一砾石层位进行测量统计。统计参数包括:砾石长轴长度、短轴长度、磨圆度和砾石成分。长度测量利用刻度尺分别测量砾石长轴和短轴长度,因测点中一些砾石粒径较小,所以测量单位精确到毫米。按照长轴将砾石分为3类(Mc Lane et al.,1995),从小到大分别为

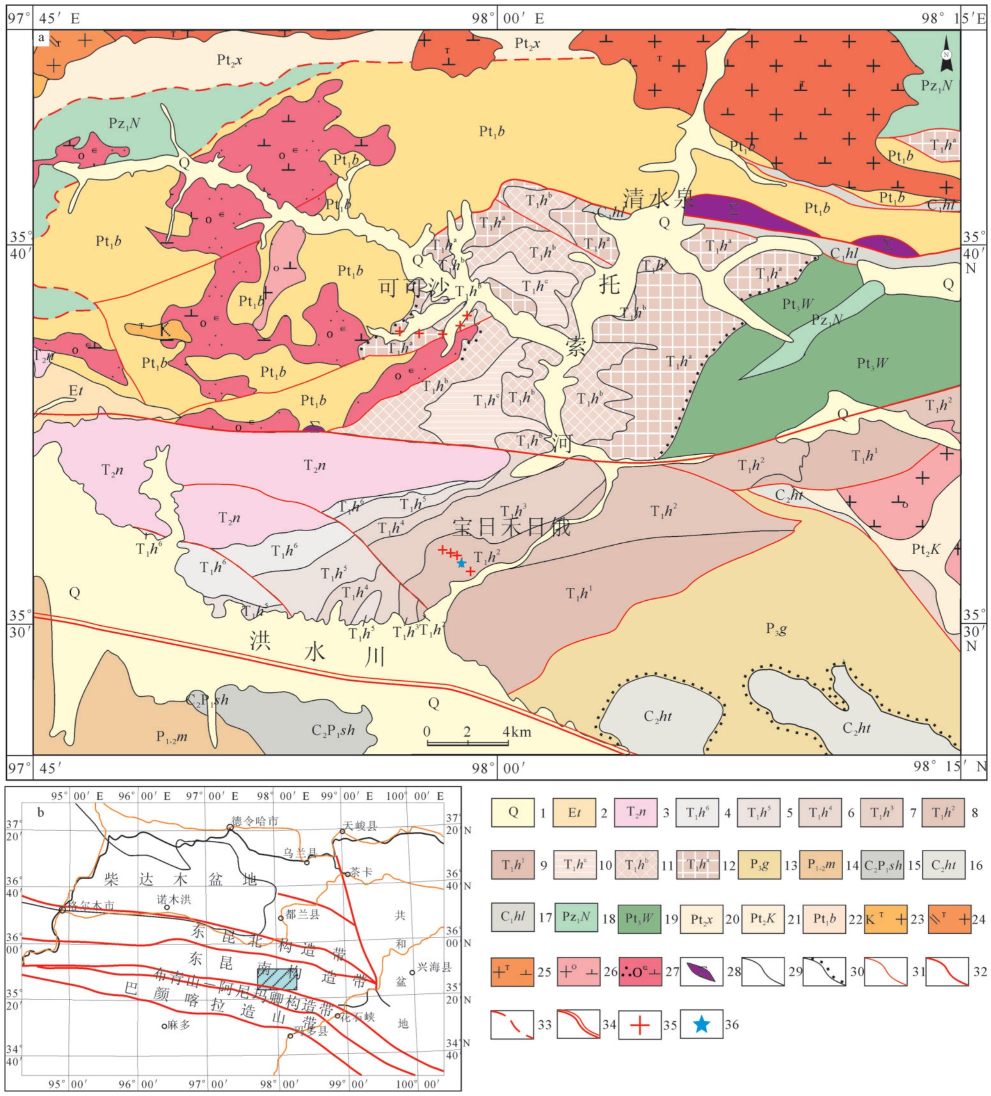

图1 东昆仑造山带东段洪水川—可可沙地区区域地质简图

1—第四系;2—古近系;3—中三叠统闹仓坚沟组;4—下三叠统洪水川组第六段;5—下三叠统洪水川组第五段;6—下三叠统洪水川组第四段;7—下三叠统洪水川组第三段;8—下三叠统洪水川组第二段;9—下三叠统洪水川组第一段;10—下三叠统洪水川组c段;11—下三叠统洪水川组b段;12—下三叠统洪水川组a段;13—上二叠统格曲组;14—中下二叠统马尔争组;15—上石炭—下二叠统树维门科组;16—上石炭统浩特洛哇组;17—下石炭统哈拉郭勒组;18—下古生界纳赤台岩群;19—新元古界万宝沟岩群;20—中元古界长城系小庙岩组;21—中元古界苦海岩群;22—古元古界白沙河岩组;23—早三叠世钾长花岗岩;24—早三叠世二长花岗岩;25—早三叠世花岗闪长岩;26—奥陶纪花岗闪长岩;27—寒武纪石英闪长岩;28—超镁铁质岩;29—地质界线;30—角度不整合;31—一般断裂;32—边界断裂;33—韧性剪切带;34—东昆南断裂带;35—砾石采集点;36—同位素年龄样品采集点

Fig.1 Simplified geological map of the Hongshuichuan Formation in the East Kulun ogrogenic belt

1–Quaternary; 2–Palaeogene; 3–Middle Triassic Naocangjiangou Formation; 4–Sixth section of Lower Triassic Hongshuichuan Formation; 5– Fifth section of Lower Triassic Hongshuichuan Formation; 6– Fourth section of Lower Triassic Hongshuichuan Formation; 7–Third section of Lower Triassic Hongshuichuan Formation; 8– Second section of Lower Triassic Hongshuichuan Formation; 9– First section of Lower Triassic Hongshuichuan Formation; 10–The c section of Lower Triassic Hongshuichuan Formation; 11–The b section of Lower Triassic Hongshuichuan Formation; 12– The a section of Lower Triassic Hongshuichuan Formation; 13–Upper Permian Gequ Formation; 14–Middle—Lower Permian Maerzheng Formation; 15–Upper Carboniferous—Middle—Lower Permian Shuweimenke Formation; 16–Upper Carboniferous Haoteluowa Formation; 17–Lower Carboniferous Halaguole Formation; 18–Lower Palaeozoic Naijtai Group; 19–Neoproterozoic Wanbaogou Group; 20–Mesoproterozoic Xiaomiao Formation; 21–Neoproterozoic Kuhai Group; 22–Paleoproterozolc Baishahe Formation; 23–Early Triassic moyite; 24– Early Triassic Monzonitei granite; 25– Early Triassic granodiorite; 26—Ordovician granodiorite; 27–Cambrian Quartz diorite; 28–Ultramafic rock; 29–Geological boundary; 30–Angular unconformity; 31–Fault; 32–Boundary fault; 33—Ductile shear zone; 34–South Kunlun orogen; 35–Gravel collection site; 36–Isotope age sampling site

小砾(D≤64 mm)、中砾(64≤D≤256 mm)和巨砾(D＞256 mm)。圆度统计利用参数X(砾石长轴长度与短轴长度的比值),将砾石分为两个类别,分别为1≤X＜2和X≥2磨圆度分为4个等级,分别为圆、次圆、次棱角、棱角,通过野外直接测量获取。砾石成分统计分为8类,分别为灰岩、砂岩、变质岩、泥质岩、硅质岩、花岗岩、流纹岩、脉石英和长石(图2)。

本次砾石测量统计点主要分为南带宝日禾日俄地区的洪水川组下部第二段和北带可可沙地区洪水川组的下部a段。其中南带宝日禾日俄地区统计点分别为:XRD−1(GPS:35°31.346′N,97°59.139′E),XRD−2(GPS: 35°31.614′N,97°58.829′E),XRD−3(GPS: 35°31.797′N,97°58.702′E),XRD−4(GPS:35°31.865′N,97°58.231′E),XRD−5(GPS:35°31.942′N,97°58.231′E),宝日禾日俄地区的测点所在层位见图3;北带可可沙地区统计点分别为:KKS−1(GPS:35°38.299′N,97°59.543′E),KKS−2(GPS:35°38.772′N, 97°59.860′E)KKS−3(GPS:35°38.611′N, 98°00.098′E),KKS−4(GPS:35°38.594′N,98°00.254′E)KKS−5(GPS:35°37.952′N,98°02.188′E),可可沙地区的测点所在层位见图4。

