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银川盆地晚上新世物质来源及其对黄河上游形成年代的约束

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摘 要 黄河上游河段的形成年代依然存在争论,而银川盆地是黄河上游物质的主要沉积区之一,该盆地沉积序列的研究能为了解黄河上游的物质来源和形成年代提供重要线索。对银川盆地钻孔(PL02)底部进行了碎屑锆石U-Pb测年和碎屑组分统计研究,并与上游黄河沉积物以及盆地周边贺兰山和鄂尔多斯高原西部的锆石U-Pb年龄数据和碎屑组分数据进行了对比分析。结果表明贺兰山和鄂尔多斯高原西部并不是银川盆地晚上新世沉积物的物质供应区,而是黄河将银川盆地以上河段地区物质输送到银川盆地。这一结果进一步证明了黄河上游兰州—银川段在晚上新世已经形成的观点。

关键词 银川盆地;晚上新世;锆石U-Pb测年;碎屑组分;物源分析;黄河上游形成年代

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0 引言

大型河流的形成年代以及水系演化受到国内外学者广泛地关注。黄河发源于青藏高原东北部的巴颜喀拉山,它将侵蚀的物质,通过河流搬运、沉积到邻近的盆地、平原和海洋中,构成了一个完整的“源—汇”系统。因此,黄河的形成演化历史一直是地学界广泛关注的重大科学问题之一,为此进行了大量的研究与讨论,并取得了许多重要的研究成果。尽管进行了大量的调查,但是由于不同学者判断黄河形成的标准不同,对黄河的形成尤其是黄河中上游河段的形成历史依然存在争论。主要分为三种观点:1)晚中新世到上新世(>3 Ma)[1-12],2)早—中更新世(约1.8~0.8 Ma)[13-20],3)晚更新世以来[21-25]。

近年来,一些学者利用碎屑锆石U-Pb测年方法对黄河中上游的形成演化开展了一定的研究[3,6,9,11-12],但由于银川盆地附近缺乏保存良好的河流阶地序列,导致对银川盆地沉积物的物源研究相对匮乏,缺乏有效的碎屑锆石U-Pb年龄数据和碎屑组分研究,限制了对银川盆地地区黄河形成演化历史的探索。

银川盆地沉积物为研究黄河上游的形成演化提供了良好的载体。假设来自黄河上游河段的碎屑物质保存在银川盆地晚上新世地层中,那么将可以得到黄河在晚上新世出现在银川盆地的结论。因此,本文对晚上新世银川盆地钻孔沉积物进行了碎屑锆石U-Pb测年研究,生成的大量碎屑锆石U-Pb年龄数据能够有效地厘清盆地钻孔底部的物质来源,并对理解黄河上游的形成演化具有重要的启示意义。

1 研究区概况

银川盆地是黄河上游流经的重要盆地之一,也是青藏高原东北缘和鄂尔多斯高原西北缘交汇的一个新生代断陷盆地[26]。银川盆地呈北北东—南南西向延展,位于海拔高度3 500 m以上的贺兰山和海拔平均高度约1 500 m的鄂尔多斯高原之间,盆地北部到石嘴山

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市惠农区,南部至吴忠市青铜峡,南北长度约165 km,东西宽度约42~60 km,面积为7 790 km^2(图1a)[27-28]。

银川盆地钻孔(PL02)位于宁夏回族自治区平罗县境内,位于黄河以西11 km和贺兰山以东22 km处,其经纬度为106°36′3.82″ E,38°55′26.6″ N,海拔高度约为1 103 m[27] 。银川盆地钻孔的钻探和取样工作于2013年9月正式开始进行,钻孔总长度为720 m,钻孔的平均取心率为94.7%[27,29],利用古地磁测年和^{14}C测年相结合的方法,得到钻孔底部的形成年代为~3.4 Ma[27](图1b)。

2　材料与方法

本研究中,用于碎屑组分和锆石U-Pb测年的样品,来源于银川盆地PL02钻孔底部,其深度为699.9 m,该段岩性为砂岩,基于前人对银川盆地钻孔的古地磁定年得到其形成年代为3.31 Ma[27]。为了对比分析银川盆地钻孔晚上新世(3.3 Ma)时期的物质来源,本文对贺兰山东麓不同河流出山口进行了现代河流沙样品(HL1-HL4)采集,并进行碎屑组分分析。同时,本文还搜集了前人在潜在源区进行的研究数据,包括贺兰山地区的碎屑锆石U-Pb年龄数据[30-33]、鄂尔多斯高原西部的碎屑锆石U-Pb年龄数据[34]和碎屑组分数据[35]以及上游黄河的碎屑锆石U-Pb年龄数据和碎屑组分数据[3,6,9]。

