Formation Mechanisms and Geomorphic Evolution of the Erlian Mudflow Fans, Eastern Guide Basin of the Upper Reaches of Yellow River

ZHAO Wuji¹, YIN Zhiqiang²*, XU Qiang³ and QIN Xiaoguang⁴

¹ School of the Earth Sciences and Resources, China University of Geosciences, Beijing 100083, China
² China Institute of Geo-environment Monitoring, Beijing 100081, China
³ State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology, Chengdu 610059, China
⁴ Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China

Abstract: Several argillaceous platforms lie along the Yellow River (YR) of the eastern Guide Basin, northeastern Tibetan Plateau, and their compositions, formation processes, and geomorphic evolution remain debated. Using field survey data, sample testing, and high-resolution remote sensing images, the evolution of the Erlian mudflow fans are analyzed. The data show significant differences between fans on either side of the YR. On the right bank, fans are dilute debris flows consisting of sand and gravel. On the left bank, fans are viscosity mudflows consisting of red clay. The composition and formation processes of the left bank platforms indicate a rainfall-induced pluvial landscape. Fan evolution can be divided into two stages: early-stage fans pre-date 16 kaB.P., and formed during the last deglaciation; late-stage fans post-date 8 kaB.P. Both stages were induced by climate change. The data indicate that during the Last Glacial Maximum, the northeastern Tibetan Plateau experienced a cold and humid climate characterized by high rainfall. From 16–8 ka, the YR cut through the Erlian early mudflow fan, resulting in extensive erosion. Since 8 ka, the river channel has migrated south by at least 1.25 km, and late stage mudflow fan formation has occurred.

Key words: the upper reaches of Yellow River, Guide Basin, mud-flow fan, forming mechanism, geomorphic evolution

1 Introduction

Mudflows are powerful currents in which clay silt and fine clay particles account for > 98% of the total solid material. They represent a special type of debris flow and have unique characteristics, including their distribution area, conditions of formation, fluid properties, and sedimentary features. Mudflow fans form from fine clay and clastic particles deposited by flowing water (Ma et al., 2005). In recent years, there has been significant scientific interest in mudslides and fans in arid areas. Some studies conclude that mudflow fan formation mechanisms are closely related to the geomorphic evolution of the mountain slopes, which are constantly evolving owing to environmental degradation and soil erosion. However, fan formation may also reflect foothill fluvial geomorphology and evolution, along with regional climate change (Ma et al., 2005; Wen et al., 2005; Chen et al., 2008; Liu, 2010; Chen, et al., 2013; Zhang et al., 2013; Chen and Cui, 2014; Ni et al., 2014; Yin et al., 2014). The conditions of mudflow formation also remain debated. Shi et al. (1994) concluded that these debris flows form in hot and humid conditions (e.g., interglacial periods). In contrast, Matthews et al. (1997) and Nott et al. (2001) suggested that mudflows form during glacial periods or in arid climatic environments. Therefore, further investigation into the causes of Quaternary debris and mudflow fans is needed.

On the northeastern margin of the Tibetan Plateau, regional geomorphic evolution is related to plateau uplift and river erosion from the upper reaches of the Yellow River (YR). In this environment, landslides and mudflows occur frequently (Huang, 2003, 2009). In the Guide Basin, Quaternary alluvial fans and mudflow fans are widely distributed on the either side of the YR, and significantly alter the micro-topography and, furthermore, seriously threaten infrastructure security in the basin. In the Guide
Basin, the north bank of the YR includes numerous clay inclined platforms, which are distributed along the river valley and differ from the normal loess landscape and alluvial fans. These platforms range in size and exhibit deep concave depressions on the surface. They also range significantly in terms of material composition, geomorphology, and vegetation. However, questions remain regarding their material composition, formation mechanisms, relationships to similar karst geomorphology in northwestern arid areas, the implications for the paleoclimate, and the relationships between mudflow fans and river course evolution.

Mudflow fan formation reflects regional climatic and morphological evolution, and our understanding of these factors is improved by studying their distribution and composition, along with the spatial structure of residual alluvial fans. In this way, ancient landscape features can be reconstructed (Liu *et al.*, 2009). Based on field investigation, borehole core samples (including grain size distribution, geochemistry, geochronology), and remote sensing image analysis of the Erlian village area, the spatial distribution, grain size composition, developmental stages, and formation mechanisms of these clay platforms are studied in-depth. Furthermore, the relationship between mudflow fan evolution and YR course changes are considered, and the post-Last Glacial Maximum (LGM) paleo-geomorphology of the eastern Guide Basin is reconstructed.

