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Fluvial Erosion and the Formation of Gully Systems over the Chinese Loess Plateau

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Abstract: Fluvial erosion constitutes one of the major environmental disasters in the middle reaches of the Yellow River in northern China. Gully erosion is extremely active over the regions of loess ridges, hills and tablelands. History of major loess gully systems is traceable to as early as ca. 600 ka B.P. by the buried palaeogullies and pedo-stratigraphic unconformities preserved in the loess-palaeosol sequences over the Loess Plateau. The subsequent episodic down-cutting and the outspread of the tributary gullies in different order are closely connected to the arrival of the southeastern maritime monsoon that brought on much precipitation and runoff to the region. The major phases of gully incision and extension occurred at 600-460 ka B.P., 240-180 ka B.P., 128-75 ka B.P. and 11.5-0 ka B.P., respectively over the Loess Plateau. This provides new insights into fluvial erosion and monsoonal climatic variation in the semi-arid loess regions.

Key-Words: Erosion History, Gully formation, Loess Plateau, Yellow River, China

1 Introduction

The largest aeolian loess extent in the world is situated in the middle reaches of the Yellow River in northern China. The soft, porous, permeable and calcareous-rich loess under the semi-arid climate and sparse vegetation is highly vulnerable to fluvial erosion. The tributaries of the Yellow River and the densely developed gully systems have been nibbling and dissecting the Loess Plateau and have created a yellowish landscape of barren ridges, hills, and tablelands with cliffy slopes and extremely dusty river waters.

History of fluvial erosion in the middle reaches of the Yellow River has long been subject of interest to scientists. Geomorphologists identified several physiographic stages of denudation or deposition by topographic, stratigraphic and palaeontological studies over the drainage area of the Yellow River in the early 20th century (Willis, et al., 1907; Andersson, 1939). This has long been applied to illustrate the landform development and the formation of loess strata in northern China during the late Tertiary and Quaternary (Liu, 1965). Extensive geomorphological investigation during 1950s-1960s concluded that the loess tablelands, loess ridges and hills are mostly inherited landform types and have been blanketing by accumulated aeolian dust over the Quaternary. The major loess gully systems have been forming since the late Quaternary (Liu, 1965; Zhang, 1981). Tang, et al. (1991) investigated the weathering and pedogenesis over the Loess Plateau with consideration of the results of fluvial erosion experiment with artificially simulated rains, it is reported that intensified sheet erosion occurred at the shift from loess formation to palaeosol formation because of increased precipitation and runoff on poorly vegetated loose loess ground at the time.

It is estimated that the sediment yield due to accelerated erosion induced by human activities is ca. 25-30% of the total sediment yield in the middle reaches of the Yellow River at the present (Jing and Chen. 1983). The data of hydrological observations on the mainstream of the Yellow River indicates that the variation of annual sediment discharge closely related to the change in annual water discharge. Therefore, intensified erosion occurs in the years with increased precipitation under the present situation of extensive and intensive human disturbance in the middle reaches of the Yellow River. (Wu, et al., 1994; Wang & Jiao,1996).

In the recent years, more detailed geomorphological analysis has been applied to investigate soil erosion and its dynamics in small gully catchment in the region. Progress has been made in understanding soil erosion under an integrative effect of landform, neo-tectonic uplifting, surface gradient, soil properties, vegetation cover, climate change, runoff yield and human disturbance, etc. (Gan, 1990; Qi, 1991; Zhang, 1993; Wang and Jiao, 1996). But the history of gully erosion, especially the connection between soil erosion and large-scale monsoonal climatic change is still a question open for discussion.

