地理学报(英文版) 2003年第13卷第4期

Geomorphologic characteristics and origin of the valley bottom troughs at the site of Three Gorges Dam

作者: LI Xusheng YANG Dayuan

This paper describes valley bottom troughs of the Changjiang River and infers the geomorphologic development of troughs. Based on the morphology of the troughs, the following conclusions are drawn. (1) The deep troughs on the Three Gorges valley bottom are formed by river downcutting along the structural zones on the background of regional tectonic uplift at about 40-30 ka BP. (2) When river downcutting occurred in the river bed of Changjiang, the jets current (particularly eddy current) with a large number of pebbles ground and eroded the valley bottom, resulting in trough formation and deepening. Meanwhile, water currents with gravels and pebbles eroded the bank and the left wall of No.76 trough as well as the right wall of No.77 trough by striking, scouring, horizontal and vertical grinding. (3) The depth of the trough is mainly determined by the intensity of the water current and the consistency of bedrock against erosion, and is not controlled by the altitude of the sea level as the base level of erosion.

Geomorphologic characteristics and origin of the valley bottom troughs at the site of Three Gorges Dam LI Xusheng1, YANG Dayuan1, KE Xiankun1, ZHOU Lufu1, CHEN Deji2, YANG Tianmin2, XUE Guofu2 (1. Dept. of Urban and Resources Sciences, Nanjing University, Nanjing 210093, China; 2. Exploration Bureau, Changjiang Water Resources Committee, Wuhan 430010, China) 1 Introduction With universality in the development, the origin of river bottom troughs in mountain regions has been one of the basic issues of geomorphology. Study on the development of river troughs is of significance to navigation, hydraulic engineering construction and mechanism analyses of natural disasters which occurred on the valley slopes (Yang, 1992). In the book of "Valley Landforms of the Upper Reaches of the Changjiang River", Shen (1965) defined 12 depressions, below the Wusong Altitude-Zero and located at the river bottom of the channel segment between Sandouping and Nanjinguan of the upper reaches of the Changjiang River, as the "troughs" and presumed the origin of these troughs to be related to the Neotectonic movement, local lithology, headward erosion in the glacial stage, etc. The distribution, morphologic characteristics and development of the troughs located at the Three Gorges channel were also analyzed and discussed preliminarily (Yang, 1992). Understanding of the visual forms and geomorphologic characteristics was not sufficient because the valley bottom troughs were generally hidden deeply under river water, which led to the shortage of direct evidences for the origin and development of the troughs. However, associated with the construction of the Three Gorges Dam, engineering investigations were carried out on the riverbed at the site of the Three Gorges Dam. Two extremely-deep lengthways troughs were exposed to the world for the first time after the water between the upper and lower cofferdams was pumped out, and a superexcellent opportunity is provided to study the morphology and the origin of the valley bottom troughs. During the construction of the Three Gorges Dam, we have investigated the troughs on site by tracking with the process of construction engineering, and this paper mainly explores the geomorphologic characteristics, the origin and the formation age of the troughs based on their morphology. 2 Distribution of the troughs in the Three Gorges channel The reaches of the Changjiang River between Baidicheng and Nanjinguan, collectively called the Three Gorges channel, are about 200 km long. A series of troughs were developed in the riverbed bottom. The average water-depth of the Three Gorges channel is more than 35 m, and the longitudinal profile line of the riverbed is tortuous with 40 m more of undulating diversity in elevation. According to the trough definition by Yang (1992), there are about 90 troughs in the Three Gorges channel of the Changjiang River, and all the troughs are more than 40 m below the lowest river level. Cumulatively, the troughs cover about 45% of the total length of the river channel. The distribution of the troughs generally has the following characteristics: (1) mostly located at the narrow section of the channel or at the lower spot of the river bend; (2) normally developed along the tectonic fissures; and (3) the major anises generally coincide with the direction of the stream flow. For the two lengthways troughs adjacent to the site of the Three Gorges