3.2 统计结果

南带宝日禾日俄地区洪水川组砾石成分、磨圆度、圆度和粒径的统计结果见表1和图3。从中可以看出,其砾石成分主要为花岗岩、变质岩和脉石英,占砾岩总数的80%~90%,其次为砂岩、泥质岩和硅质岩,几乎没有灰岩、流纹岩;砾石形态主要呈次棱角—次圆状,占砾石总数的60%~70%;反映圆度的参数X主要为1~2,占砾石总数的70%~80%;并且约90%的砾石为小砾。北带可可沙地区洪水川组砾石

图2 洪水川组砾岩层野外宏观照片
γ—花岗岩;m—变质岩;ss—砂岩;p—泥质岩
Fig. 2 Macroscopic characteristics of Hongshuichuan Formation conglomerate layer
γ−Granite;m−Metamorphic rock;ss−Sandstone;p−Pelite

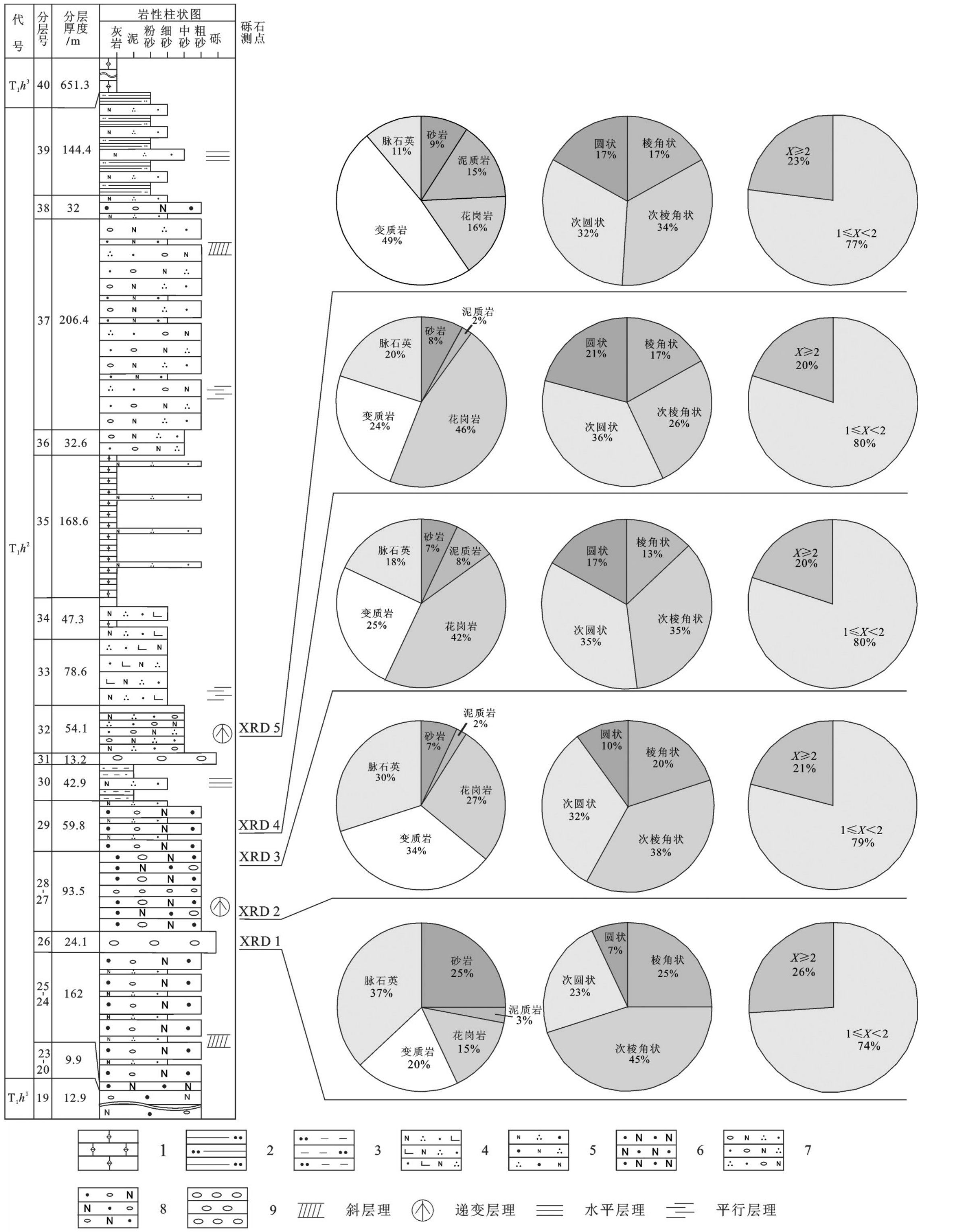

图3 南带宝日禾日俄地区洪水川组第二段地层柱状图及砾石特征

1—泥晶灰岩；2—粉砂质页岩；3—粉砂质泥岩；4—钙质长石石英砂岩；5—长石石英砂岩；6—长石砂岩；7—含砾长石石英砂岩；8—含砾长石砂岩；9—砾岩

Fig. 3 The histogram and the gravel characteristics of second section in southern Hongshuichuan Formation

1−Micrite；2−Silty shale；3−Sily mudstone；4−Calcareous feldspathic quartz arenite；5−Feldspathic quartz arenite；6−Arkose；7−Shingly feldspathic quartz arenite；8−Shingly arkose；9−Conglomerate

表1 南带宝日禾日俄地区洪水川组第二段砾石统计结果

Table 1 The statistical results of the gravel in the second section of southern Hongshuichuan Formation

统计点	XRD 1		XRD 2		XRD 3		XRD 4		XRD 5	
	F	F%	F	F%	F	F%	F	F%	F	F%
岩性										
灰岩/个	0	0	0	0	0	0	2	0	2	0
砂岩/个	213	25	44	7	39	7	50	8	86	9
泥质岩/个	22	3	13	2	47	8	0	0	0	0
硅质岩/个	0	0	0	0	5	0	11	2	138	15
花岗岩/个	139	15	158	27	253	42	307	46	154	16
流纹岩/个	0	0	0	0	0	0	0	0	0	0
变质岩/个	172	20	201	34	145	25	162	24	441	48
脉石英/个	316	37	171	30	108	18	134	20	105	11
小计	862	100	587	100	597	100	666	100	926	100
磨圆度										
棱角状	215	25	119	20	83	13	120	17	170	17
次棱角状	377	45	221	38	208	35	178	26	335	34
次圆状	198	23	184	32	204	35	246	36	306	32
圆状	55	7	58	10	105	17	145	21	169	17
小计	845	100	582	100	600	100	689	100	980	100
圆度 X（砾石长短轴直径比）										
1≤X<2	432	74	396	79	273	80	487	80	589	77
X≥2	150	26	105	21	67	20	124	20	172	23
小计	582	100	501	100	340	100	611	100	761	100
砾径										
小砾（D≤64 mm）	572	98	485	97	451	84	515	84	913	100
中砾（64<D≤256 mm）	10	2	16	3	81	15	94	15	52	0
巨砾（D>256 mm）	0	0	0	0	3	1	2	1	0	0
小计	582	100	501	100	535	100	611	100	965	100

成分、磨圆度、圆度和粒径的统计结果见表2和图4。从中可以看出，其砾石成分主要为灰岩、砂岩和变质岩，占砾石总数的80%~90%，其次为脉石英和泥质岩，几乎没有流纹岩；砾石形态主要呈次棱角状，占总数的40%~55%；反映圆度的参数X主要为1~2之间，占砾石总数的60%~70%；并且砾石几乎全为小砾类别。