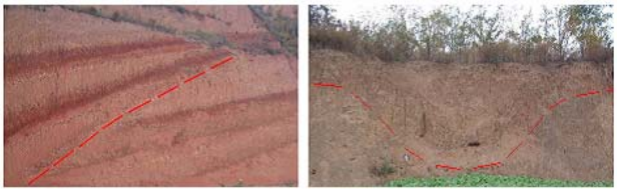

Figure 1 The buried palaeogullies and pedo-stratigraphic unconformity showing the past gully erosion persevered in the Loess-palaeosol sequence over the Chinese Loess Plateau. **Left**: the margin of a palaeogully occurred at 600-460 ka BP; **Right**: a palaeogully occurred at 11.5-0 ka BP. And infilled by Holocene palaeosol (S0) and the recent loess (L0 with its topsoil)

In order for understanding the comprehensive impact of global change and human activities on soil erosion in the middle reaches of the Yellow River, the Quaternary history of soil erosion, and especially the occurrence of various erosion phases and their mechanisms must be studied multi-disciplinarily. The progress in studies of the Chinese loess and monsoonal climatic variation enable an in-depth investigation into how and when soil erosion occurs in this region. This paper presents the results of our research on gully erosion phases and their correlations to monsoonal climatic change.

2 Phases of gully incision

Gully erosion is extremely active over the Loess Plateau. Generally, gully density is 1-3 km/km^2 in the regions of loess tableland, 3-8 km/km^2 in the regions of loess ridges and hills. The down-cutting and regression of gully erosion on land could be largely intensified by climatic change. Gully density is therefore increased and the loess land became more dissected ridges and hills. The area occupied by gullies could reach 50-60% in the region of loess ridges and hills and 80-90% of the sediment yield would come from fluvial gully erosion. Palaeo-geomorphological and loess-palaeol stratigraphical investigations were carried out in purpose of tracing the history of gully development (Yuan, et al., 1987 Sun and Gao, 1990 Zhang, 1993; Lu and Yuan, 1995 and the author's own unpublished data). The episodic gully erosion is recorded by the buried palaeogullies and the pedo-stratigraphic unconformity found in the loess-palaeosol sequences over the Loess Plateau (Fig. 1). It is generalized by our own investigation over the Loess Plateau that the cross-section development of a main gully (e.g. 6-10 km long and >150 m deep) has experienced 4 major phases of vertical erosion (Fig. 1):

The first phase of gully vertical erosion occurred at ca. 600-460 ka B.P. in response to formation of the tripled palaeosol S5 on hilltops and tablelands. The present loess ridges and hills were only gently undulated landform. Loess tablelands occupied much larger areas than that of the present. The eroded ground surface or the margin of a palaeogully has been preserved as a local pedo-stratigraphic unconformity along the main gully because of the accumulation of the aeolian loess interbedded with palaeosol S5-S4-S3-S2-S1-S0 on hillside afterward (Fig. 1).

The second phase of gully vertical erosion occurred at ca. 240-180 ka B.P. in response to formation of the doubled palaeosol S2 on hilltops and tablelands. The gully cuts into loess strata ca. 40-60 m deep with slope gradient 15-25º. After that, the gully slopes have been blanketed by aeolian loess interbedded with palaeosol S1-S0 and another local unconformity has therefore been formed along the main gully.

The third phase of gully vertical erosion occurred at ca. 128-75 ka B.P. in response to formation of the tripled palaeosol S1 on hilltops and tablelands during the last interglaciation. The gully cuts further into loess strata ca. 80-100 m deep with slope gradient 25-50º. The gully slopes have been blanketed by the Malan Loess (L1) and the Holocene palaeosol S0 and the recent loess (L0 with its topsoil) which accumulates from 75 ka B.P. to the present time.

The forth phase of gully vertical erosion has started since ca. 11.5 ka B.P. in response to the initiation of the Holocene palaeosol S0 on hilltops and tablelands. The gully cuts further into loess strata ca. 10-15 m deep with a slope gradient of 50-60º (Fig. 1).

3 Phases of gully extension

A well-developed major loess gully system has 4 orders of tributary gullies generally according to Strahler's system (Fig. 2). The development of the tributary gullies is correlatable to the cross-section development of their main gullies. The length of a gully, that has been developing since 600 ka B.P., is generally 6-10 km and depth over 150 m (>300 m on the northern and western parts of the region). The elevation of the gully bottom is close to its destination stream or river and therefore it has lost its potential of vertical erosion. Because it cuts down through the unconformity surface between the Quaternary loess and the Neocene Red clay formation, the seepage of ground water supplies a small stream in the gully. It represents the forth order gully in a major gully system.