# 2 Geological Setting

The Guide Basin, which is typical of Cenozoic rift basins, is located between the Laxiwa Gorge and Songba Gorge on the upper reaches of the YR, and is surrounded by the Baji, Wailigong, Laji, and Zhamazari mountains (Pan, 1994). The basement is composed of thick Proterozoic and Triassic stratum, which are overlain by Neogene purple conglomerates, sandstone, and silty mudstones. In turn, these are unconformably overlain by gluteite, the Guide Group mudstone, and Quaternary eluvial strata that extend to depths of > 1000 m (Song *et al.*, 2001; Liu *et al.*, 2013). The region is influenced by the Garang-Ashigong and Daotanghe-Debei faults, as well as by the Swire-Proterozoic metamorphic thrust on the top of the red Neogene stratigraphy. Carbonates are widely distributed throughout the stratigraphy. The region is within the semi-arid inland climatic area; however, due to its location on the southern margin of Lajishan Mountain, rainfall in the study area is high and can reach 700 mm per annum, which is 2–2.5 times more than in adjacent areas (Ma, 2003).

The YR extends west-east through the basin and its elevation ranges significantly from 2170 m to 5011 m. At its widest point, the YR valley is ~6.5 km, although this falls to 2.5 km in the Ashigong area. The entire basin has an area of ~42 km². In the eastern Guide Basin, Holocene sandy gravel (Q₄₆₋₇₄; Fig. 1) and Middle Triassic argillaceous sandstone (T₂) are mainly distributed along the south bank of the YR, while the north bank is composed on weathered Neogene red mudstones and Cretaceous shale strata (Ngd). The Neogene red clay and sub-clay sediments provide a rich source of material for alluvial and mudflow fans on both sides of the valley. The

![Fig. 1. Geological map of the Yellow River valley, eastern Guide Basin, China.](image-url)
YR floodplain and terraces have been cultivated as arable land, which represents the most extensive human economic activity in the region.

3 Samples and Method

The distribution and geomorphology of the mudflow fans were detailed in a field survey, conducted from 2012 to 2014. Samples for grain size, petrological, and $^{14}$C geochronological analysis were collected from the surface of the first stage fan and from borehole cores drilled from the second stage fan (Fig. 2). Samples GD-01–04 are from the surface of the early stage mudflow fan, among which GD-01, 02, and 04 are red clay samples, while GD-03 is a strongly weathered shale sample. Sample GD-05 is a standard red clay sample in Guide Basin. Samples EL-001–005 are from the surface of the late stage mudflow fan. Three boreholes (ZK01–03) were drilled in the late mudflow fan (Fig. 2), from which borehole core samples were taken and comprehensive stratigraphic columns generated (Fig. 3).

Samples for grain size analysis (GD-01–05 and EL-001–005) were separated following the sedimentary grain-size distribution modes separation method (Yin et al., 2008, 2009). Using this method, the grain-size intervals are divided with high accuracy, allowing subtle characteristics to be analyzed, which is critical for distinguishing different sedimentary environments. Median grain size diameters and sentiments percentages were calculated (Table 1). Whole rock compositional data for the mudflow sediment (GD-01), shale (GD-03), and red clay (GD-05) were collected by X-ray fluorescence (XRF1500) at the Institute of Geology and Geophysics, Chinese Academy of Sciences (Table 2). Dating by $^{14}$C

---

**Fig. 2.** Satellite image of the study area. Yellow dashed lines and blue line denote the outlines of the early and late mudflow fans, respectively. Sampling sites on the surface of the early and late mudflow fans are denoted by black circles. Red circles denote borehole sites along profile I–I'. Uneven red arrow denotes the current mudflow channel.
geochronology was performed on samples GD-01 and ELZK1-01 (Table 3), and conducted at the Beta analytic laboratory of American. Sample ELZK1-01 is ancient riverbed silty clay taken from ZK1, and the $^{14}$C geochronology of this sample is used to date the formation of the late mudflow fan.