Dam, i.e., Nos. 76 and 77 troughs of the Three Gorges channel (Figure 1), the bottom of the riverbed is at 10.6 m a.s.l. while the deepest point of the trough bottom at -10.7 m a.s.l. 3 Geomorphic characteristics of the troughs adjacent to the dam site 3.1 The troughs with precipitous and even vertical walls The Sandouping channel of the Changjiang River is about 400 m wide at the surface and 325 m wide where the channel is less than 30 m deep. Eroded boulders and rocks are widely distributed on the surface of the shallow beach. However, the top of the troughs, which is more than 40 m deep, is only 40 m wide. The two lengthways troughs, which are adjacent to the dam site, developed with precipitous and even vertical walls and formed a U-shaped valley (Figure 2). 3.2 Intense erosion and abrasion displayed on the left wall of No.76 trough Numerous abrasion troughs were developed along the water-current direction on the precipitous wall of the left side of No.76 trough. In width most of the abrasion troughs are only tens of centimeters while a few can be more than half a meter, and these troughs generally extend horizontally along the rock fissures. On the wall surface of No.76 trough, some vertical erosion fissures and abrasion troughs were also developed, of which the bigger ones were developed into the "cutting troughs" while the smaller normally in form of the deep and narrow abrasion fissures along the tectonic fissures. Densely dotted abrasion sockets were developed vertically downwards and formed the unique "cabbage-like" shapes on the surface of slight-slope granite cliffs, miraculous like the karst landform in the calcareous-rock regions. Rock cores remaining at the bottom center of some abrasion sockets indicate that the abrasion sockets were formed by continuous gravel abrasion under the eddy currents. Numerous vertical abrasion troughs and sockets were developed on the upstream face of a diabase vein crossing vertically the trough wall, in contrast, no abrasion trough or socket is found but only weathered and collapsed rock debris and relics on the downstream face of the diabase vein. These suggest that the left wall of No.76 trough experienced intense erosion by jet current and strong abrasion by the eddy current and descending current armed with gravels. 3.3 Strong impact and abrasion occurred on the rock ledge in No.76 trough A rock ledge near the right side of No.76 trough extends towards the trough center and splits the trough into two parts. The left profile of the rock ledge, i.e., the right wall of the left trough, shows an eroded smooth fissure plane. Huge rock fragments, which seem to be the remained broken rocks after reef explosion, were piled up on the top of the rock ledge. Many potholes of several centimeters in diameter are found in the upstream face of these piled rock fragments, indicating the strong impact from the rock gravels. Dense small abrasion troughs were developed and extend horizontally at the edge of upstream face of the rock fragments. In addition, vertical abrasion sockets with the typical form of pothole can be also found in some specific spots of the rock ledge, indicating that the rock ledge of No.76 trough experienced strong impact and abrasion from the jet current with the rock gravels. 3.4 Vertical abrasion fissures and troughs developed on the right wall of No.77 trough The up margin of the left wall of No.77 trough shows a polyline form which coincides with the trend of the trough, and each segment of the trough wall tallies with the surface of the joint fissures. Dense abrasion troughs, erosion fissures and abrasion sockets were developed vertically along the surface of the wall. Most erosion fissures extend along the tectonic fissures, and their transverse sections are narrower in the mouth but with a deep bottom, different in form from the arc-formed abrasion troughs. The abrasion sockets display the pocket form and their bottoms have not yet been abraded through. The development of numerous abrasion troughs, erosion fissures and abrasion sockets formed many coniform or steepled rock pillars remained in the trough wall after abrasion and erosion. In addition, the right wall of No.77 trough was cut off by the underwater eroded-grooves, indicating the existence of strong subsidence-flow with a great number of gravels along the surface of the right wall of the trough. 