

宁夏沙坡头黄河大弯的成因分析^①

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摘要:黄河在宁夏沙坡头形成了“几”字形河曲地貌,并在河曲凸岸发育了 3 级河流阶地。本文针对沙坡头大弯河流阶地特征、阶地年龄,以及大拐弯的成因进行了分析,探讨本区地貌发育的机制。结果表明:(1)沙坡头大弯 3 级河流阶地形成的主要原因是构造抬升作用,气候变化对此处阶地形成的作用不明显。在区域新构造活动强烈的背景下,约中更新世末期中卫盆地开始抬升,黄河河道被固定,河流下切形成本区的最高阶地 T₃;约在 70 kaB. P.、8 kaB. P. 形成 T₂、T₁ 阶地。(2)沙坡头黄河大拐弯是由香山—天景山断裂左旋走滑位错,以及水流受地球自转偏向力的河流内生动力共同作用的结果,并且河流的内生动力作用远大于前者的贡献。

关键词:黄河;沙坡头;河流阶地;大弯;成因

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Genetic-analysis of the Yellow River Big Bend in the Shapotou Area, Ningxia Hui Autonomous Region

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Abstract: The Shapotou area is located in Zhongwei city in the Ningxia Hui Autonomous Region, which is also situated in the arc area on the northeastern side of the Qinghai-Tibet plateau with very active neo-tectonic movements in mainland China. The Yellow River crosses the Xiangshan-Tianjingshan fault and flows through the Shapotou. The Xiangshan-Tianjingshan fault is mainly a left-lateral strike-slip. The Yellow River formed a beautiful geomorphological meander, the Big Bend, which is similar to the "Ω" type. It developed three river terraces on the convex bank since it turns around in the Shapotou area. Over the past few decades, geologists have conducted many studies in this strong neo-tectonic movement and special tectonic setting, concerned with active faults, the tectonic deformation process in the Quaternary, the scales and rates of active fault displacement, and the causes of the Shapotou Big Bend. However, there is not a comprehensive analysis of the origins of the Big Bend. The research on the river terrace is one of the most important topics in geomorphology. River terraces are the most reliable records of river histories. The meandering river is ubiquitous in nature; meandering is a natural property of rivers.

This paper focuses on the characteristics and ages of river terraces and analyzes the causes of the Big Bend to explore the causes of landforms in this area from the vertical and horizontal directions. Based on field investigations and comparisons to former studies, three terraces were re-

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vealed. The formation age of the highest terraces is ~ 170 ka B. P. The T_2 and T_1 terraces were subsequently formed at ~ 70 ka B. P. and 8 ka B. P., respectively. The three river terraces in the Shapotou Big Bend formed mainly due to tectonic uplift, while the impact of climate change is not obvious on the formation of the terraces. Climate change is not the only element that controls river incisions; the terraces in this area depend on tectonic uplift. In the context of strongly regional neo-tectonic activities, when the Zhongwei Basin was elevated in approximately the Late Pleistocene, resulting in the fixing and down-cutting of the Yellow River, the highest terrace (T_3) began to form. The T_2 and T_1 terraces were subsequently formed. This indicates that there have been at least three intensive tectonic movements. These three events are at least comparable to the "Gonghe Movement" and "Ruorgai Movement." According to the largest of the left-lateral displacements of the Xiangshan—Tianjingshan fault, which is less than 880 m, the fault is not the only reason that the Big Bend formed. There are at least 2 200 m displacements due to the river endogenous characteristics. Under the common function of the Xiangshan—Tianjingshan fault, which is a left-lateral strike-slip fault, and the rotation of the Earth's tilt toward power which is the natural evolution of water system, the Yellow River of the Big Bend in the Shapotou area is formed. The concave bank has been eroded and the convex bank has been deposited, so the planar shape of the Shapotou Big Bend is formed. River endogenous characteristics play more important roles than the strike-slip fracture displacements in the Big Bend.