### 4 Results and Discussion

#### 4.1 Geological and geochemical characteristics

##### 4.1.1 Distribution of mud (debris) flows

Table 3 $^{14}$C geochronology of alluvial sediments and mudflow samples

<table>
<thead>
<tr>
<th>ID</th>
<th>Locations</th>
<th>Sample position</th>
<th>Sample types</th>
<th>$^{14}$C chronology (a.B.P.)</th>
<th>$2\sigma$ (95%) (a.B.P.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GD-01</td>
<td>Top of early mud flow fans</td>
<td>0.15m depth to the earth surface</td>
<td>Red clay</td>
<td>16170±30</td>
<td>17200±17410</td>
</tr>
<tr>
<td>ELZK1-01</td>
<td>Trailing edge of late mud flow fans</td>
<td>ZK1 boreholes</td>
<td>Silty clay</td>
<td>7980±30</td>
<td>8995±8715</td>
</tr>
</tbody>
</table>

Note: $^{14}$C half-life is 5568 years and chronology results from the Beta laboratory of United States.

As a result of Qingshui-Tibet Plateau uplift and erosion by the YR, the study area is characterized by broken and weathered rocks, steep slopes, and debris flows (Zhao and Liu, 2003; Zhang et al., 2003; Shi et al., 2015). Field survey results show at least 66 modern debris (mud) flow gullies, as well as 20 ancient and modern large-scale mudslides and debris flow fans, which are located on the both sides of the YR (Fig. 4). Differences in lithology occur on either side of YR (Fig. 1), and the 10 alluvial fans of the left bank are mainly composed of clay with < 5% gravel, and can be classified as viscous mudflows. On
the basis of landscape characteristics, two large terraces fans can be identified on the north bank. The first platform is distributed across the transition zone of the piedmont and valleys, and contains numerous deep concave depressions on the surface that are similar to karst dissolution funnel rugged topography (Fig. 5). The leading edge of the platform has been eroded away by the YR, with 10–50 m cliffs truncating the shape of the mudflow fans. The second platform is distributed to the south, beneath the former fans, and was again formed by clay transportation. The debris flow fans on the right bank have not been subjected to intense erosion, and maintain classic flow fan morphology and smoothed surfaces. The Golf debris flow fan of Chada village (Fig. 5) has a Holocene sand gravel content of 60%–80% and mainly represents a diluted debris flow induced by rainfall.

The left bank red clay platform zone is spatially distributed around the Xiwantai, Erlian, and Ashigong villages. Of the platforms, three are paleo-clay platforms, while seven are modern mudflow fans (Fig. 1). The largest mudflow fan area contains the Erlian ancient and modern red clay platforms; however, the early stage residual mudflow fan in this area extends just 2.35 km², and the surfaces are characterized by concave depressions of different sizes. The Ashigong-Deqinshi fault cuts the first stage clay platform, and the broken red mudstone stratigraphy provided plentiful material for the formation of the Erlian area mudflow. Modern mudflow gullies cut the first stage platform and present a hazard to the local population and infrastructure (e.g., the roads). Since the late Pleistocene, these two stages of clay platform formation have changed the micro-geomorphology of the YR valley.

4.1.2 Geomorphology of the Erlian mudflow fan

On the basis of elevation and geomorphology, the clay platforms can be divided into two main steps. The first, those with elevations of 2260–2360 m, are distributed in a N-E orientation along Laji Mountain (Fig. 6). This group contains three typical residuary clay platforms, on top of which are concave depressions of various sizes (Fig. 5). The surface material is composed of Neogene mudstone and shale (with the mudstone content > 90%). No vegetation covers the platform surfaces, which are easily broken. A modern mudflow gully cuts through the early red clay platform, and carries unconsolidated mud and shale to the front edge of the low step fan, below the road. Fan-shaped concave landforms are distributed along the river valley and together they form a step of outwardly inclined platforms, the surfaces of which typically contain concave depressions, which in northwest inland China infer a high-rainfall climate.

The second step platform is below the first and has a top elevation of 2220–2190 m. The composition of the material is similar to that of the early mudflow fan, and there is a 50-m-high scarp between the two steps, which was formed by YR erosional activity. The late stage Erlian mudflow fan is located below the scarp of the second step platform, and formed from material transported down the mudflow gully from the northern mountain area, and not from the upstream YR. The total area of the late mudflow fan is ~0.75 km², and it has an average thickness of ~16 m, and a volume of ~1.2 × 10⁷ m³. In front of the late stage mudflow fan is the alluvial flat of the YR, which is continuously eroded by river action. A 6.5-m scarp has formed between the late stage mudflow fan and the alluvial flat (Fig. 6).