3.5 Pressure-released cracks and colluvial deposition developed on the left side of No.77 trough wall The precipitous left wall of No.77 trough was developed along the extending direction of the trough as the general polyline form but as the folding form in some specific sites, of which the eminent parts are mainly the comparatively integrated rock masses or epidotization rock belts in the broad fracture zones. In contrast, on the left wall of the trough many pressure-released cracks paralleling with the riverbed or the surface of the trough wall were developed (Figure 3) while no abrasion trough, erosion fissure or abrasion socket is found, and the cracks are embedded with many pebbles and gravels. Bent surface of the trough wall was formed and colluvial deposition was left at the bottom of the trough wall after the cracks collapsed. 3.6 An undercutting hollow formed at the base of No. 77 trough At the bottom of No.77 trough a large-size undercutting hollow was formed at about -5 m a.s.l. while an eroded deep round hole was formed at about -10 m a.s.l. within the bottom of the hollow (Figure 4). Additionally, wide and shallow abrasion sockets were also developed at different sites of the trough bottom, and round pebbles still remained in some abrasion sockets. Thus, it can be seen that the river troughs were developed by strong undercutting and intense abrasion of the edd y currents with rock gravels, similar to the formation of the river bottom potholes in the mountain regions. 4 Discussion on the origin of the troughs at the site of the Three Gorges dam 4.1 Structural foundations for trough development The development of the two lengthways troughs at the site of the dam is controlled by the fissure structures. A series of tectonic fissures were formed in the dam region under the function of the tectonic movements. The lengthways NNW and transverse NNE, NE-NEE tectonic fissures were mostly developed and widely distributed in the dam region with the large-scale, smooth and straight fracture planes and strong extensibility. Most fissures are about 20 m long, alternating with some fissures of about 40-80 m long. The trough just coincides with the extending direction of the fissures (Figure 5), which indicates that the troughs were formed by river downcutting along the tectonic fissures and the trough orientation is controlled by the lengthways fissure structures. Meanwhile, the local rocks are mainly the anterior Sinian-system crystalline rocks cut by the tectonic fissures; the function of the water currents on the rocks are mainly reflected as abrasion, erosion and undercutting on the rock surface. The rocks were cut into smaller blocks by the intersection of the lengthways and transverse fissures, which provided advantageous conditions for the current erosion, accelerating the trough development. Therefore, the deepest points of the troughs, i.e. the sites which are most liable to be deeply cut, normally appeared in structural zones of high intensity where joints and fissures, lengthways and transverse to the stream flow direction, intersect. Regional tectonic uplift in the dam region also provided advantageous conditions for the trough development. In the Three Gorge region exist two-stage planation surfaces with elevations of about 2000-1500 m a.s.l. and 1000-800 m a.s.l. respectively. Besides, multi-stage river terraces also exist along the Three Gorge valley (Shen, 1965), and according to the investigation, four-stage river terraces occurred in the channel between Fengjie and Nanjinguan, and the relative height of the fourth terrace is about 92-101 m, possibly formed in the mid-late stage of the Middle Pleistocene (Yang, 1988). These show the occurrence of the extensive structural uplift in the Three Gorge region. 4.2 Dynamic conditions for trough development It can be known from the analyses on the trough morphology that the current erosion played a key role on the trough development. The dynamic forces of the trough development at the site of the Three Gorge Dam come from jet current erosion, eddy current abrasion and descending current undercutting armed with gravels. In the region of the Changjiang River the rainfall is abundant and the maximal fluctuation of the water levels between the flood and the low water seasons can reach 30 m or more. According to the field data of 1877-1980, the average discharge at the outlet of the Three Gorges was 14,300 m^3s^{-1} with a maximum of 71,100 m^3s^{-1} (Yang, 1992). The gradient of water surface in the Three Gorge channel is also relatively high, and in the gorge channel within the flood season, it may reach 5-6‰ with a current velocity of 5-7 ms^{-1} (Yang, 1992), together with the sharp increases of the sediment concentration and the bed load content. Although the spread of flow can reach hundreds of meters in