Key words: The Yellow River; Shapotou; river terrace; big bend; genesis

0 引言

黄河在沙坡头的夜明山流出黑山峡、跨过香山—天景山弧形断裂后,向东北流入中卫盆地。在香山—天景山断裂与中卫盆地之间,黄河地貌上呈现出美丽的“几字形”河曲形态(图1),地质学家对此区域的新构造运动、断裂性质及运动特征、阶地演变及形成时代、地貌演变过程等^[1-9]多方面开展了详细的研究,包括沙坡头大弯的成因。丁国瑜^[1]在讨论香山—天景山断裂的左旋性质时提出断裂活动导致了黄河左旋位错而形成现今沙坡头大弯;刘传正^[10]认为两组走滑断裂是导致沙坡头大弯形成的原因。构造因素一直用来解释沙坡头大弯的成因,但据尹功明等^[11]研究认为香山—天景山断裂自本研究区黄河固定以来左旋位错最大不足 880 m,纯构造事件不足以形成现今的大拐弯地貌。同时,香山—天景山断裂北侧大弯处的黄河阶地的成因还没有过详细研究^[9],而对香山—天景山断裂南侧夜明山一带的黄河阶地已有过深入研究,认为是香山—天景山断裂的逆冲作用导致多达 9 级阶地的形成^[12-13]。本文根据香山—天景山断裂北侧大弯处的黄河阶地分布特征、年龄,以及香山—天景山断裂活动性、水流自然特性等多方面因素,分析沙坡头大弯现今地貌成因。

1 区域地质概况

沙坡头黄河大弯位于宁夏中卫市,腾格里沙漠的东南缘,地貌上是青藏高原、黄土高原、鄂尔多斯高原和阿拉善高原的过渡地带;构造上处在青藏高原东北缘弧形断裂带内。该弧形断裂带是在 SW—NE 方向的水平挤压构造应力下,青藏块体向古老而稳定的阿拉善地块和鄂尔多斯地块挤压而形成的,主要由弧形逆冲断层以及相关褶皱组成断块山地与断陷盆地相间的地貌格局^[14-15],自南向北有海原断裂、香山—天景山断裂、烟筒山断裂和牛首山断裂,中卫盆地夹于香山山地与烟筒山地之间^[1-2,16](图1)。

青藏块体前期主要表现为挤压、逆冲,在早更新世中晚期至中更新世初,高原内 NW 和 NWW 向断裂的活动性质由挤压逆冲转变为左旋走滑^[17]。因此,香山—天景山断裂是一条以左旋走滑为主兼具逆冲分量的断裂,沿断裂带发生地质体的位移、水系的位错等,断裂的左旋走滑量在冲沟上表现为几十米到几百米甚至千米不等^[3-4]。