4.1.3 Mudflow fan stratigraphy

A comprehensive mudflow fan stratigraphy was compiled from the borehole core data. Borehole ZK1 is 36.5 m deep and located at the back of the second clay mudflow platform. Structurally disordered light-brown and brown-red mudflow sediments occur at 0–29.5 m depth are that host gray blocks and minor gravel. A gray-colored river terrace gravel occurs at 29.5–36.5 m depth, in which the gravel content is ~50%–55%, and the gravel roundness is low. ZK2 is 23.0 m deep and located in the central section of the late mudflow fan, above the ancient YR alluvial flat. Brown-red mudflow sediments with a gravel content of ~5%–10% are found at 0–13.7 m depth. The gravel mainly consists of intensely weathered mudstone. At 13.7–14.0 m, a yellow-gray clay unit occurs. Gray, yellow-gray, and white gravel with a high degree of gravel roundness occur at 14.0–23.0 m depth. ZK3 is 16 m deep and located at the front edge of the late mudflow fan. Structurally disordered brown-red mudflow sediments, mainly consisting of heavily weathered mudstone, occur at 0.4 m depth. The rock unit at a depth of 4.0–16.0 m is a river terrace gravel layer with a high degree of gravel roundness. The detailed stratigraphic column compiled from the borehole data shows that the thickness of the mudflow fan is reduced from 29.5 m at the trailing edge, to 4.0 m at the front (Fig. 3).

4.1.4 Grain size analysis

The median grain size of both the first mudflow platform and the Neogene red clay is 6.045 μm (Table 1). There are four grain-size modes, of which the second mode (where the median grain size is 1–10 μm) is dominant, and accounts for 52.8%–81.4% of each sample (Fig. 7). In the second mode, the grain-size range is 3.5–4.9 μm and thus, it is a medium suspension mode with strong suspension properties (Yin et al., 2008) and can
Fig. 4. National (a) and local (b) maps denoting the geographical location of the study area, and the distribution of debris flow gullies (light orange), early (yellow) and late (dark orange) mud (debris) flow fans, and other topographical (e.g., the Yellow River) and infrastructure (e.g., residential development) features within the study area.

Fig. 5. Study area overview photograph showing the geomorphology of early (the red lines) and late (the yellow lines) alluvial and debris flow fans of the Yellow River, eastern Guide Basin, China.
Early mud flow fans

The early scarp

The Erlian mud flow gully

The first stage of clay platform

Late mud flow fans

The late scarp

The second stage of clay platform

The floodplain

Fig. 6. Study area photograph showing the early and late mudflow fans (black arrows), scars eroded by the Yellow River (yellow arrows), clay platforms (red dashed line), and the Erlian mudflow gully (red arrow).

easily be carried long distances by weak rainfall or ice-snow melt water. The mudflow fans are affected by a number of features, including the Ashigong-Deqinshi fault, a broken topography characterized by highly eroded gullies, and exposed rock with low vegetation cover (no more than 2% on the hillside). During rainfall or snowmelt, loose and unconsolidated weathered layers become saturated, leading to slope instability and sliding. Therefore, the unique suspension grain-size modes of the north bank Neogene red clay result in a plentiful source of material for the formation of the two mudflow platforms.

The median grain size for the dominant mode of the late mudflow fans is 4.9–5 μm (Fig. 7), which is smaller than that of the ancient alluvial fan (6.045 μm); however, as both are < 10 μm, both fall within the fine suspension mode (Yin et al., 2008). The median grain size of the early mudflow fan is coarser than that of the late mudflow fan. This is because the late mudflow fan materials have travelled a greater distance and coarse grain deposition occurs early in material transportation; thus, the late mudflow fans are finer and better sorted (Yin et al., 2008).

### 4.1.5 Whole rock compositions and sinkhole topography

The early stage mudflow fan is mainly composed of semi-consolidated Neogene red mud-stone and physically weathered, weakly textured muddy shale. The red clay samples (GD-01 and GD-05) have SiO₂ contents of nearly 50wt% (Table 2), while the shale (GD-03) is just 7.27wt% SiO₂, but 47.5wt% CaO. The high SiO₂ contents in the
undecomposed semi-consolidated clay of the mudflow fan make the material difficult to transport away. In contrast, the high CaO in GD-03 reflects a high concentration of carbonates, which are particularly vulnerable to dissolution. Therefore, the bi-modal nature of the mudflow fan rocks has resulted in a ‘funnel’ or ‘sinkhole’ topography (Fig. 8a). The red clay platforms represent the material left behind as the carbonates of the early mudflow fan are continuously dissolved by water. This selective dissolution of carbonate rich rocks is characteristics of alluvial mudflow fans.

