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Holocene paleoearthquakes of the Daqingshan fault detected from knickpoint identification and alluvial soil profile

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A B S T R A C T

Are there any effective methods to reveal paleoearthquakes on normal faults except traditional trenching technique? In this paper, we study Holocene paleoearthquakes of the Daqingshan fault which is a normal fault along the Daqingshan piedmont of Inner Mongolia in China. We identify knickpoints from stream profiles and study alluvial soil profiles to reconstruct the Holocene paleoearthquakes of the fault. From the fault's footwall we extract 25 gullies from IRS-P5 DEM data, and identify knickpoints in the profile that result from fault motion disturbing each channel. We combine the retreat distances and the knickpoint retreat rates to determine each knickpoint's forming time. We study alluvial fan outcrops that contain various paleosol sequences. As three distinct Holocene paleosols developed in the Daqingshan piedmont alluvial fans, we assume that the soil profile development was interrupted by fault activity preserved by interbedded gravel between the paleosols. The gravel layer between two adjacent paleosol layers represents material transported there after a paleoseismic event. Thus we date paleosol layers which are above and below the gravel layer to constrain paleoseismic events. Since trenches had been made by our predecessors along the fault to reveal the Holocene paleoearthquakes, we identify the Holocene paleoearthquake records from both sides of the fault, and then compare the results with the results from the trenches. The final result demonstrates that the knickpoints' sequence in the footwall and the paleosols' ages in the hanging wall correspond very closely with the Holocene paleoearthquakes along the Daqingshan piedmont fault. Methods in this paper have future application value to study paleoearthquakes on other normal faults with similar structure to the Daqingshan fault.

1. Introduction

Paleoseismology is the study of prehistoric earthquakes based on the interpretation of the geological record that these earthquakes have left behind (Krinitzsky and Slemmons, 1990; McCalpin, 1996; Wallace, 1981). Trenching is mainly used to discover the geological record. The earliest trenches are digged to study San Jacinto fault in California. Sieh et al. made pioneering trench study in Pallett Creek and Wallace Creek of the San Andreas fault (Sieh, 1978, 1984; Sieh and Jahns, 1984; Sieh et al., 1989). Markers have been discovered to distinguish a paleoearthquake triggered by dip–slip faulting in previous studies (Wallace, 1977; Carver, 1987; Crone et al., 1987; McCalpin, 1996; Yeats, 1996). Mostly, trenches are shorter than a few tens of meters long. But field survey and empirical relationships between magnitude and rupture width show that extremely large earthquakes probably produced huge surface rupture width even more than 100 m (e.g., He et al., 2012; Donald and Kevin, 1994). So trenching fails when the width of the surface rupture exceeds the length of the trench.

The Daqingshan fault (F4 in Fig. 1) lies in Inner Mongolia in northern China, approximately 200 km in length. The fault moves fiercely since the late Quaternary (The Research Group on 'Active Fault System around Ordos Massif', 1988). Predecessors have digged more than 20 trenches to reveal its Holocene paleoearthquakes (Wu et al., 1995; Nie et al., 1996; Ran et al., 2002, 2003). The existing problems about the Holocene paleoearthquakes of the Daqingshan fault are: 1, Previous trenching results show inconsistent about the same paleoseismic events; 2, Previous trenches along the fault are from 10 to 30 m long which probably cannot cover the surface rupture width.

In this paper, we selected the Daqingshan fault as the case study to seek paleoearthquake records from both the footwall and hanging wall. On the footwall, we extract Digital Elevation Models

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(DEM) based on IRS-P5 stereo images and identify gully knickpoints, and then we interpret paleoearthquakes based on the analysis of this series of knickpoints. On the hanging wall, we studied alluvial fan outcrops that contain various paleosol sequences. We compare the paleoseismic events obtained from both the footwall and the hanging wall with the results from the previous trenches. The results show that the Holocene paleoseismic catalog of the Daqingshan fault tend to be complete and accurate, and the method of studying paleoearthquakes from both sides of the fault is feasible. Methods in this paper have future application value to studies of other normal faults which have similar structure with the Daqingshan fault.

2. Geological background

The Daqingshan piedmont fault (F4 in Fig. 1) lies in Inner Mongolia in northern China, east of Baotou and west of Hohhot and is approximately 200 km in length. This fault is in ENE direction and trends southward as a typical normal dip–slip fault. Together with Wolf-Seertengshan (F1 in Fig. 1) and Wulashan faults (F2, F3 in Fig. 1) to the west, it is part of the northern fracture zone of the Yellow River fault-bend basin and controls the basin's formation and development (Fig. 1). The fault moves fiercely since the late Quaternary with 4.6 mm/a average slip rate in late Pleistocene and 2.8 mm/a average slip rate in the Holocene (The Research Group on 'Active Fault System around Ordos Massif' and CEA, 1988). 5 segments were divided along the whole fault because activities of piedmont fault zone are uneven in spatial distribution since the late Pleistocene (Fig. 2, Ran et al., 2003; He et al., 2007).