中卫盆地是受早期山前逆冲断裂控制的压陷盆地,从第三纪至第四纪早期,盆地沉积范围比较大,至第四纪晚期,盆地轮廓发生变化,规模有逐渐缩小的趋势^[17]。

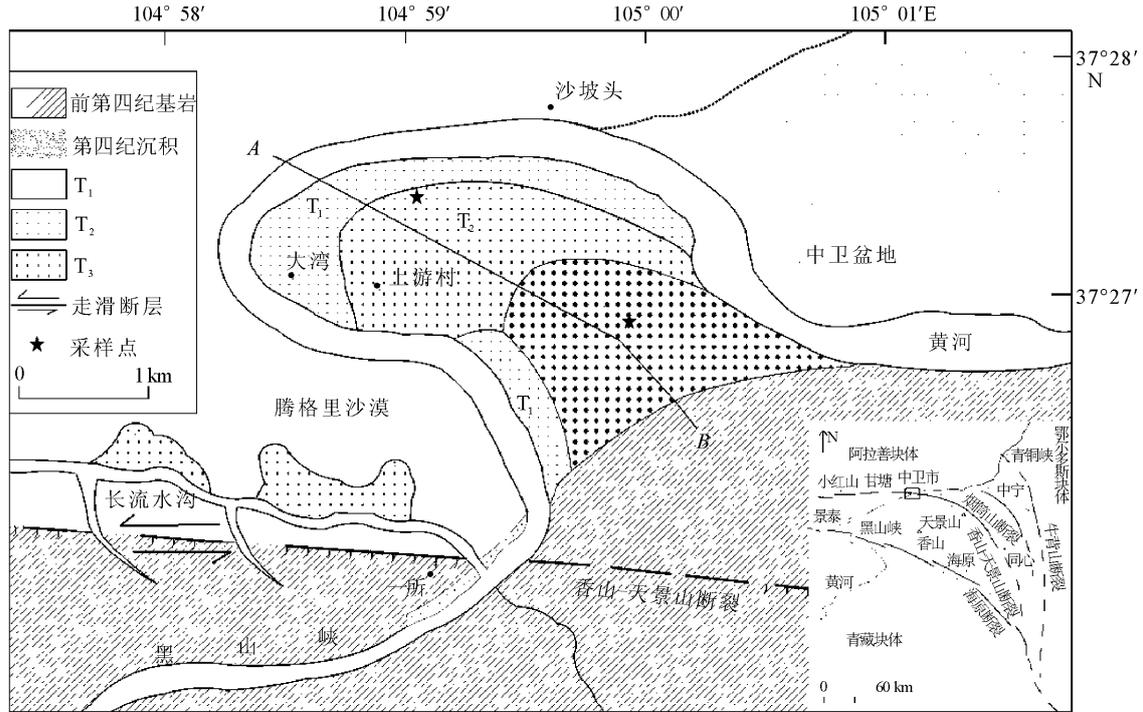


图 1 宁夏沙坡头河流地质地貌简图(据文献[1]修改)

Fig. 1 The Sketch map of geological and geomorphological features along the Yellow River in Shapotou area, Ningxia (revised according to reference [1])

2 沙坡头大弯地貌特征及阶地划分

在沙坡头黄河“几”字形区域河道西侧是腾格里沙漠覆盖的平坦基岩区域,河道东侧发育多级河流阶地。前人对此处阶地级数的划分不一:丁国瑜^[1]划分出 2 级阶地和 1 级台地面、尹功明等^[11]和阎满