4.2 Evolution of the early mudflow fans

4.2.1 Formation processes and geochronology

$^{14}$C chorology of GD-01 samples of surface of early mud flow fans is 16170±80 a.B.P. (Table 3), which indicated that it formed in the Last Glacial Maximum (Birchfield, 1987; Broccoli and Manebe, 1987) before 16 kaB.P. Most of Qinghai-Tibet Plateau Covered by snows during the LGM period (An et al., 1990; Ding et al., 2002; Li et al., 2002; Hou et al., 2012; Liu et al., 2013), relatively low temperature limited the growth of vegetation, therefore, the northern mountainous basin without vegetation growth in the LGM. However, during the late LGM, increasing temperatures resulted in snowmelt, which carried the red clay down slope by near-source transportation, our studies shown that field data suggest that during this time high lakes also existed to store LGM melt water. Furthermore, evidences from the nearby Jianzha Basin indicate abundant regional rainfall during the LGM and the last deglaciation. The formation of the early mudflow fan is also indicative of a humid climate. During this period, at least three major mudflow fans developed in the Erlian village area, on north bank of the YR. Each mudflow fan shows a complete morphology, with the paleo-YR channel located at the front edge, but with no scarp formation.

4.2.2 Post-formation erosion

Since 16 ka, and especially since the Younger Dryas (~13 ka, Johnsen et al., 1992; Dansgaard et al., 1993; Bond et al., 1993), rapidly rising temperatures and the resulting ice-snow melt have increased water volumes in the upper reaches of the YR. Consequently, the erosional strength of the YR has increased. The result of $^{14}$C dating shows that the ancient riverbed (sample ELZK1-01) on the back edge of the late mudflow fan is 7980 yrs in age (Table 3), indicating that the paleo-YR channel roughly followed the current path of the Xining-JiuZhi highway (Fig. 2). Therefore, at between ~16 ka and ~8 ka, the YR cut the early stage mudflow fan though the middle (Fig. 9b). The resulting lateral erosion led to the formation of a 50 m high scarp in front of the fan (Fig. 10), and a river gravel layer formed at the scarp. The presence of this layer confirms that the YR riverbed was located near the scarp during the early Holocene. Based on the scarp height (50 m) and the erosional interval (~8000 years), a mean erosion rate of 6.25 mm/y is inferred.

4.3 Evolution of the late mudflow fan

4.3.1 Depositional sequence

The late stage mudflow fans also formed over an extended time period, with the main gullies all forming during the later stages. Due to differences in scales and catchment capacity, climate change, and YR channel wandering, the formation sequences of the individual late stage mudflow fans are unique. Based on their shapes and colors, different surface characteristics (e.g., rivers, vegetation, and mudflow fans; Qin et al., 2010; Qiao and Li, 2000) can be distinguished using remote sensing petrography analysis methods (Qin and Yin, 2012). In this study, a Google Earth image of the study area highlights

![Image](a) The scarp of the early stage mud flow fan
![Image](b) Mud balls

Fig. 8. Photographs of early (a) and late (b) mudflow fans in Erlian village. Major landform characteristics, including early mudflow concave depressions (a) and late mudflow mud balls (b), are labeled.
the contact relationships (e.g., cut though, transform, destroy, coverage, and bury) of three mudflow fans, including the Erlian mudflow fan (Fig. 11).