综合上述统计结果，南带和北带洪水川组砾石均经过中距离搬运，砾石具有中等的成熟度，但两者的物源存在一定差异。

为了进一步研究南带和北带洪水川组砾石的沉积特征，本文对砾石测量数据进行了以下计算。先将砾石长轴长度做Φ值转换，即将数据转换成以2为底的负对数(Krumbein W C, 1934)，公式为$\Phi=-\log_2(x/x_0)$。其中，x为以毫米为单位的砾石粒径；x_0为参考粒径，等于1 mm。经过Φ转换后，再对每个测点砾石的Φ值数据进行统计频率直方图和累计频率曲线。通过累计频率曲线获得Φ_5、Φ_{16}、Φ_{25}、Φ_{50}、Φ_{75}、Φ_{84}和Φ_{95}的值（Φ_n指在累计频率曲线上n%所对应的Φ值）。然后使用这些Φ值利用Folk and Ward(1957)公式计算平均粒径（M_Z）、标准偏差（σ_1）、偏度（SK_1）和峰度（K_G）。其中$M_Z=(\Phi_{16}+\Phi_{50}+\Phi_{84})/3$，$\sigma_1=(\Phi_{84}-\Phi_{16})/4+(\Phi_{95}-\Phi_5)/6.6$，$SK_1=(\Phi_{16}+\Phi_{84}-2\Phi_{50})/(2\Phi_{84}-\Phi_{16})+(\Phi_5+\Phi_{95}-2\Phi_{50})/(2\Phi_{95}-\Phi_5)$，$K_G=(\Phi_{95}-\Phi_5)/2.44(\Phi_{75}-\Phi_{25})$。

宝日禾日俄地区洪水川组5个测点砾石长轴长度Φ值的累计频率曲线和频率直方图及计算数值见图5和表1。从累计频率曲线和频率直方图可以看出，这5个测点砾石长轴粒径均符合正态分布。

表2 北带可可沙地区洪水川组a段砾石统计结果

Table 2 The statistical results of the gravel in the a section of northern Hongshuichuan Formation

统计点	KKS 1		KKS 2		KKS 3		KKS 4		KKS 5	
	F	F%	F	F%	F	F%	F	F%	F	F%
岩性										
灰岩/个	426	75	214	47	234	49	75	25	168	42
砂岩/个	76	13	103	22	88	19	41	14	62	15
泥质岩/个	0	0	19	4	28	6	24	8	0	0
硅质岩/个	0	0	0	0	0	0	0	0	0	0
花岗岩/个	0	0	0	0	0	0	0	0	0	0
流纹岩/个	0	0	9	2	11	2	5	2	0	0
变质岩/个	64	12	81	18	85	18	118	39	138	33
脉石英/个	0	0	32	7	29	6	39	12	39	10
小计	566	100	458	100	475	100	302	100	407	100
磨圆度										
棱角状	188	35	92	20	76	16	70	21	113	27
次棱角状	282	53	210	45	262	55	132	40	179	43
次圆状	53	10	126	27	114	24	107	33	105	25
圆状	9	2	34	8	19	5	20	6	17	5
小计	532	100	462	100	471	100	329	100	414	100
圆度 X（砾石长短轴直径比）										
$1 \leqslant X < 2$	342	70	227	59	225	54	196	62	229	61
$X \geqslant 2$	146	30	160	41	188	46	121	38	148	39
小计	488	100	387	100	413	100	317	100	377	100
砾径										
小砾（$D \leqslant 64$ mm）	447	92	387	100	411	100	317	99	377	100
中砾（$64 < D \leqslant 256$ mm）	40	8	0	0	2	0	3	1	0	0
巨砾（$D > 256$ mm）	1	0	0	0	0	0	0	0	0	0
小计	488	100	387	100	413	100	320	100	377	100

从均值可以看出，砾石均属于小砾；标准偏差主要集中在0.95，仅有XRD3测点标准偏差较大为1.34。偏度主要在−0.1~ +0.1之间，呈近于对称。峰度介于0.8~1.24之间。

可可沙地区洪水川组5个测点砾石长轴长度 Φ 值的累计频率曲线和频率直方图及计算数值见图5和表2。从累计频率曲线和频率直方图可以看出，这5个测点砾石长轴粒径均符合正态分布。可可沙地区砾石均值均属于小砾；标准偏差从0.82~1.08不等，整体上具有由底到顶变小的趋势；偏度主要介于−0.1~ +0.1之间，呈近于对称。峰度介于0.81~0.96之间，变化较小。

按照Folk and Ward对这些统计量的分类，其中宝日禾日俄地区，除测点XRD−3砾石分选较差外，其余测点分选均为中等；粒径分布曲线除了XRD−1偏向细粒，XRD−3偏向粗粒外，其余测点均呈近对称分布；测点XRD−2表现为宽峰，测点XRD−1和XRD−3表现为尖峰，测点XRD−4和XRD−5表现为中等峰度。可可沙地区，除了KKS−1测点分选较差，其余测点分选均为中等；粒径分布曲线上除了测点KKS−1呈偏向细粒，其余测点呈近对称分布；各个测点峰度介于中等峰度到宽峰之间。

3.3 结果分析

根据图5、图6和表3的统计分析结果显示，南带洪水川组第二段各个测点砾石成分、粒径、磨圆等可以发现，该段砾石由底到顶，花岗岩和变质岩砾石具有逐渐增多的趋势，而脉石英砾石逐渐减少；从平均粒径、峰度和偏度可以看出，砾石粒径呈

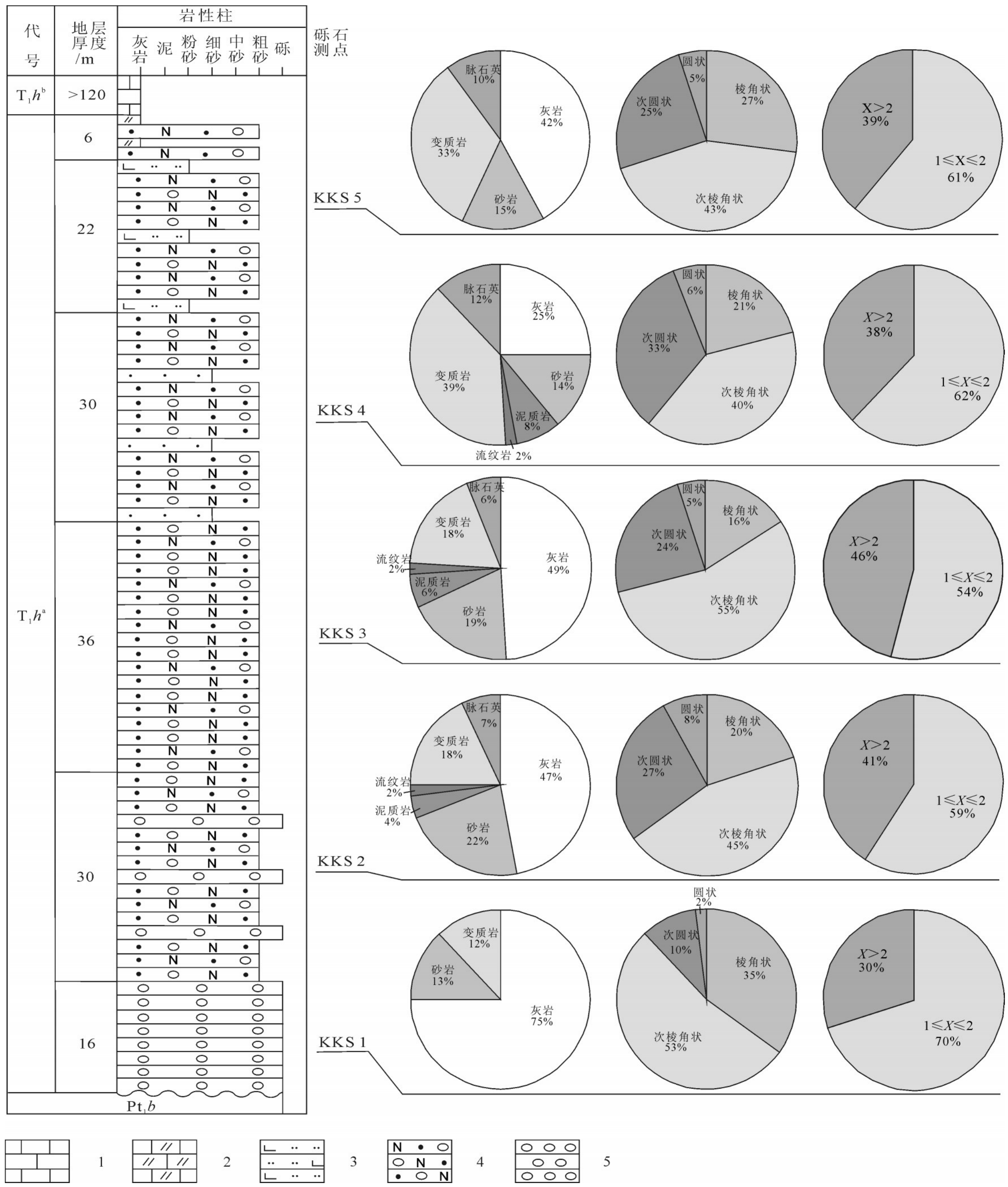

图4　北带可可沙地区洪水川组a段地层柱状图及砾石特征

1—灰岩;2—白云质灰岩;3—钙质粉砂岩;4—含砾长石砂岩;5—砾岩

Fig. 4 The histogram and the gravel characteristics of a section in northern Hongshuichuan Formation