存等^[8]划分出 3 级阶地、胡海涛等^[19]划分出 5 级阶地、冯希杰等^[9]划分出 7 级阶地。

对比前人划分结果及野外对阶地剖面的测量,我们认为大弯地区只发育 3 级基座阶地(图 1~图 4)。最高阶地相对拔河高度约 80~100 m,阶地沉

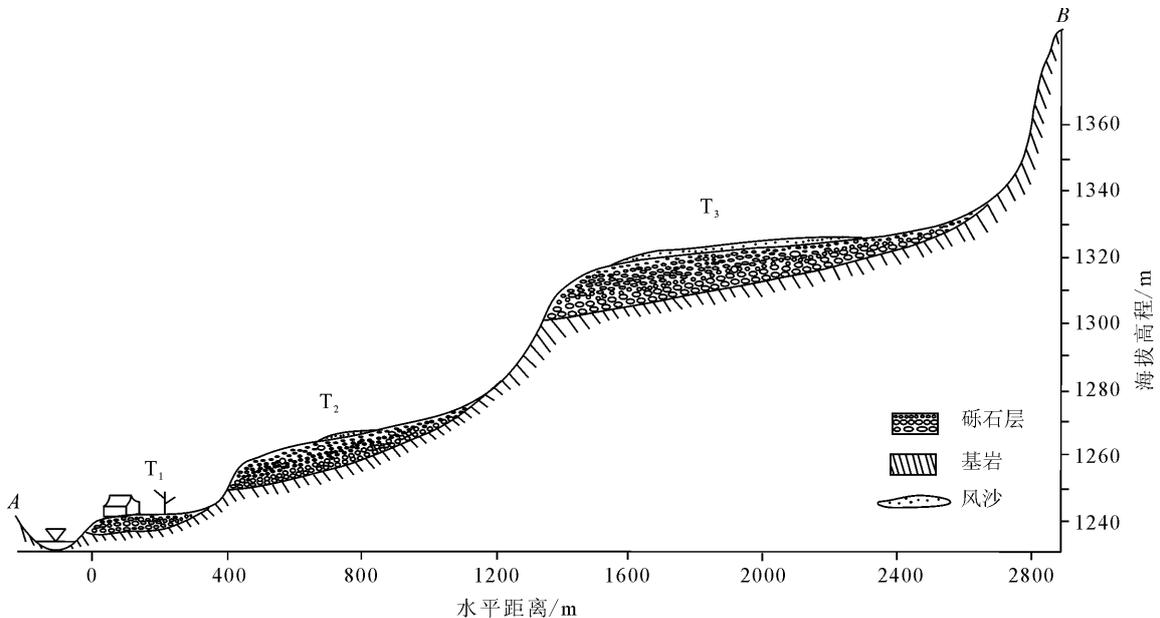


图 2 沙坡头黄河大弯一带阶地剖面图(剖面位置见图 1)

Fig. 2 Profile of the Yellow river terraces in Shapotou area



图3 沙坡头黄河大弯河流阶地地貌(镜向东南)

Fig. 3 Photo of the Yellow river terraces in Shapotou area (View towards the southeast)

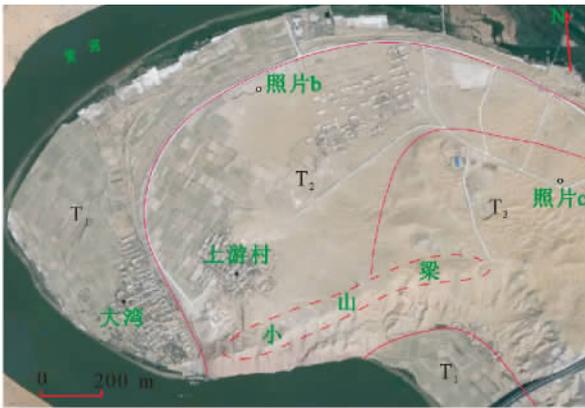


图4 沙坡头附近卫星影像图(底图据 Google Earth)

Fig. 4 Satellite image of Shangyou village and adjacent area in Shapotou area(According to Google Earth)

积物主要是磨圆度较好的砾石,粒径以 8~20 cm 为主,偶见巨大砾石。砾石层中几乎无泥沙,没有二元结构特征。基座为第三系的红色泥岩或砂岩。

我们划分的 T_1 、 T_2 阶地与前人划分基本一致^[1,8-9,11,19]。丁国瑜^[1]认为的台地是我们划分的 T_3 阶地,因为此“台地”堆积的是典型的黄河砾石、未固结,与中卫盆地南侧南山台子的堆积有明显区别,并且测年结果也表明这些堆积物的时代为中更新世晚期。胡海峰等^[19]划分的 T_5 (即他们划分的最高阶地)与我们的 T_3 阶地无论是范围和高程都是一致的。而冯希杰等^[9]划分的 T_6 和 T_7 的范围与我们的 T_3 一致,二者之间有现代沙丘存在,经我们这次差分 GPS 测量阶地面是可以相连的,是阶地向山地方向的自然延伸,二者可以合并。胡海峰等划分的 T_3 、 T_4 以及冯希杰等划分的 T_3 — T_5 阶地位于上游村南侧的一个很狭窄的小山梁上(图 4)。从图 3 可以看出,这个小山梁高差不足 20 m(处于 T_3 前缘黄河砾石底部与 T_2 后缘黄河砾石之间),由泥盆纪的砂岩^[20]组成。小山梁北坡往东延伸时,与 T_2 、 T_3 之间的坡面相连,坡面形态自然,小山梁南坡

受后期黄河侵蚀,成为陡坡(图 4)。小山梁非常狭窄,在小山梁顶部未见原生的黄河砾石分布。我们从高程以及地貌特征分析,在此不应发育有阶地,即胡海峰等^[19]划分的 T_3 、 T_4 是不存在的。因此,研究区自黄河被固定以来,只发育有 3 级阶地。