2.1　锆石U-Pb测年方法

银川盆地钻孔样品中的碎屑锆石挑选工作在河北省区域地质调查院实验室进行,共计377颗锆石颗粒被用于U-Pb年龄测试。锆石U-Pb同位素测年分析利用美国亚利桑那大学同位素地球化学实验室激光年代测试中心的多接收激光烧蚀—等离子体质谱仪(Laser Ablation Multi-Collector Inductively Coupled Plasma Mass Spectrometer)[36]进行测量。准分子激光剥蚀利用Photon Machines公司生产的Analyte-G2 ArF 193 nm进行。激光束斑的直径设定成30 μm,利用氦气作为剥蚀物载气,氩气作为调节灵敏度的补偿气。普通Pb校正使用Andersen的处理方法,单一数据点的误差均为1σ。

单一锆石颗粒所测的U-Pb同位素定年结果将获取到^{207}Pb/^{206}Pb、^{207}Pb/^{235}U和^{206}Pb/^{238}U三组比值年龄。本文中涉及到的所有锆石U-Pb年龄结果均经过最佳年代和不谐和度筛选,其标准为:1)最佳年龄:如果^{206}Pb/^{238}U<1 000 Ma,则采用^{206}Pb/^{238}U值作为最佳年龄;如果^{206}Pb/^{238}U>1 000 Ma,则采用^{207}Pb/^{206}Pb值作为最佳年龄。2)不谐和度(discordance)过滤:最佳年龄<1 000 Ma,不谐和度=(^{207}Pb/^{235}U-^{206}Pb/^{238}U)/^{207}Pb/^{235}U×100);最佳年龄>1 000 Ma,不谐和度=(^{207}Pb/^{206}Pb-^{206}Pb/^{238}U)/^{207}Pb/^{206}Pb×100);选择不谐和度在−10%~15%之间的最佳年龄作为有效年龄[3,37]。

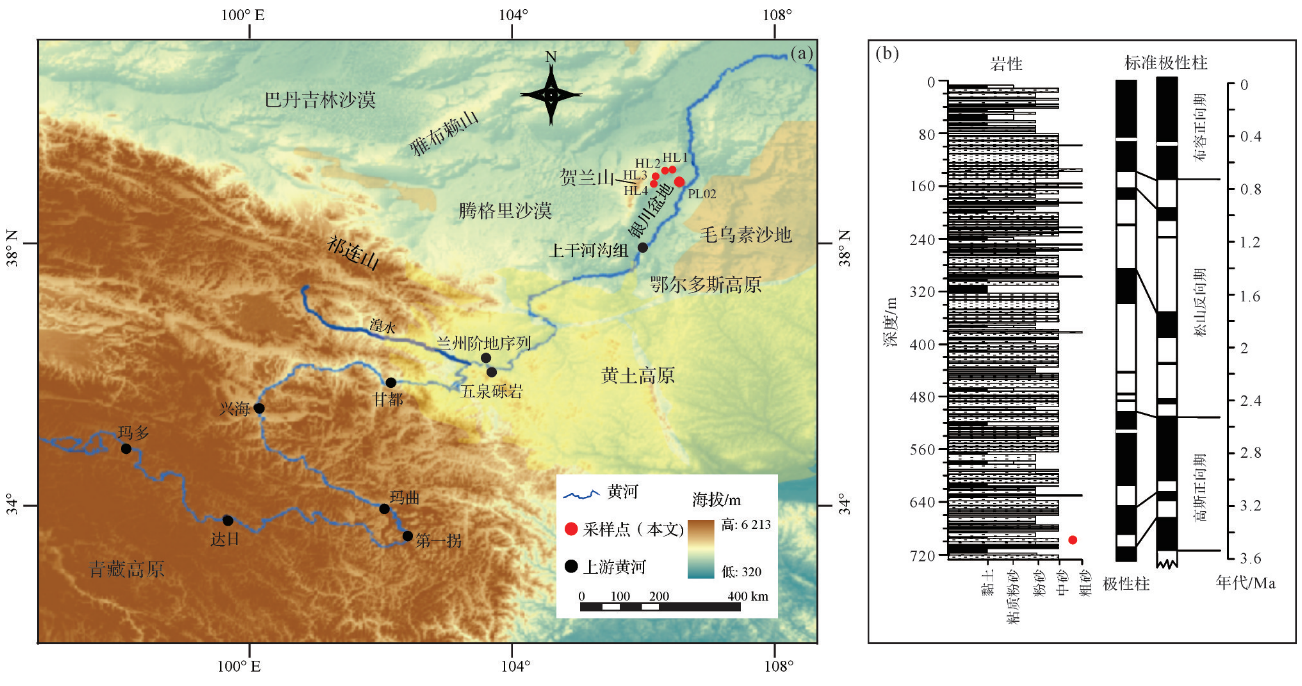

图1　银川盆地区域位置图(a)及PL02钻孔岩性和年代(b,修改自文献[27])