1-Limestone;2-Dolomite limestone;3-Calcareous siltstone;4-Shingly arkose;5-Conglomerate

现出由小变大再变小的特征;相应的其分选度也呈现出由中等变差再变中等的特征;其磨圆度表现出逐渐变好的趋势。

北带洪水川组a段砾石由底到顶,呈现出灰岩砾石逐渐减少,变质岩砾石逐渐增多的趋势(图6);图5和表3的结果显示出,北带洪水川组a段从底到顶砾石的平均粒径逐渐变小、峰度呈宽峰—中等,偏度表现为偏向细粒,这些特征表明砾石呈逐渐变

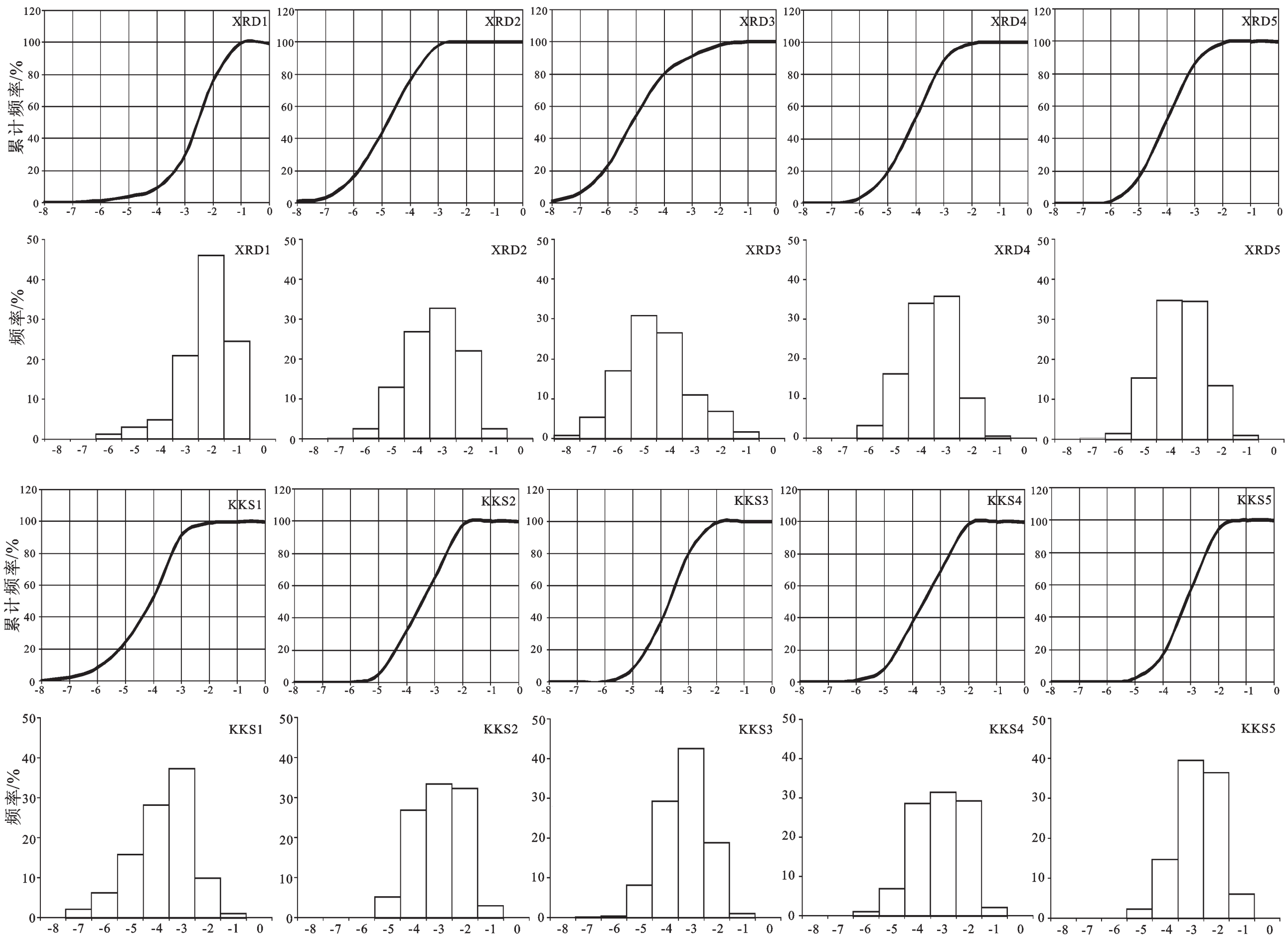

图5 洪水川组砾岩综合累计频率曲线图及频率直方图

Fig.5 The curvilinear diagram and the histogram of size-frequency distribution from conglomerate layer in Hongshuichuan Formation

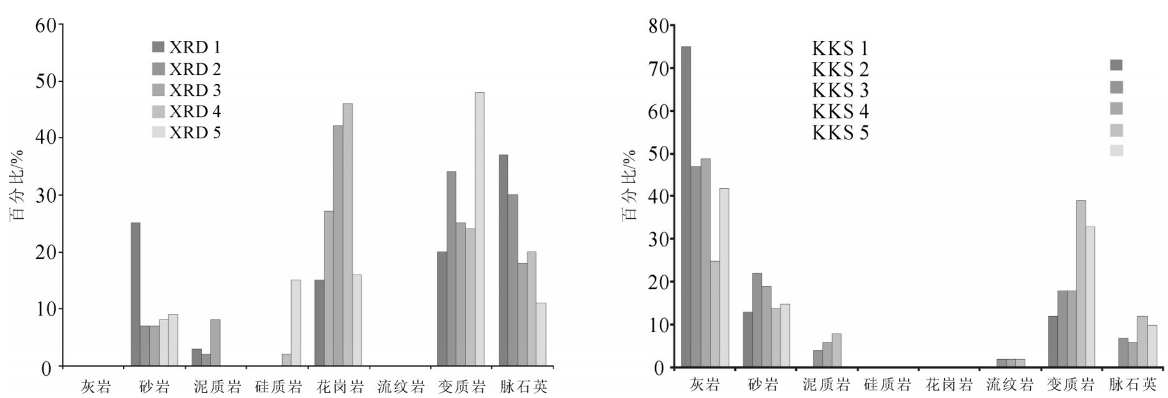

图6 洪水川组下部层位砾石岩性统计柱状图

Fig.6 The histogram of gravel lithology in Hongshuichuan Formation

小的趋势。

4 花岗岩砾石锆石U-Pb年龄

测试样品(样品号XRD368-1)采自宝日禾日俄地区洪水川组第二段砾岩中的花岗岩砾石，地理坐标为 35°31.614′N、97°58.829′E。花岗岩砾石大小约为27 cm×20 cm，呈次圆状，圆度1≤*X*≤2。岩石类型为灰白色细粒黑云母二长花岗岩。

表3 洪水川组砾岩综合粒径累计频率分布统计量(Krumbein,1934)
Table 3 Cumulative frequency curve of phi—transformed grain—size data of Hongshuichuan Formation gavel (after Krumbein,1934)

点位	平均粒径/ϕ	标准偏差(σ_1)		偏度(SK_1)		峰度(K_G)		粒度分布曲线
XRD1	-2.56	0.95	分选中等	-0.13	偏向细粒	1.24	尖峰	偏向细粒
XRD2	-3.47	0.94	分选中等	-0.08	偏向细粒	0.8	宽峰	近对称
XRD3	-5.02	1.34	分选较差	0.14	偏向细粒	1.17	尖峰	偏向粗粒
XRD4	-4.13	0.95	分选中等	-0.07	偏向细粒	0.91	中等	近对称
XRD5	-4.05	0.95	分选中等	0.01	偏向细粒	0.93	中等	近对称
KKS1	-4.24	1.08	分选较差	-0.27	偏向细粒	0.94	中等	偏向细粒
KKS2	-3.47	0.95	分选中等	-0.1	偏向细粒	0.81	宽峰	近对称
KKS3	-3.74	0.85	分选中等	-0.06	偏向细粒	0.97	宽峰	近对称
KKS4	-3.6	0.99	分选中等	-0.04	偏向细粒	0.82	宽峰	近对称
KKS5	-3.17	0.82	分选中等	-0.07	偏向细粒	0.96	中等	近对称