T_1 阶地:基座阶地,拔河高度约 8~10 m,阶地宽度约 200~400 m,被村庄和农田占据。阶地上部为河漫滩沙—粘土堆积,厚 10~30 cm(见图 5(a))。下部为厚 4~8 m 的砾石层,砾石含长英质成分,磨圆度好,粒径约 8~20 cm 为主。砾石层中透镜体沙样品光释光年龄为 (8.46 ± 0.36) ka B. P.^[21]。

T_2 阶地:基座阶地,前缘阶地顶面拔河高约 40 m,阶地宽度 800~1 100 m,阶地部分被现代风沙覆盖,发育沙丘。砾石层厚 4~10 m,粒径约 8~20 cm 为主,偶见 1 m 以上砾石,含丰富的长英质,砾石层理较明显,磨圆度和分选好。砾石层中透镜体沙样品(见图 5(b))光释光年龄为 (71.84 ± 2.59) ka B. P.^[21]。

T_3 阶地:基座阶地,前缘阶地顶面拔河高约 80 m,阶地宽约 1 400~1 600 m,阶地上发育现代沙丘。砾石层厚达 15 m,粒径以 8~20 cm 为主,并含有 1 m 以上砾石,含丰富的长英质砾石,层理较明显,磨圆度好,分选好(见图 5(c))。砾石层中透镜体沙样品(见图 5(d))光释光、ESR 年龄分别为 (169 ± 6) ka B. P.、 (194 ± 29) ka B. P.^[11]。

3 讨论

从图 1、图 4 可以看出,沙坡头大弯地貌是由 3 级河流阶地、黄河的大拐弯构成。显然阶地和大拐弯的成因可能是不同的,河流阶地可能与垂向上的作用相关,大拐弯更可能与水平方向的作用相关。因此,为了分析讨论清晰,我们分别对这二方面进行分析。