Image analysis reveals five depositional stages for the late mudflow fans of the floodplain and second YR platform: (1) Late stage-I: A fan-shape deposit with sticky mudflow properties covered an area of 2.313 km² (the largest area of the five stages). Today, this area is a residential neighborhood of Erlian village; (2) Late stage-II: an irregularly shaped 0.916 km² deposit overlaid the stage-I fans. Today, this area is also part of residential Erlian village; (3) Late stage-III: Deposition covering an area of 0.304 km² was mainly distributed along both sides of the gullies, which were <30 m in width; (4) Late stage-IV: Mudflow deposition over an area of ~0.063 km² was distributed along 15 m wide swaths along the both sides of the main gullies. For stage-IV, deposition stratification is clearly visible and grain sizes are observed to be fine in upper layer, but coarse in lower layers; Late stage-V: The primary channel of the modern mudflow gully has been altered owing to human reformation of the environment. Fans from this latest depositional stage cover an area of 0.034 km², and the front of the fans extend to the YR floodplain and partly occupy the river course. A feature of the current depositional regime is the deposition of oval mud balls in the gully bed after rainfall. These balls are 2–40 cm in diameter, and have red clay cores, surrounded by mud membranes and fine sand particles, which adhere to the ball surfaces (Fig. 8b).

4.3.2 Formation processes

Given the 14C age of 7980 yrs for the paleo-riverbed at the base of borehole ZK1 (Table 3), it can be inferred that late stage mudflow fan deposition was initiated from ~8 ka. During the early Holocene temperatures rose rapidly (Imbrie, 1984; Qin et al., 2008; Qin and Yin, 2012), and

![Fig. 9. Schematic maps of the evolutionary relationships in the Erlian early (orange) and late (yellow) mudflow fans, and in the inferred paleo (dark blue) and modern (light blue) Yellow River channels.](image)

![Fig. 10. Profile map (along profile I-I'; Fig. 2) of Erlian early (orange) and late (yellow) mudflow fans.](image)
ice-snow melt waters significantly increased. In a similar manner to the early stage mudflow fan deposition process, the large volume ice-snow melt water carried unconsolidated mudstone down toward Erlian village and the late stage mudflow fans covered the gravel riverbed. At the same time, the YR channel migrated south (Fig. 9c) by at least 1.25 km, as based on the borehole data. Mudflow accumulation has continued until the present.

5 Conclusions

In this study, field observations, borehole core sample analysis (including grain size distribution, whole rock geochemistry, and $^{14}$C dating), are used to analyze the distribution, evolution, and formation mechanisms of Holocene mudflow fan deposits distributed along the YR valley of the eastern Guide Basin, northeastern Tibetan Plateau. Based on the results of this study, a number of conclusions can be made:

1. At least 66 mudflow gullies and 20 large-scale mudflow fans can be identified along the YR in the eastern Guide Basin. Due to lithological differences in the stratum on either side of the river, the flows on the right bank are mainly dilute debris flows with a gravel content of 60%–80%, while on the left bank, flows are viscous mudflow deposits, commonly used today for residential development or agricultural purposes.

2. The widespread concave depressions on the left bank argillaceous platform have very high carbonate contents. These concave features formed owing to rainfall-induced carbonate dissolution in a process similar to karst landform formation.

3. The early mudflow fans of the north bank pre-date 16 ka, and formed by ice-snow melt water transportation and deposition during the LGM. This indicates that the region experienced a cold and humid climate with high rainfall. Late stage mudflow fan deposition was initiated at ~8 ka and formation processes were again related to glacial snowmelt, this time the result of early Holocene climate warming; thus, both stages of mudflow fan evolution were affected by climate change. These results provide insights into both the paleo-climate and currently active depositional processes in arid-semiarid regions.

4. In the Erlian village area, mudflow fan deposition and YR erosion can be divided into three stages: (a) Early mudflow fan deposition occurred at ~16 ka; (b) from 16–8 ka the paleo-YR cut and eroded these deposits, and; (c) since 8 ka, late stage mudflow fan deposition has been ongoing. During this time the YR channel has migrated south by at least 1.25 km. The late stage mudflow fan deposition can be further sub-divided into five sequences; however, due to a lack of a suitable material for dating, further investigation is needed to confirm the temporal details of these phases.

Acknowledgements

The research is financially supported by the National Nature Science Foundation of China under Grant No. 41372333, 41172158 and China Geological Survey (grant No. 1212011220123).
References


Qin Xiaoguang and Yin Zhiqiang, 2012. Earthquake and local rainfall triggered giant landslides in the unconsolidated sediment distribution region along the upper Yellow River.


**About the first author**

ZHAO Wuji, male, born in 1986 in Shandong Province. He is a PhD graduate of China University of Geosciences (Beijing). His major is Quaternary geology and study orientation is the evaluation and planning of geological landscape.

Email: wojiejie@126.com; phone: 18606496763.