4.1 花岗岩砾石岩石学特征

野外地质特征显示(图7a),砾石岩性为细粒黑云母二长花岗岩,呈灰白色,细粒花岗结构,块状构造。矿物粒径1~2 mm,岩石发生蚀变。镜下特征显示(图7b),岩石主要矿物由斜长石(40%)、碱性长石(35%)、石英(20%)及少量黑云母(5%)组成。斜长石呈半自形—他形粒状,可见聚片双晶,表面绿泥石化;碱性长石主要以微斜长石和条纹长石为主,呈半自形—他形粒状,发育格子双晶,表面发生高岭土化;石英呈他形粒状,充填于长石颗粒间;黑云母,片状,呈细小鳞片状分布。

4.2 样品采集和测试方法

本次工作在花岗岩砾石中共分析测试了24粒锆石,锆石同位素组成分析及稀土元素分析结果列于表4和表5。单颗粒锆石U-Pb同位素组成分析在西北大学大陆动力学国家重点实验室激光剥蚀电感耦合等离子体质谱(LA-ICP-MS)仪上完成。分析仪器为配备有193 nmA Rf-excimer激光器的Geo-Las200M型(Microlas Gottingen Germany)激光剥蚀系统和Elan6100DRC型四极杆质谱仪。分析采用激光剥蚀孔径30 μm,剥蚀深度20 ~ 40 μm,激光脉冲为10 Hz,能量为32~36 mJ。锆石年龄计

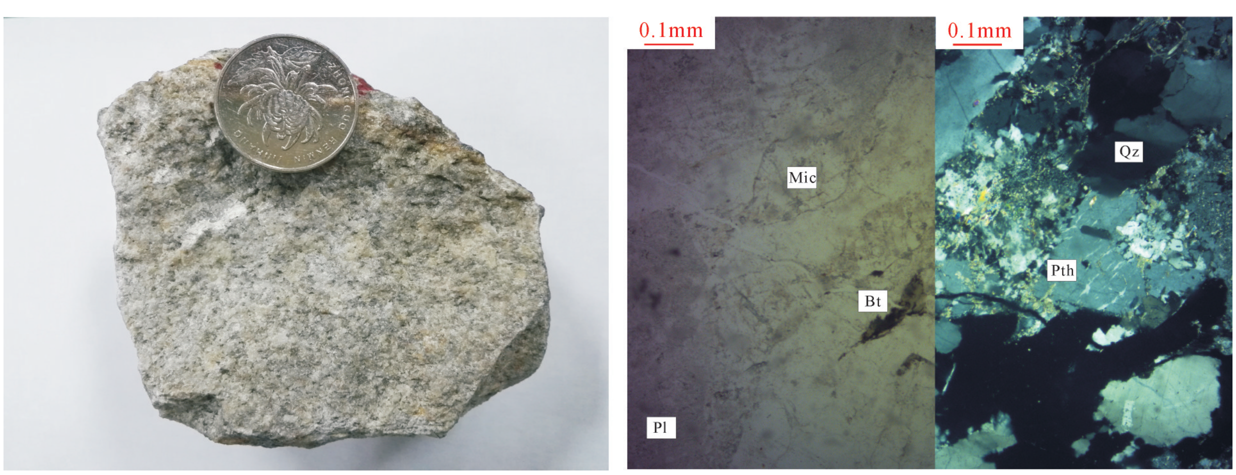

图7 洪水川组第二段花岗岩砾石手标本及显微照片(左—单偏光;右—正交偏光)
Pl—斜长石;Bt—黑云母;Mic—微斜长石;Pth—条纹长石;Qz—石英
Fig.7 Hand specimen photographs and microphotographs (Left—plainlight; right—crossed nicols) for the gravel of granite
Pl-Plagioclase; Bt-Biotite; Mic-Microcline; Pth-Perthite; Qz-Quartz

表4 宝日禾日俄地区洪水川组第二段花岗岩砾石(XRD368−1)LA−ICP−MS锆石U−Pb同位素测试结果

Table 4 LA−ICP−MS zircon U−Pb isotope data of granite from Hongshuichuan Formation(XRD368−1)

测点号	同位素含量/10^{-6}			Th/U	同位素比值						年龄/Ma					
	^{232}Th	^{238}U	^{206}Pb		^{207}Pb/^{206}Pb	±σ	^{207}Pb/^{235}U	±σ	^{206}Pb/^{238}U	±σ	^{207}Pb/^{206}Pb	±σ	^{207}Pb/^{235}U	±σ	^{206}Pb/^{238}U	±σ
1	72.34	232.41	134.19	0.31	0.0712	0.0025	1.5761	0.0454	0.1606	0.0020	961.8	69.0	960.8	17.9	960.2	11.3
2	58.04	75.50	59.63	0.77	0.0780	0.0024	2.0953	0.0499	0.1949	0.0023	1145.7	59.1	1147.3	16.4	1147.9	12.4
3	9.81	128.89	48.82	0.08	0.0600	0.0026	0.8074	0.0312	0.0976	0.0013	602.3	91.4	601.0	17.6	600.6	7.8
4	141.36	337.66	107.61	0.42	0.0580	0.0019	0.6480	0.0168	0.0810	0.0009	529.8	69.7	507.2	10.4	502.1	5.3
5	727.25	812.32	251.33	0.90	0.0566	0.0016	0.5951	0.0124	0.0762	0.0008	476.1	61.5	474.1	7.9	473.5	4.6
6	370.22	386.76	309.11	0.96	0.0785	0.0020	2.1298	0.0348	0.1968	0.0020	1158.4	48.6	1158.5	11.3	1158.3	10.6
7	110.56	161.70	122.03	0.68	0.0766	0.0022	1.9853	0.0422	0.1879	0.0021	1111.4	55.8	1110.5	14.4	1109.9	11.2
8	200.97	236.83	70.66	0.85	0.0581	0.0022	0.5806	0.0183	0.0725	0.0009	533.2	79.7	464.9	11.7	451.0	5.1
9	58.65	106.16	80.66	0.55	0.0765	0.0028	1.9821	0.0609	0.1878	0.0025	1109.3	70.5	1109.4	20.7	1109.3	13.8
10	36.83	67.88	53.20	0.54	0.0812	0.0025	2.0925	0.0491	0.1869	0.0022	1226.4	58.0	1146.4	16.1	1104.3	11.8
11	97.04	160.15	127.68	0.61	0.0776	0.0024	2.0594	0.0501	0.1926	0.0023	1135.5	60.2	1135.4	16.6	1135.2	12.3
12	121.37	206.17	64.15	0.59	0.0565	0.0019	0.5833	0.0159	0.0749	0.0008	470.0	73.2	466.6	10.2	465.6	4.9
13	122.52	205.05	63.36	0.60	0.0560	0.0023	0.5769	0.0215	0.0748	0.0010	450.7	90.1	462.5	13.8	464.8	5.8
14	30.65	132.44	99.80	0.23	0.0751	0.0020	1.8748	0.0374	0.1812	0.0019	1069.7	53.4	1072.2	13.2	1073.5	10.6
15	124.72	1008.18	1144.08	0.12	0.0993	0.0021	3.8836	0.0400	0.2838	0.0025	1610.6	38.3	1610.3	8.3	1610.2	12.8
16	75.30	175.69	51.55	0.43	0.0599	0.0035	0.6019	0.0324	0.0729	0.0012	599.0	120.2	478.4	20.5	453.7	7.4
17	151.42	245.42	77.62	0.62	0.0565	0.0018	0.5891	0.0150	0.0756	0.0008	471.2	68.5	470.3	9.6	470.0	4.9
18	30.94	1137.21	1126.85	0.03	0.0991	0.0023	3.6051	0.0505	0.2640	0.0026	1606.9	42.1	1550.7	11.1	1510.0	13.3
19	96.94	416.99	147.49	0.23	0.0599	0.0019	0.7358	0.0184	0.0892	0.0010	598.4	66.1	560.0	10.7	550.7	5.8
20	69.06	144.00	81.57	0.48	0.0742	0.0028	1.7966	0.0582	0.1758	0.0025	1045.8	73.5	1044.2	21.1	1043.7	13.4
21	68.49	376.34	391.80	0.18	0.0923	0.0021	3.2695	0.0432	0.2569	0.0025	1473.8	42.1	1473.8	10.3	1474.0	12.7
22	49.26	111.59	63.46	0.44	0.0709	0.0041	1.5514	0.0835	0.1588	0.0031	953.1	112.5	951.1	33.2	950.3	17.5
23	88.09	314.71	284.65	0.28	0.0859	0.0021	2.7262	0.0426	0.2303	0.0023	1335.2	45.7	1335.6	11.6	1336.0	12.2
24	68.40	153.74	123.85	0.44	0.0761	0.0023	1.9505	0.0462	0.1859	0.0022	1097.9	58.8	1098.6	15.9	1099.0	11.9