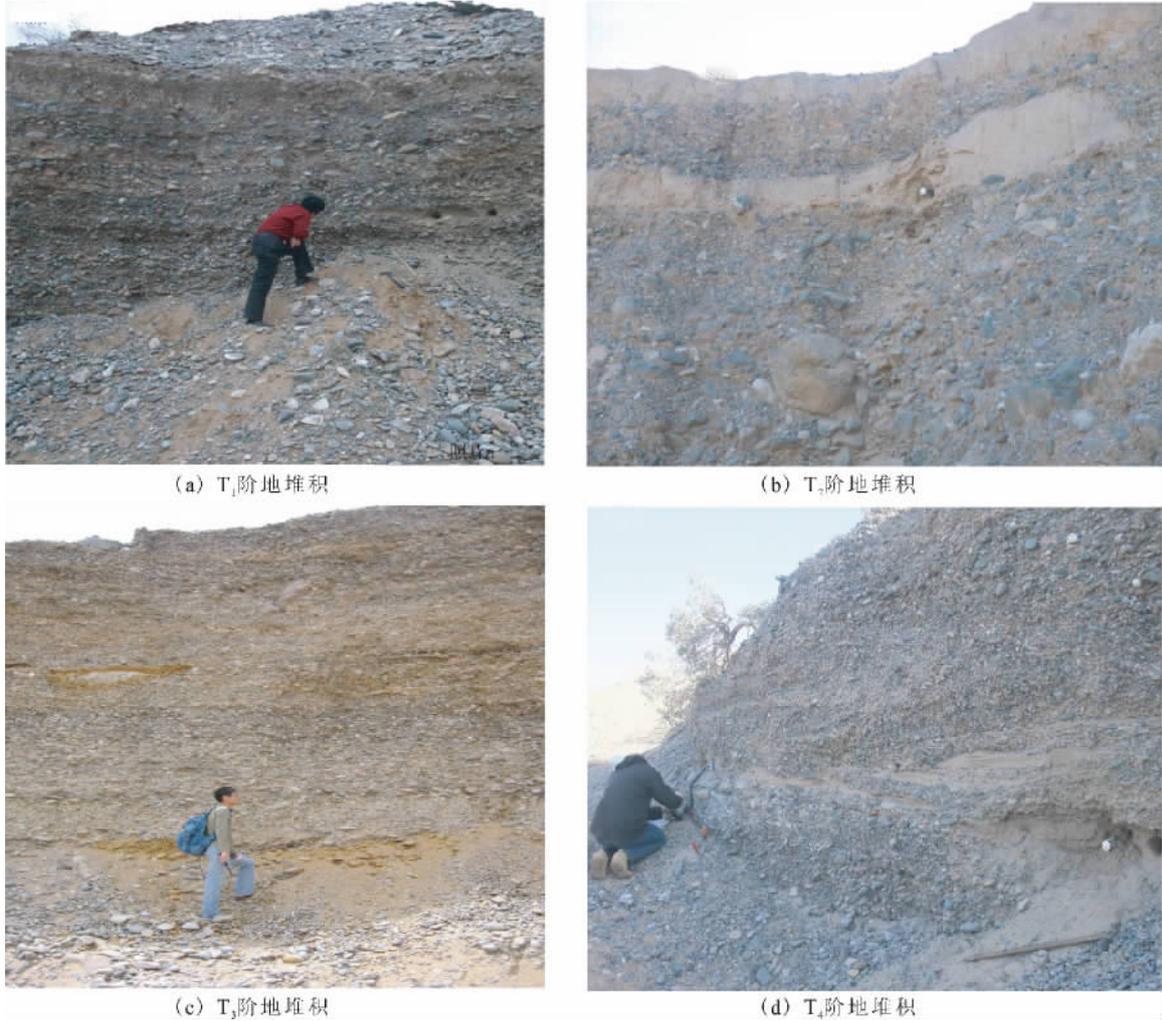


图 5 沙坡头黄河阶地堆积物(照片位置见图 4)

Fig. 5 The Yellow River terrace deposits in Shapotou area

3.1 河流阶地的成因分析

河流阶地是过去河流的河床由于内外因的变化而被废弃的一种河流地貌^[22],其地貌形态和沉积物都记录了河流系统的构造活动、气候因素变化及侵蚀基准面变化^[23-27]。

黄河的侵蚀基准面是海平面, Schumm^[28] 研究表明海平面的升降对大河影响的最大范围在河口之上大约 300 km 河段。而沙坡头地区距河口的位置远远大于 300 km, 所以海平面下降很难影响到此处。

气候干湿变化通过影响河流的水量和含沙量来影响河流过程和河流地貌。当河流有较高的能量和高的沉积物供应, 阶地面高差可达到 5~15 m, 河流沉积砾石多为地方性基岩碎屑, 磨圆度低, 分选差, 有多个二元结构, 堆积物中有泥石流楔入, 河流沉积物中常有斜坡堆积, 一般为堆积阶地^[29]。仅仅依靠气候变化, 河流无法持续下切形成多级阶地^[30]。沙坡

头河流阶地砾石以长英质为主, 磨圆度好, 分选好, 表明此处阶地砾石并非本地来源; 沙坡头河流阶地无二元结构; 沙坡头发育高差约 80~100 m 的 3 级基座阶地; 潘保田等^[31] 在研究兰州东盆地黄河阶地成因时得出气候变化不是黄河 T₁ (130 ka)、T₂ (50 ka)、T₃ (10 ka) 阶地形成的主要原因。沙坡头黄河阶地堆积物测年结果与该段黄河阶地形成年代接近, 气候变化也不是阶地形成的充分条件。综上所述, 沙坡头大弯河流阶地的形成并不是气候变化作用下可以形成的。

构造运动造成侵蚀基准面和河床坡度的变化, 影响河流系统中侵蚀、搬运和堆积过程, 当地壳抬升时, 河床纵比降增大, 水流下切侵蚀, 力图使新河床达到原先位置, 靠近谷坡两侧的老谷底形成阶地; 地壳相对稳定时期, 河流以侧蚀和堆积为主^[24]。构造运动的间歇性使得河流的下蚀与堆积交替进行, 可形成多级阶地, 多级阶地分布的高度范围可达数百