Fig.1　(a) Location map of Yinchuan Basin and (b) the lithology and ages of drill core PL02 (modified from reference [27])

2.2 碎屑组分方法

银川盆地钻孔和贺兰山东麓样品的碎屑组分统计采用Gazzi-Dickinson的方法进行栅格结点统计，样品中超过300个碎屑颗粒被统计，该实验统计在意大利米兰比可卡大学沉积物源分析实验室完成。简要操作如下：首先，对样品进行碎屑薄片的制作，再对薄片的局部(一般为1/3~1/2的部分)进行染色处理，以便于能够准确识别出砂岩样品中的碳酸盐岩和钾长石等碎屑；其次，根据砂质粒径大小选择适合的栅格间距在显微镜下进行统计，统计完一个视域后，移动到相邻的另一个视域继续统计，确保单一颗粒没有被重复统计[38]。对于粒径大于62.5 μm的碎屑颗粒均被统计为矿物而不是岩屑[38-41]。碎屑组分统计结果按照石英(Quartz，简写Q)、长石(Feldspar，简写F)和岩屑(Lithic fragment，简写L)三大类呈现，并根据Garzanti[39-40]和何杰等[41]对砂岩分类命名方案进行命名，该方案采取完全对称的设计，按照各端元含量的多少，只要某一端元组分的含量超过10%即参与命名。

3 结果

3.1 锆石U-Pb测年结果

锆石U-Pb测年实验获得了377颗碎屑锆石U-Pb年龄数据，经过去除不谐和度过大的数据后，共计291个锆石U-Pb数据符合本文研究所用标准，被用来进行数据分析和处理。银川盆地钻孔样品中碎屑锆石颗粒的U-Pb年龄范围为200~3 000 Ma，大致可以划分为5个年龄成分区间，其中主要由200~300 Ma和400~500 Ma两个主要峰值区间，以及900~1 000 Ma、1 700~2 000 Ma和2 300~2 600 Ma三个次一级峰值区间组成(图2)。

3.2 碎屑组分统计结果

银川盆地钻孔样品碎屑组分中，石英含量为60%，长石含量为14%，岩屑含量为26%。在该样品碎屑组分含量高低为Q>L>F>10%QFL，根据Garzanti[39-40]和何杰等[41]对砂岩分类的命名方案，命名为长石岩屑石英砂岩(图3)。

贺兰山东麓不同河流现代沉积样品(HL1~HL4)的碎屑组分有所差异。贺兰山样品HL1的碎屑组分中，石英含量为37%，长石含量为8%，岩屑含量为56%，该样品碎屑组分含量高低为L>Q>10%QFL>F，命名为石英岩屑砂岩；贺兰山样品HL2的碎屑组分

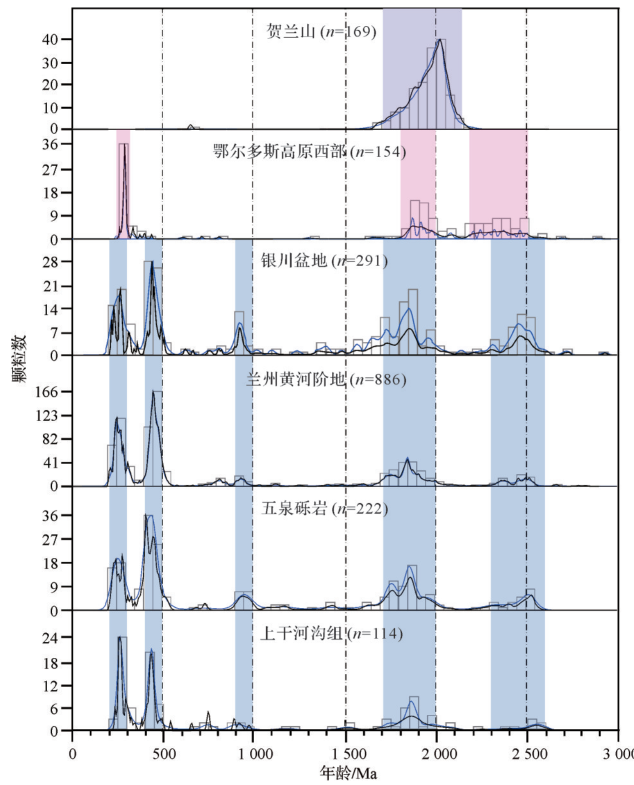

图2 银川盆地钻孔与潜在源区碎屑锆石U-Pb年龄谱对比(贺兰山锆石数据来源于文献[30-33]，鄂尔多斯高原西部锆石数据来源于文献[34]，上游黄河锆石数据来源于文献[3,6,9])