表5 宝日禾日俄地区洪水川组第二段花岗岩砾石(XRD368-1)锆石稀土元素含量测试结果

Table 5 Rare earth element composition of granite zircon from Hongchuichuan Formation(XRD368-1)

测点号	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	∑LREE	∑HREE	∑REE
1	0.462	9.33	0.302	2.71	4.17	0.92	22.92	9.66	124.3	48.27	217.52	46.71	449.49	77.43	17.894	996.3	1014.194
2	0.17	4.68	0.282	3.5	6.72	1.844	39.19	15.03	183.55	68.71	288.96	58.58	529.9	89.04	17.196	1272.96	1290.156
3	0.031	0.669	0.0225	0.182	0.286	0.11	2.67	1.605	26.84	14.17	85.04	22.48	243.47	45.87	1.3005	442.145	443.4455
4	0.459	6.8	0.259	3.44	6.68	0.954	28.96	8.89	85.37	27.33	102.53	19.78	173.99	28.9	18.592	475.75	494.342
5	10.37	84.62	2.361	11.8	5.98	2.37	19.09	6.35	71.73	27.21	126.27	29.05	302.88	56.52	117.501	639.1	756.601
6	0.082	16.07	0.748	11.3	18.1	4.83	63.64	20.57	202.63	65.55	256.1	50.4	458.05	76.71	51.13	1193.65	1244.78
7	0.032	7.72	0.152	3.55	8.64	2.085	49.99	20.03	244.33	90.75	378.98	76.21	688.28	114.16	22.179	1662.73	1684.909
8	0.036	9.26	0.121	1.57	3.07	0.839	17.57	7.53	94.84	38.81	184.04	42.66	435.97	81.92	14.896	903.34	918.236
9	9.64	58.97	3.4	18.79	7.48	1.39	24.34	9.71	121.18	46.33	210.03	47.75	474.75	84.28	99.67	1018.37	1118.04
10	0.03	3.57	0.099	2.01	4.97	1.383	27.59	11.68	144.11	54.15	234.21	47.75	439.49	74.74	12.062	1033.72	1045.782
11	1.142	17.07	1.553	11.85	8.86	1.634	36.3	14.84	186.98	71.48	308.74	63.44	580.51	96.43	42.109	1358.72	1400.829
12	0.029	8.67	0.033	0.85	2.27	0.637	11.06	5.2	68.72	29.13	148	35.63	382.92	74.17	12.489	754.83	767.319
13	0.028	8.77	0.07	0.92	2.35	0.432	15.37	6.05	79.47	33.2	157.62	36.44	365.42	70.49	12.57	764.06	776.63
14	0.025	3.84	0.033	0.324	0.515	0.245	2.49	0.964	11.36	4.77	23.91	6.14	69.34	14.57	4.982	133.544	138.526
15	0.026	9.94	0.029	0.57	1.92	0.206	8.87	2.87	33	13.4	72.72	19.36	227.98	49.69	12.691	427.89	440.581
16	0.274	5.94	0.331	2.91	4.57	1.18	18.98	5.76	62.07	21.96	90.77	18.53	177.08	32.58	15.205	427.73	442.935
17	0.034	19.93	0.0414	0.5	1.38	0.318	6.81	2.417	31.4	13.09	63	14.73	155.4	30.93	22.2034	317.777	339.9804
18	0.079	2.47	0.0495	0.36	0.66	0.069	5.19	3.3	57.52	28.71	172.14	50.41	610.85	125.26	3.6875	1053.38	1057.068
19	0.577	11.15	0.212	1.66	2.27	0.818	14.87	6.29	79.28	32.94	159.46	36.66	382.96	75.67	16.687	788.13	804.817
20	0.408	5.52	0.435	5.28	11.1	3.17	66.73	23.53	277.72	103.54	450.04	91.33	845.64	148.04	25.913	2006.57	2032.483
21	0.033	7.14	0.046	0.94	2.51	0.249	15.4	6.06	73.83	26.19	115.58	26.19	277.22	52.97	10.918	593.44	604.358
22	1.486	7.23	0.929	7.75	7.99	2.98	43.83	15.28	179.25	68.73	314.53	68.08	659.92	117.17	28.365	1466.79	1495.155
23	0.027	17.18	0.081	1.85	4.41	0.233	28.69	11.74	149.07	59.03	266.3	55.71	502.23	81.04	23.781	1153.81	1177.591
24	0.033	3.87	0.037	0.63	1	0.456	4.61	1.567	18.65	7.05	31.32	7.15	74.19	14.65	6.026	159.187	165.213

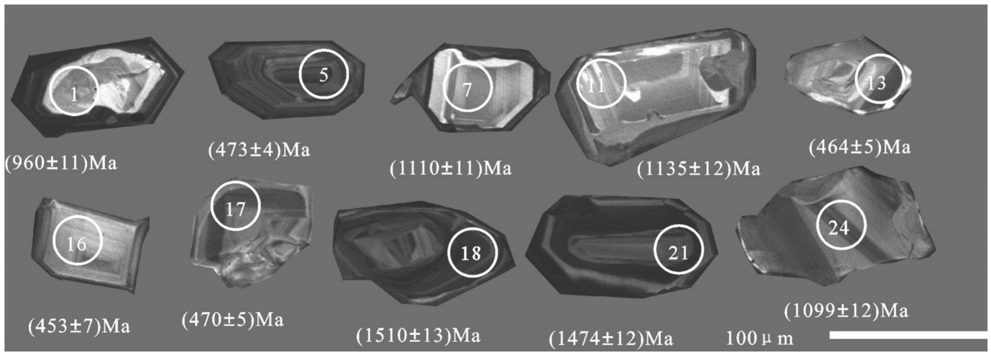

图8 洪水川组第二段花岗岩砾石(样品XRD368−1)的锆石阴极发光(CL)图像及其年龄值
Fig.8 The zircon cathodoluminescence(CL)images of sample XRD368−1

算采用国际标准锆石91500作为外标,元素含量采用美国国家标准物质局人工合成硅酸盐玻璃NIST SRM610作为外标,^{29}Si作为内标元素进行校正。详细的实验原理和流程及仪器参考文献(Yuan et al., 2004)。

4.3 锆石特征

花岗岩砾石测试样品(XRD368−1)中的锆石形态主要为长柱状晶体,其次为短柱状晶体,长宽比主要介于1:1~2:1,粒度介于80~120 μm。从阴极发光图像(CL)可以看出(图8),锆石颜色主要为灰白—暗灰色,按锆石结构可以划分为两类锆石,一类锆石发育生长韵律环带或明暗相间的条带,显示了岩浆锆石的特征;另一类锆石内部具有较好的生长韵律环带,但其边部发育溶蚀结构,个别发育增生结构,新生锆石以再生边形式围绕老的锆石内核生长,与锆石内核具有明显界限,增生边具有明显的韵律环带,可能反映了后期岩浆热事件。

锆石内部存在的Th、U、REE等可以为锆石年龄的解释提供重要的地球化学信息(Poitrasson et al., 2002; Belousova et al.,2002; Hoskin et al.,2003; Hoskin et al.,2003)。花岗岩砾石样品(XRD368−1)中锆石稀土元素测试结果(表5)显示,轻稀土元素总体上较低,总量为1.30×10^{-6}~117.50×10^{-6},而重稀土元素含量相对较高,总量为159×10^{-6}~2006×10^{-6}。从锆石稀土元素球粒陨石标准化配分图(图9a)可以看出,锆石的稀土元素从La到Lu含量迅速增加,并且具有明显的Ce正异常和Eu负异常,整体上为左倾模式的轻稀土元素亏损型。在Th−U图解中(图9b),主体位于Th/U=0.4线上,有少量位于Th/U=0.1线上。综上所述花岗岩砾石样品中锆石以岩