米^[32]。沙坡头地区基座阶地的沉积砾石厚度大,不具有二元结构,阶地面宽,不同级阶地高差达 80~100 m,符合构造运动形成的阶地的特征。

Starke^[29]提出的构造上升区域河流对气候变化响应的模式认为:在构造稳定的区域,气候周期性变化形成的阶地前后缘高差很小;在构造运动强烈的区域,以宽谷型阶地为主,阶地面之间的高差较大;在强烈构造抬升区,低阶地后缘远低于高阶地堆积的底部。从图 2 沙坡头黄河大弯一带阶地剖面图,根据 Starke^[29]的理论,沙坡头黄河大弯一带阶地的成因应该为强烈构造抬升区中的构造事件形成的。

沙坡头位于青藏高原东北缘断裂带内,该区域晚第四纪以来活动强烈。青藏高原及其周边地区河流阶地的研究都表明有受到构造运动的影响^[33-36]。在沙坡头大弯处河流阶地的基座多为第三系的红色泥岩或砂岩,其抗侵蚀能力较差,有助于黄河的下切而形成基座阶地。

中卫盆地在第三纪至第四纪早期沉积范围较大,至第四纪晚期盆地轮廓发生变化,规模逐渐缩小。这是盆地与其西南侧弧形山地间发育的活动断裂带随时间向盆地内部迁移,由挤压逆冲转为剪切走滑的结果。另外中卫盆地北东侧的烟筒山断裂带约在中更新世末期开始强烈活动,使得中卫盆地在内的烟筒山断裂西南盘抬升^[17-18]。中卫盆地的抬升导致黄河开始被固定,受隆升作用开始形成阶地。若中卫盆地一直处于沉降状态,黄河只会形成辫状河,不发育阶地。沙坡头大弯最高阶地(T₃)形成时代恰处在中更新世末期,这与中卫盆地在中更新世末期发生构造事件逆转(从沉降转变为隆升)是一致的。

研究表明,青藏高原第四纪时期包括现今仍处于隆升之中,晚第四纪发生过多次构造事件,使得在青藏高原内及边缘的河流之中发育构造成因的阶地^[37-43],如 0.15 Ma 前后的“共和运动”^[23]、0.01 Ma 前后的“若尔盖运动”^[44]。沙坡头处于青藏高原东北缘、第四纪以来有过多次活动的走滑兼逆冲的香山一天景山断裂的北侧^[7]。综上所述,沙坡头大弯三级阶地主要是在构造作用下形成的,此三级阶地记录了本区域的三次构造事件。

3.2 大拐弯的成因分析

弯曲性河流在自然界中普遍存在是由区域构造条件、气候变化、河流自我调节等因素共同作用的结果^[45]。

当河流穿过断层时,断裂的水平错动可使河道发生扭曲和变形,河流的平衡状态遭到破坏,要达到新的平衡,必然引起河槽内部水动力变化,进而使得河道变迁^[46]。丁国瑜^[1]认为香山一天景山断裂导致黄河 3 km 位错形成现今的大弯。尹功明等^[11]最新研究认为香山一天景山断裂导致的黄河位错最大不足 880 m,而目前大拐弯距离达 3 000 m。因此,香山一天景山断裂的左旋走滑使得黄河水道发生左移,但是现今大弯的形成不完全是断裂的作用。

岩石抵抗侵蚀的强弱对沙坡头大弯的形成有重要的影响,水系遇到障碍后会发生转向。沙坡头小湾村附近有泥盆纪的残丘^[11],河水受到残丘的阻挡向北流去,沙坡头大弯的形成受到水系的自然演变的影响。