The footwall of the Daqingshan fault is composed by hard rock, and drainage system spreads from mountain down to the Hohhot Baotou basin into Yellow River. The streams of the drainage system can be divided into three orders. The first-order streams are longer than 30 km. The second-order streams are between 10 km and 20 km long. The third-order streams are less than 10 km long each, and there are many gullies near the fault without tributaries. Knickpoints on the third-order stream gullies have been preserved very well because there is less discharge, meaning lower stream power than the other streams. We selected third-order stream gullies to study knickpoints interpreting the paleoearthquakes on the fault.

The width of piedmont alluvial fans of the Daqingshan spread around several kilometers. Currently all the alluvial fans in clear patterns on the landscape are formed in the Holocene. Development of alluvial fans can be divided into three periods. Those in the early period have the largest scale with more than 10 km length. The metaphase alluvial fans took shape in the mid and late Holocene, whose scale is still larger and sectors are distinguishable. The fan bodies are generally about 5–6 km long and 3–4 km wide covering on early alluvial fans. The alluvial fans in the late period formed in the late Holocene, mainly at gully outlets and under cliffs. The sectors are mostly independent, complete and in small scales, with no more than 2–3 km in length and 1–2 km in width. Multiple paleosol layers of different stages widely develop in the outcrops of piedmont alluvial fans. Paleosol development indicates a stable geographical process. Its formation processes often mark deposition intermissions in Quaternary period (Xi, 1990; Gong et al., 1989). In midstream of the Yellow River, formation ages of paleosols in loess area are generally concentrated in three year ranges: 2000a–3000a, 4600a–7400a and 8100a–9900a (Li, 1985). Paleosol development in piedmont alluvial fans of the Daqingshan is affected by regional climate change, and the Holocene paleosol ages in this area are basically the same with the developmental phase of the regional paleosols.

As in the field, gullies are preserved well, and paleosols are better exposed at the three middle segments which are also comparably complete in studying paleoseismic events by trenches. We choose the three middle segments (Tuyou West segment, Tuzuo West segment and Bikeqi segment) of the fault to study knickpoints of gullies and paleosols of alluvial fans.

3. Paleoearthquakes from knickpoint identification

3.1. DEM extraction and accuracy assessment

We extract the river longitudinal profiles and quantify the relevant parameters with the availability of high resolution DEM based on IRS-P5 stereo images. The IRS-P5 satellite produces stereo

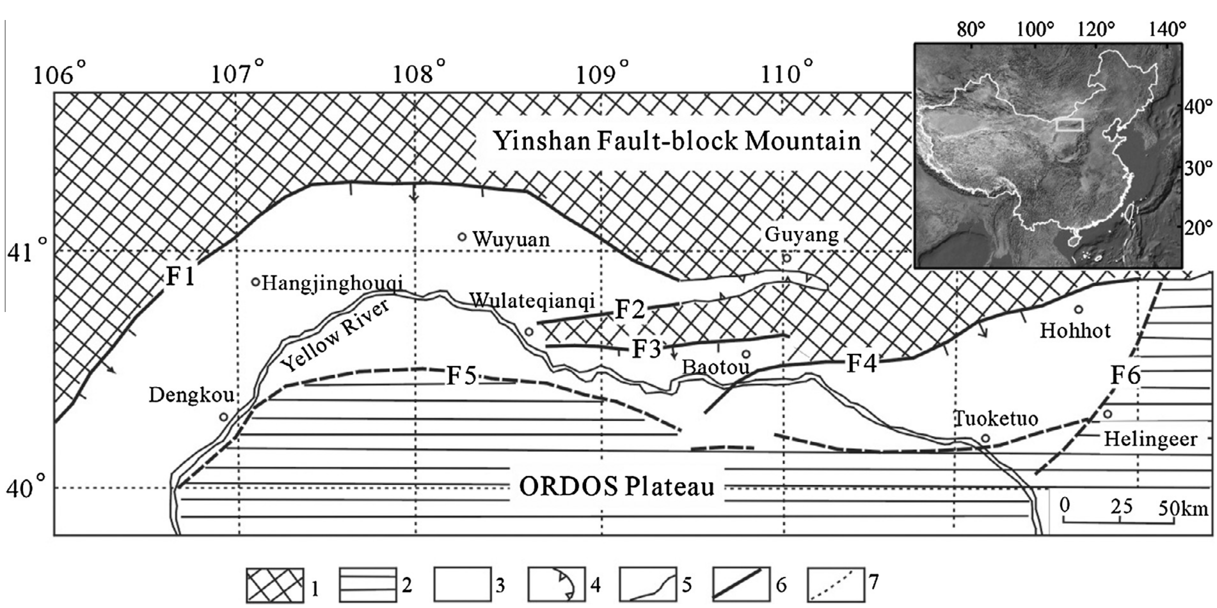

Fig. 1. Regional topography map of Yellow River fault-bend basin. 1. Fault-block mountain, 2. Fault-block tableland, 3. Fault basin, 4. Basin boundary of Quaternary period, 5. Landscape unit boundaries, 6. Holocene fault, 7. Pleistocene fault. Fault number: F1, Wolf – Seertengshan piedmont fault; F2, North of the Wulashan fault; F3, South of the Wulashan fault; F4, Daqingshan piedmont fault; F5, The northern margin fault of the Ordos Plateau; F6, Helingeer fault.