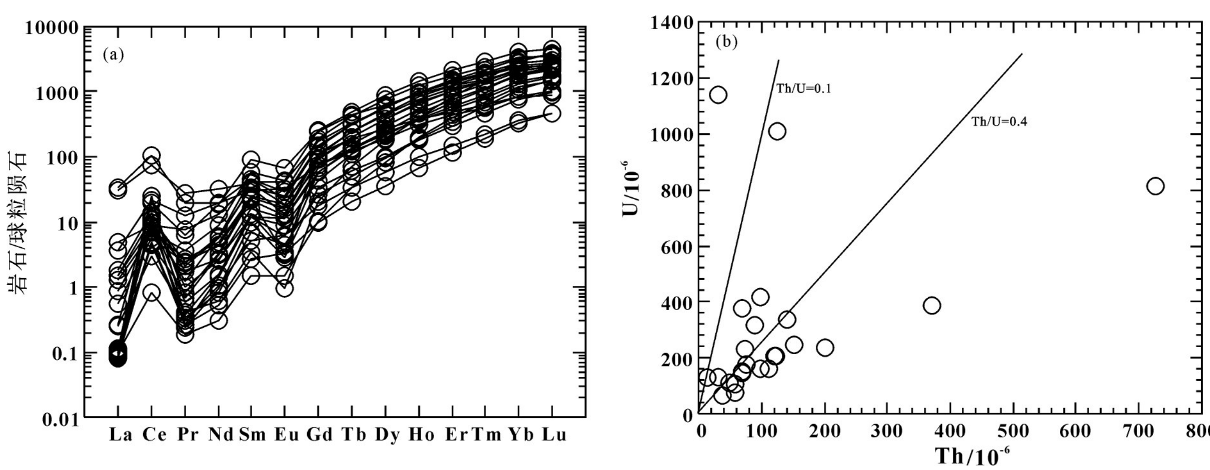

图9 洪水川组第二段花岗岩砾石(样品XRD368−1)的锆石微量元素特征
(球粒陨石标准化数据引自Sun,1989)
Fig.9 The trace element characteristics of zircon from Sample XRD368−1

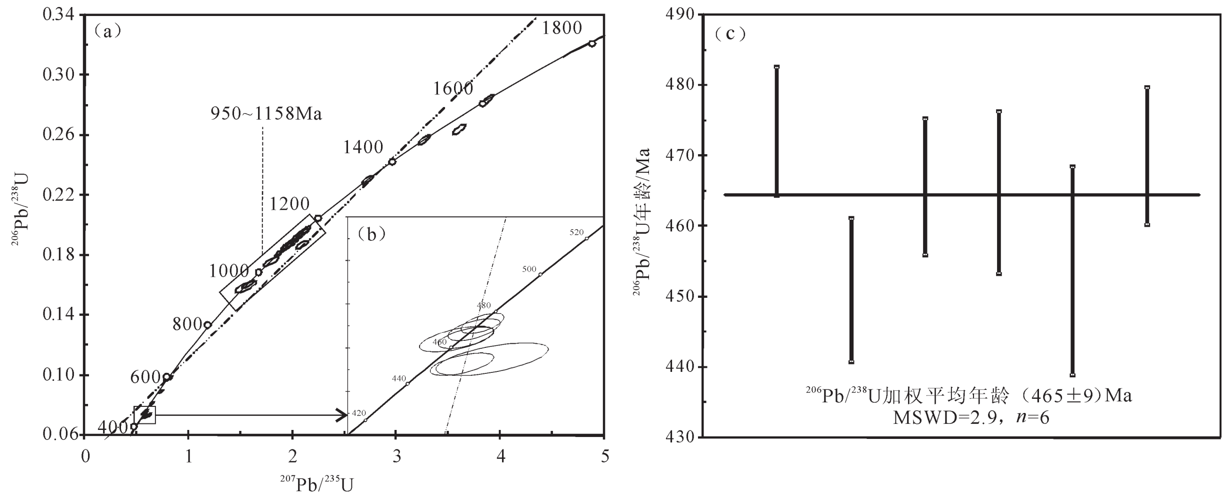

图10 洪水川组第二段花岗岩砾石LA-ICP-MS锆石U-Pb年龄谐和图
Fig.10 Zircon LA-ICP-MS age diagram of granite gravel in the second member of Hongshuichuan Formation

浆成因锆石为主,有少量变质锆石。

4.4 锆石U-Pb年龄

通过LA-ICP-MS测年方法获得花岗岩砾石样品中24粒锆石U-Pb同位素组成,在^{207}Pb/^{235}U-^{206}Pb/^{238}U谐和图上表现出较好的谐和性(图10a)。测试结果显示锆石年龄范围主要在1336~1610 Ma、950~1158 Ma、453~473 Ma三个年龄段。

表面年龄值1336~1610 Ma的测点有4颗,锆石具有明显的变质增生边,反映了该类锆石为早期变质锆石,可能来自东昆仑地区中元古代变质基底;年龄为950~1158 Ma的测点共有11颗,Th/U比值多大于0.4,锆石岩浆环带较发育,且可见明显的增生环带,部分可见熔蚀结构,反映该类锆石为捕获岩浆锆石;表面年龄为453~473 Ma的测点共有6颗,Th/U比值大于0.4,且具有较好的岩浆环带,反映了该类锆石也为岩浆成因锆石,直接指示了花岗岩的结晶年龄。将年龄值为453~473 Ma的锆石进行计算,获得加权平均年龄为(465±9) Ma(MSWD=2.9,n=6)(图10c),表明该花岗岩形成时代为中奥陶世。

5 讨 论

5.1 洪水川组底部砾岩层沉积物源

砾岩一般属于近源沉积,砾石成分受外界改造较小,所以能直观地反映物源区性质,揭示盆缘邻区山脉隆升和侵蚀演化过程(章朋等,2016)。通过上文对南、北带洪水川组下部层位砾石的对比分析,南、北带砾石成分存在较大的差异。北带洪水川组砾石成分主要为灰岩和变质岩,平均粒径集中在Φ=−3~−4,分选中等,长短轴之比在1≤X≤2区间的砾石占总数的38%~46%。南带洪水川组砾石成分主要为花岗岩和变质岩,平均粒径分布在Φ=−2~−5,分选中等,长短轴之比在1≤X≤2区间的砾石占总数的20%~26%。综合对比南、北带砾石特征可知,北带洪水川组砾石呈扁平状较多,具有较低的成分成熟度。这些特征说明北带洪水川组砾石经过了较短距离的搬运磨蚀作用,反映出北带洪水川组距离物源区较近,进而暗示了洪水川组的沉积物源位于其北侧地区。

通过对比研究区内发育的地层发现,在托索河一带仅有清水泉地区的石炭系哈拉郭勒组中发育有灰岩地层,且地层附近出露有古元古界白沙河岩组,白沙河岩组与洪水川组呈不整合接触关系,因此可以推测北带洪水川组底部物源可能为清水泉地区的哈拉郭勒组沉积地层和白沙河岩组变质地层。宝日禾日俄地区附近仅有早古生代岩浆岩与古元古界白沙河岩组,且白沙河岩组与洪水川组呈不整合接触,同时从该地区洪水川组底部获得的花岗岩砾石年龄为(465±9)Ma,推测南带洪水川组底部物源应为东昆南构造带的早古生代岩浆岩和古元古界白沙河岩组变质岩层。

5.2 源区性质及背景

洪水川组下部层位主要为一套粗碎屑岩沉积组合。主要岩性为砾岩、含砾粗粒长石砂岩、中粗

表6 东昆仑地区已发表的早古生代侵入岩年龄统计

Table 6 The statistics of published data about early Paleozoic ages in East Kunlun