The third order tributary gullies in a major gully system have been developing since 240 ka B.P. They have cut into the loess-palaeosol strata 100-150 m deep and have a length of ca. 4-6 km (Fig. 2).

The second order tributary gullies have been developing since 128 ka B.P. They have cut into the loess-palaeosol strata 30-50 m deep and have a length of ca. 2-4 km.

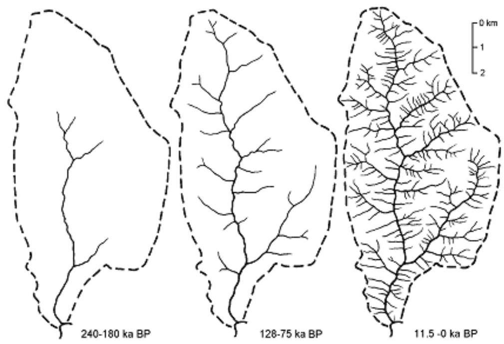

Figure 2 Maps showing the episodic development of the Laozhuanggou gully system with a catchment of 52.72 km^2 on the Luochuan loess tableland (Source: Zhang, 1993, revised).

The first order gullies have developing since ca. 11.5 ka B.P. They have cut into the loess-palaeosol strata <30 m deep and have a length of ca. 1-2 km (Huang, et al. 2002a).

There are numerous gullies with a length of ca 200-300 m and depth <10 m densely distributed on hill slopes in all of the loess regions. These gullies are developing since ca. 3000 a B.P. Their vertical and regressive erosion are nibbling and dissecting the loess land most actively.

Age (ka B.P.)	Gully density (km/km2)	Number of gullies
240-180	0.284	4
128-75	0.891	35
11.5	3.337	533
Present time	7.708	2774

Table 1 History of gully development in the

catchment of the Laozhuanggou gully (forth-order, catchment 52.72 km^2) on the Luochuan loess tableland in the middle reaches of the Yellow River (Source: Gan, 1990 revised)

Statistical result shows that the number of first-order gullies is ca. 55-85%, the second and the third-order gullies 12-30% and forth-order gullies 3-15% in the region of loess ridges and hills such as Suide and Mizhi counties in Shaanxi, and Dingxi and Qinan Counties in Gansu Province (Gan, 1990).

The formation of the gullies in each order was started during the soil formation on the hilltops and tablelands at the arrival of warm-wet climate. The gully erosion phases are therefore, attributable to the arrival of increased precipitation and runoff brought on by strengthened southeastern maritime monsoon.

Human land-use of arable cultivation has a history of ca. 8000 years over the middle reaches of the Yellow River (Huang, et al, 2002b). Different approaches have been taken to estimate the components of natural erosion and accelerated soil erosion in the region. The accelerated gully regressive erosion could be estimated by tracing the history of gully development. The average rate of gully regressive erosion is ca. 0.10 m/a during the Holocene (Zhang, 1993). However, the investigations by historical geographers show that the regressive rate of gullies is ca. 2-5 m/a in the southern regions of loess tablelands, and 5-10 m/a in the regions of loess ridges and hills since ca. 1500 A.D. (Shi, 2001). Sometimes a gully can even extend 100-200 m by regressive erosion during a strong rainstorm (Zhang, 1993).

4. Conclusions

Basically, the loess landforms in the middle reaches of the Yellow River are aeolian depositional topography that has been shaped to loess ridges, hills and tablelands by fluvial erosion, and also aeolian erosion to north and west regions. Human activities have emerged as an important dynamic force joined the natural processes in shaping the landscape in this environmentally sensitive semi-arid to arid zone since 3000 a B.P. due to quick increase in population. History of major loess gully systems is traceable to as early as ca. 600 ka B.P. by the buried palaeogullies and the pedo-stratigraphic unconformities preserved in the loess-palaeosol sequences over the Loess Plateau. The subsequent episodic down-cutting and the outspread of the tributary gullies are closely connected to the arrival of the southeastern maritime monsoon that brought on much precipitation and runoff to the region at 600-460 ka B.P., 240-180 ka B.P., 128-75 ka B.P. and 11.5-0 ka B.P., respectively.

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