Fig.2 Comparison between detrital zircon U-Pb ages for Yinchuan Basin drill core and potential provenance areas (Helan Mountain data from references[30-33]; western Ordos Plateau data from reference[34]; upper Yellow River data from references[3,6,9])

中，石英含量为69%，长石含量为7%，岩屑含量为24%，该样品碎屑组分含量高低为Q>L>10%QFL>F，命名为岩屑石英砂岩；贺兰山样品HL3和HL4的碎屑组分相似，石英含量为36%~37%，长石含量为21%~22%，岩屑含量为40%~42%，这两个样品碎屑组分含量高低为L>Q>F>10%QFL，命名为长石石英岩屑砂岩。

4 讨论

4.1 银川盆地物质来源

利用概率密度分布函数(Normalized probability density plots，简写PDP)、核密度估计方法(Kernel density estimation plots，简写KDE)和直方图方法对银川盆地钻孔底部样品及其潜在源区的锆石U-Pb数据进行对比分析(图2)以及碎屑组分Q-F-L三角图分析

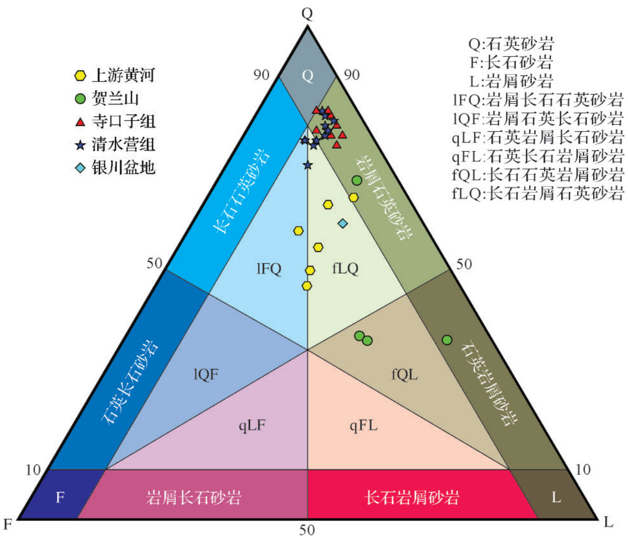

图3　银川盆地钻孔与潜在源区碎屑组分特征(修改自文献[41],鄂尔多斯高原西部数据来源于文献[35],上游黄河数据来源于文献[3])

Fig.3　Petrographic composition of Yinchuan Basin drill core and potential provenance area (modified from reference[41]; Western Ordos Plateau data from reference[35]; upper Yellow River data from reference[3])

(图3)。为了进一步进行直观对比银川盆地与潜在物源区的锆石U-Pb数据,本文同时对以上锆石年龄数据进行非矩阵多维标度(Non-metric multidimensional scaling,简写MDS)统计分析(图4),MDS图中样品与样品间的实线代表着这两个样品最相近(实线越短越相近),而样品与样品间的虚线则说明这两个样品存在次相关关系(虚线越长越不相关)。

从概率密度分布函数(PDP)、核密度估计方法(KDE)和直方图(图2)显示,鄂尔多斯高原西部地区

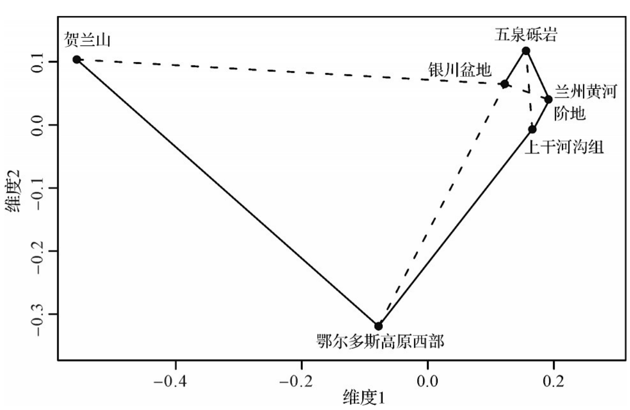

图4　银川盆地与潜在源区锆石U-Pb年龄的非矩阵多维标度统计分析图

Fig.4　Non-metric multidimensional scaling (MDS) plot of zircon U-Pb age data of Yinchuan Basin drill core and comparison with potential sources