岩体	分析方法	构造属性	年龄/Ma	资料来源
万宝沟岩体	角闪石 Ar-Ar	弧型	450	莫宣学等，2007
按纳格闪长岩体	LA-ICP-MS	岛弧型	474.1±2.4	孔会磊等，2014
德拉托郭勒岩体	Rb-Sr	弧型	476	莫宣学等，2007
祁漫塔格鸭子泉闪长岩	LA-ICP-MS	弧岩浆岩	480±3	崔美慧等，2011
阿拉克湖岩体	Rb-Sr	弧型	508	殷鸿福等，2003
可可沙石英闪长岩	LA-ICP-MS	岛弧型	515.2±4.4	张亚峰等，2010
白日切特花岗闪长岩	LA-ICP-MS	岛弧型	438±3	刘战庆等，2011b

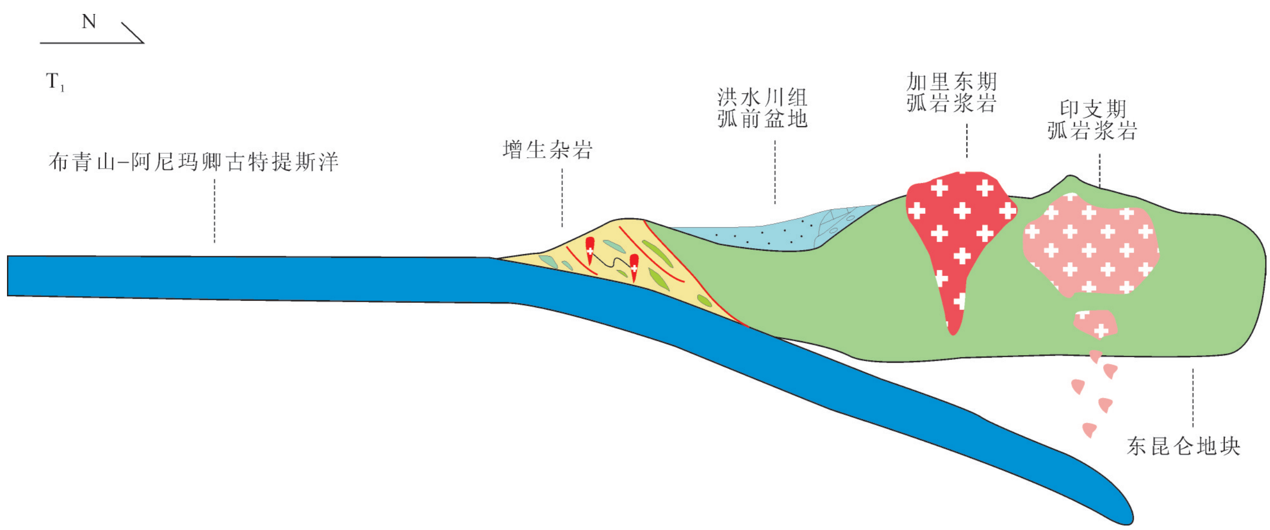

图11 洪水川组弧前盆地构造原型示意图(据李瑞保等(2015)改)

Fig.11 Schematic diagram of Hongshuichuan for-arc basin

粒长石砂岩及细砂岩，发育交错层理、平行层理。整体呈由底到顶粒度逐渐变细，具退积型沉积序列特点，反映出破坏型扇三角洲的特点。洪水川组三段和四段，主要为粉砂质页岩、粉砂岩夹泥晶灰岩的组合。三段和四段下部页岩发育水平层理，灰岩和泥岩互层的组合特征显示混积型陆棚沉积序列。五段主要为一套钙质粉砂岩、细砂岩和中粒钙质长石岩屑杂砂岩互层组成的鲍马序列组合。整体上呈现出向上变粗、岩层厚度变厚的趋势。该套岩石组合形成于半深水—深水盆地斜坡环境。六段主体为一套粉砂钙质板岩偶夹灰岩，成重复性韵律组合。上部为一套陆缘碎屑岩夹砾岩组合。整体由底到顶显示出水体变浅，沉积物粒度变粗的由浅海向滨海环境演化的特征。洪水川组的沉积序列表现出一个完成的浅水—深水—浅水的海平面演化过程，该特征与弧前盆地的沉积特征相似。

东昆仑南缘布青山—阿尼玛卿构造带记录有晚古生代洋盆信息。东昆仑南缘布青山—阿尼玛卿构造带内各地区报道的蛇绿岩年龄(陈亮等，2000)，以及OIB型、N-MORB型、E-MORB型等各类型蛇绿岩特征(陈亮等，2000；张智勇等，2004；刘占庆等，2011b,2011c；李瑞保等，2014，2015b；杨杰等，2014；)，反映出在晚古生代东昆仑南缘发育布青山—阿尼玛卿古特提斯洋盆。在东昆南构造带哈拉尕吐—哈图地区发育近东西向展布的大型陆缘弧型花岗岩基，岩体形成时代为晚二叠世(254.9±1.5)Ma(陈国超，2011)，岩体成因与布青山—阿尼玛卿古特提斯洋壳于晚二叠世—中三叠世向北俯冲密切相关(孙雨等，2009；李瑞保等，2012；李瑞保，2012)。在大地构造位置上，洪水川组是介于北侧弧岩浆岩和南侧布青山蛇绿构造混杂岩之间弧前沉积盆地的产物(陈有炘等，2015)。

布青山—阿尼玛卿古特提斯洋于晚二叠世开始向北俯冲,形成了年龄为260 ~237 Ma的陆缘弧型花岗岩。如Xiong et al.(2012)报道的东昆仑诺木洪岩体形成于261 Ma;孙雨等(2009)等报道的哈拉尕吐岩体形成于255 Ma;陈国超(2014)报道的香家南山岩体和哈拉尕吐岩体分别形成于251 Ma和254 Ma。洪水川组为弧前盆地沉积产物,其物源应主要为该时期形成的弧岩浆岩。然而,洪水川组下伏地层上二叠统格曲组的碎屑锆石峰值年龄为426 Ma(杨森等,2016);笔者从宝日禾日俄地区洪水川组下部第二段获得的花岗岩砾石年龄为(465±9) Ma;刘图杰(2015)发现宝日禾日俄地区洪水川组第一段和第二段的碎屑锆石峰值年龄为478 Ma和468 Ma。然而其上部层位的碎屑锆石峰值年龄主要为252 Ma和247 Ma,而早古生代时期锆石年龄较少。岳远刚(2014)研究发现托索河地区洪水川组碎屑锆石峰期年龄以434 Ma为主,其次为243 Ma。同时在东昆仑地区确证分布有大量的加里东期岩浆岩(表6)。由此可知,洪水川组下部层位的物源主要为加里东期岩浆岩。以上特征说明在早三叠世时期东昆南构造带的晚海西期—早印支期陆缘弧型花岗岩并未向弧前盆地提供沉积物质。暗示在该时期晚海西期—早印支期陆缘弧型花岗岩虽已侵位,但并未出露地表遭受剥蚀,同时陆缘弧型花岗岩的形成与侵位导致早期变质基底及早古生代弧岩浆岩抬升遭受剥蚀,因而使下伏石炭系哈拉郭勒组遭受剥蚀,使距离源区较近的北带洪水川组沉积地区接受以灰岩砾石为主的沉积;在持续隆升和剥蚀作用下使早古生代弧岩浆岩和变质基底迅速抬升出露地表遭受剥蚀,成为南带洪水川组的主要物源区(图11)。

综上,东昆仑东段早三叠世早期,在布青山—阿尼玛卿古特提斯洋的俯冲影响下,弧前盆地的物源主要为早期变质基底和早古生代弧岩浆岩。而晚海西期—早印支期陆缘弧型花岗岩未提供物源的事实,指示出该陆缘弧型花岗岩并未出露地表遭受剥蚀,暗示在该时期布青山—阿尼玛卿古特提斯洋处于向北俯冲的起始阶段。

6 结 论

(1)通过对东昆仑东段洪水川组南北带砾石的综合统计分析得出,北带可可沙地区洪水川组底部层位的碎屑物质主要来自北侧东昆南构造带的下伏地层石炭系哈拉郭勒组沉积地层和古元古界白沙河岩组变质岩系;南带宝日禾日俄地区洪水川组底部层位的沉积物质主要来自其北侧的早古生代弧岩浆岩以及古元古界白沙河岩组变质岩系。

(2)在早三叠世早期,弧前盆地底部的物源主要为古元古界变质基底和加里东期弧岩浆岩,暗示了在该时期布青山—阿尼玛卿古特提斯洋处于向北俯冲的起始阶段。

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