the flood period, the discharge flow cross section is mainly centered in the channel part of the river. Besides, the river course near the Three Gorge Dam is just located at the river bend. The Changjiang River flows across the site of the dam from the direction of NW40o and turns to flow out to the direction of NE70o at Sandouping. Therefore, the current flow at the site of dam mainly displays complicated flow pattern with jet current and boil eddy. The single boil eddy can reach tens of to one hundred meters in diameter with a huge undercutting intensity. The jet current with a great number of gravels and sands produced numerous erosion fissures, abrasion troughs, abrasion sockets and undercutting hollows on the bedrock surfaces by the continual erosion, abrasion and undercutting along the tectonic fissures. Because the troughs at the site of Three Gorges Dam were formed by jet current erosion, eddy current abrasion and descending current undercutting, the greatest depth of the troughs is mainly determined by the intensity of the local water current as well as the consistency of bedrock against the erosion. Therefore, the depth of the troughs can reach 10 m or more below the sea level, and is not controlled by the altitude of the sea level of 2000 km far away. 4.3 The age of the trough erosion By deeply digging the deposition in No.77 trough, 12 samples of the deadwood were collected for 14C-dating measurement at different horizons of the deposition (Figure 6 and Table 1). The 14C-dating data of the deadwood samples collected from the trough bottom mostly range from 30 ka BP to 40 ka BP. It can be inferred preliminarily that the strong downcutting of the trough occurred at about 40-30 ka BP. Studies (Shi et al., 1999; 2002) showed a strong summer monsoon happened within 40-30 ka BP in the Tibetan Plateau, which resulted in an abnormal warm and humid climate with 2-4oC higher in temperature and 40% or several times more in precipitation than at present. High rainfall and huge inundation in the upper reaches of the Changjiang River led to the formation of the gravel strata along the Chuanjiang River (i.e., the segment of the Changjiang River in Sichuan province); 14C-dating data of the deadwood samples from the gravel strata were 39,300±2600 a BP and 33,200±1500 a BP (Liu, 1983). High rainfall and huge inundation at 40-30 ka BP was liable to produce the jet current and strong eddy current in the channel of the Three Gorges, which led to intensive erosion, abrasion and undercutting, finally formed troughs with precipitous walls. It is necessary to point out that the trough formatio n were earlier than the age of the deadwood samples fallen into the troughs, because the formation of a rock trough normally needs thousands of years but tree growth only several decades; only after the trough formation could the dead woods fall into them. 5 Conclusions (1) The deep troughs on the Three Gorges valley bottom are formed by river downcutting along the structural zones on the background of regional tectonic uplift. The data of 14C dating indicate that the downcutting of the troughs occurred at about 40-30 ka BP. (2) When river downcutting occurred in the river bed of Changjiang, the jets current with a large number of pebbles ground eroded the valley bottom, resulting in trough deepening. Meanwhile, water currents with gravels and pebbles eroded the bank and the left wall of No.76 trough as well as the right wall of No.77 trough by striking, scouring, horizontal and vertical grinding. The left wall of No.77 trough was developed after trough deepening, when the pressure-released fracture formed on trough bank. (3) The trend of the troughs was controlled by lengthways fissure structures. The deepest points of the troughs are normally located at the intersection of the lengthways fissures with the transverse ones. The depth of the trough is mainly determined by the intensity of the water current and the consistency of bedrock against erosion, and is not controlled by the altitude of the sea level as the base level of erosion. Acknowledgements Thanks for the valuable instruction from the Exploration Corporation of the Three Gorges, the active cooperation from the Exploration Institute of the Three Gorges, the great support from the staff members of the Three Gorges Project and the positive participation of Wu Shize, Feng Yanxun, Ye Yuanming, Wang Xilei, Liao Libin, Pan Jinhe, Lei Ronghua, Zhang Jianxin, Ren Lixiu, Xu Dingqing and Zhang Liping in this project.

关键词： valley bottom trough; geomorphologic characteristic of valley bottom; the Three Gorges