的锆石U-Pb年龄成分主要为250~300 Ma、1 800~2 000 Ma和2 200~2 500 Ma。相对于银川盆地钻孔底部样品,鄂尔多斯高原西部地区的锆石U-Pb年龄组分的峰值向更老或更年轻的年龄组分偏移,并且缺少400~500 Ma和900~1 000 Ma这两组年龄组分;同时在碎屑组分Q-F-L三角图(图3)中,鄂尔多斯西部地区的碎屑组分多集中于岩屑石英砂岩区与银川盆地样品的长石岩屑石英砂岩差异明显,因此我们认为鄂尔多斯高原西部地区没有为银川盆地提供物质。

贺兰山地区的锆石U-Pb年龄仅存在一个显著的1 700~2 200 Ma的年龄单峰成分(图2),与银川盆地钻孔底部样品相比缺少了200~300 Ma、400~500 Ma、900~1 000 Ma和2 300~2 600 Ma这四个成分区间;同时贺兰山样品的碎屑组分与银川盆地钻孔样品在Q-F-L三角图(图3)中所处的区域划分显著不同,因此贺兰山也不是银川盆地钻孔底部的物质来源区。这一结论与先前通过对比银川盆地钻孔与发源于贺兰山的现代河流沉积物的重矿物数据所得结论一致[8]。

银川钻孔底部样品与黄河上游兰州阶地序列、五泉砾岩、青铜峡地区上干河沟组的碎屑锆石U-Pb年龄都具有200~300 Ma和400~500 Ma两个主要峰值区间,以及900~1 000 Ma、1 700~2 000 Ma和2 300~2 600 Ma的年龄组分(图2)。碎屑组分Q-F-L三角图(图3)也显示银川盆地与大部分上游黄河样品的碎屑组分都处于长石岩屑石英砂岩区,表明其母岩类型相似或相同。

非矩阵多维标度统计(MDS)分析(图4)结果显示银川盆地钻孔样品靠近上游黄河样品,而远离贺兰山和鄂尔多斯高原西部的样品,表明了上游黄河流经区域的物质经由黄河侵蚀、搬运再沉积到银川盆地[3,8]。

4.2　黄河上游形成年代

碎屑锆石U-Pb年龄谱(图2)和碎屑组分对比(图3)分析结果显示,银川盆地钻孔底部物质与黄河银川河段以上的物源一致,表明银川盆地自晚上新世已经开始接受来自黄河上游的沉积物供应。前人对兰州地区形成于3.6~2.2 Ma的五泉砾岩组和青铜峡地区上干河沟组进行的碎屑锆石U-Pb年龄、重矿物组合、砂岩岩相学以及河流古流向研究结果表明黄河上游兰州段和青铜峡段在晚上新世已经存在[3,6,8-9]。以上数据共同指示了黄河上游兰州—青铜峡—银川段在晚上新世就已经形成[3,6-9],支持了黄河上游至少在晚上新世就已形成的观点。

5 结论

锆石U-Pb测年数据和碎屑组分数据共同显示了晚上新世银川盆地沉积物不是来源于周边的贺兰山和鄂尔多斯高原西部地区,而是来源于上游黄河地区。进一步指示了黄河上游兰州—青铜峡—银川段在晚上新世就已经形成,支持了黄河上游至少在晚上新世就已形成的观点。

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Late Pliocene Sedimentary Provenance of the Yinchuan Basin and Its Constraints on the Formation Age of the Upper Yellow River

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Abstract: The formation age of the upper reaches of the Yellow River is still debated. The Yinchuan Basin is one of the main sedimentary areas in the upper reaches of the Yellow River, and its sedimentary sequence provides important clues to an understanding of the material source and formation age of the upper Yellow River. In this study, detrital zircon U-Pb age geochronological and petrographic composition data were determined for Late Pliocene sediments from the bottom of drill core PL02 in the Yinchuan Basin. This information was compared with other data for potential sources. The results show that the Helan Mountain and the western Ordos Plateau were not the source areas of Late Pliocene sediments in the Yinchuan Basin. Rather, the Yellow River transported material from the upper-reach areas to the Yinchuan Basin. This result further supports the view that the Lanzhou-to-Yinchuan portion of the upper Yellow River was formed in the Late Pliocene.

Key words: Yinchuan Basin; Late Pliocene; zircon U-Pb ages; petrographic composition; provenance analysis; formation age of upper Yellow River