沙坡头黄河弯曲形成的因素还有河流内生特性:沙坡头大弯形成的一个内在条件是水体运动的轨迹趋向弯曲这一特性^[47]。促进沙坡头大弯形成的条件还有地球自转偏向力(科里奥利力),水流向右偏转,使得河流发生侧蚀作用,河流不断侵蚀凹岸,在凸岸不断沉积^[48]。沙坡头黄河大弯受弯道离心力和地球偏转力的影响,从凸岸由水面流向凹岸的水流(表流)和从凹岸由河底流向凸岸的水流(底流)构成一个连续的螺旋形向前流动的横向环流(图 6(a)),形成凹岸和凸岸相间分布的河曲形态(图 6(b))。

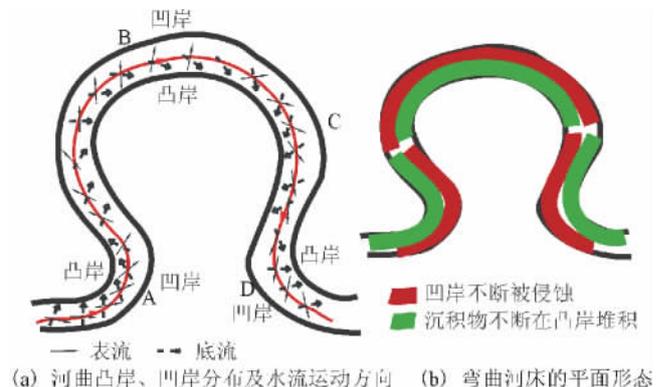


图 6 河曲水流运动方向及平面形态示意图

Fig. 6 Sketch map of meander stream current direction and planar shape

历史资料记录的沙坡头黄河多年平均径流量 $3.50 \times 10^{10} \text{ m}^3$, 多年平均输沙量 $1.6 \times 10^8 \text{ t}^{[49]}$, 即多年平均径流量 $1\ 109.8 \text{ m}^3/\text{s}$, 多年平均输沙量 5.1 t/s 。如前所述,在本研究区的黄河阶地中没有堆积沙、粉沙,表明此地的黄河水动力是非常强的,使得黄河水含大量的泥沙来不及沉降。阶地堆积物主要

是 8 cm 以上的砾石为主。因此,抗侵蚀能力不强的砂岩、泥岩在水动力极强的黄河水作用下,必定产生凹岸侵蚀、凸岸堆积。图 6 说明,黄河在出黑山峡后受到断裂的左旋走滑向左偏转,在地转偏向力的作用下侵蚀右岸,在图 6(a)中的 A 处形成凹岸;之后水流向北流去,水流受惯性力影响侵蚀北岸,在图 6(a)中的 B 处,在南岸发生堆积作用;又因地势的西高东低,水流向东流去,在图 6(a)中 C 处发生侵蚀;然后水流在地转偏向力及离心力作用下,继续侵蚀凹岸,即图 6(a)中 D 处。

因此,现今的大拐弯形态必定有河流内生动力学成因。尹功明等^[1]研究认为自本区的黄河被固定以来,香山—天景山断裂导致的黄河位错最大不足 880 m,而目前大拐弯距离达 3 000 m。所以由河流内生动力学成因引起的黄河拐弯至少达 2 200 m。显然,沙坡头的大拐弯成因是以河流内生动力学导致河流拐弯为主,香山—天景山断裂左旋位错贡献的拐弯为辅。

4 结论

(1) 沙坡头黄河只在河流凸岸发育 3 级阶地,凹岸没有发育阶地。沙坡头大弯河流阶地是构造事件形成的阶地,气候作用不明显。在中更新世末期,中卫盆地由沉降转变为抬升,黄河河道被相对固定,形成最高级阶地 T_3 ,又约在 70 kaB. P.、8 ka B. P. 形成 T_2 、 T_1 阶地。

(2) 沙坡头的黄河大拐弯是由香山—天景山断裂左旋走滑位错,以及水流受地球自转偏向力的河流内生动力共同的作用结果,并且后者(导致拐弯约 2 200 m)的作用远大于香山—天景山断裂左旋位错(约 880 m)的贡献。

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