Surface Rupture and Slip Distribution along the Zheduotang Fault in the Kangding Section of the Xianshuihe Fault Zone

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1. Introduction

The Xianshuihe fault zone (XSHF) is one of the most active strike-slip faults on the eastern Tibetan Plateau and absorbs most of the deformation associated with the crustal extrusion of the plateau [1]. Consequently, many strong earthquakes have occurred along this fault zone [2]. Traditionally, the XSHF is divided (from north to south) into the Luhuo section, Daofu section, Qianning section, Kangding section, and Moxi section (Figure 1(b)) [3]. Most of these sections consist of a single fault, except for the Kangding section, which consists of three branch faults: west to east, the Yalahe fault, Selaha fault, and Zheduotang fault (ZDTF) (Figure 2). The ZDTF exhibits an apparent surface rupture compared to the other two faults. Due to the relatively steep slopes in the area, previous scholars mainly used tape to measure the offsets along the ZDTF at a few easily accessible points [4, 5]. Although they obtained accurate offsets, the scattered offset data were insufficient to constrain individual events’ ruptures. Additionally, it has not been possible to definitively constrain the recurrence behaviors of strong earthquakes along the ZDTF to assess its seismic hazard.

The coseismic and cumulative offsets of recent surface rupture events can be reconstructed to constrain the slip distribution and estimate the magnitudes of future earthquakes. Furthermore, slip distributions can provide vital information to understand earthquake recurrence behaviors (e.g., variable slip, uniform slip, and characteristic slip models) and to assess the seismic hazards that fault present [6–8]. Light detection and ranging (LiDAR) data, high-resolution satellite images, and field observations, we mapped the surface trace of the fault in detail and measured the horizontal and vertical offsets geomorphological landforms along the fault. The binned cumulative offset probability density (COPD) distribution was calculated to analyze single-event and multievent cumulative offsets. We found that the ZDTF has scarp along its entire ~46 km length, and the offset distributions of its northwestern (NW) and southeastern (SE) sections feature different characteristics. The SE section follows a uniform slip model based on the relationship between cumulative and coseismic offsets. We estimated the maximum potential earthquake magnitudes of the NW section and SE section to be M6.6 and M7.0, respectively, from the measured offsets and empirical formulas. Finally, we discussed the seismic hazard of the ZDTF based on our findings and paleoearthquake data. The NW section is at risk of large earthquakes recurring in the future, whereas the SE section has a low risk of a >M7.0 earthquake recurring in the next 100 years. If these two sections rupture at the same event in the future, the maximum potential magnitude of the ZDTF is M7.2.
resolution satellite images, and unmanned aerial vehicle (UAV-) based photogrammetry allow the offset landforms along a fault trace to be mapped and measured in fine detail, thus enabling statistical analysis of the offset distribution. Several studies using these methods have produced new insights into fault slip behaviors and seismic hazards [9–16].

The area surrounding the ZDTF is rich in precipitation, with an average rate of 659.8 mm/yr during 1970–2000; the precipitation is concentrated in June, July, August, and September, with the rainfall in June, July, and August contributing more than half of the annual precipitation (data from China Weather, http://www.weather.com.cn). Thus, gullies can quickly form in the adjacent mountainous regions due to floods. Geomorphic features like gullies are vital because they record earthquake events. In particular, the ZDTF is located mainly in a remote area with few human modifications. Thus, the faulted landforms developed along the fault trace are well preserved, providing favorable conditions to study the fault’s surface slip characteristics and earthquake recurrence behavior. Accordingly, we can obtain abundant and clear geomorphic offset markers that record the surface ruptures of large historical earthquakes along this fault.

LiDAR can estimate precise offsets, but it is time-consuming, labor-intensive, and sometimes impracticable due to the geographical environment of faults [17–19]. Specifically, the ZDTF is near Kangding Airport, which prohibits the takeoff of UAVs, so LiDAR and UAVs cannot be utilized to obtain the slip distribution. Previous studies indicated that inexpensive and convenient digital elevation models (DEMs) generated from high-resolution satellite stereo images can provide delicate topographical information [20, 21]. Hence, in this study, we selected Pléiades satellite images with a 0.5 m × 0.5 m pixel resolution to construct a high-resolution DEM [22–26]. Faulted landforms were interpreted, offsets were measured, and the cumulative offset probability density (COPD) was used to identify the fault slip characteristics. The magnitudes of future earthquakes can be

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**Figure 1**: Fault geometry (from a 1:4000000 Active Tectonic Map of China) and strong earthquake epicenters (from the Data Sharing Infrastructure of the National Earthquake Data Center) along the XSHF showing the prominent peaks, cities, active faults (those of the XSHF are in red), and tectonic blocks. The background is a 90 m DEM from the Shuttle Radar Topography Mission (SRTM). GZ–YSF = Ganzi–Yushu fault; XSHF = Xianshuihe fault; LMSF = Longmenshan fault; DLSF = Dalangshan fault; ANHF = Anninghe fault; ZMHF = Zemuhe fault; XJHF = Xiaojinhe fault; YLXF = Yulongxi fault; LTF = Litang fault; JSJF = Jinshajiang fault; BTF = Batang fault.
estimated by analyzing the most recent earthquake offsets and the cumulative offsets of several earthquakes. In addition, we can understand the recurrence behavior and assess the seismic hazard of the ZDTF.

2. Geological Background

The XSHF is located along the eastern margin of the Qinghai–Tibet Plateau and is within the middle section of the North-South Seismic Belt, one of China’s most intense seismic zones that have produced many large seismic events. The XSHF formed in the Qinghai–Tibet Plateau during the late orogenesis of the Songpan–Ganzi complex [27]. The XSHF separates the Sichuan-Yunnan block to the south from the Bayan Har block to the north [2]. Being an essential component of the north-south seismic belt has played a notable role in the late Cenozoic crustal deformation of the eastern Qinghai–Tibet Plateau [28].

The ZDTF is a branch fault of the Kangding section of the XSHF. According to paleoearthquake and geomorphological analyses, the ZDTF is divided into a northwestern (NW) section and a southeastern (SE) section by Kangding Airport (Figure 2), which is 16 km from Duoriagamo village and 30 km from Zheduotang village. In 1955, the ZDTF produced the M7.5 Kangding earthquake, which caused 70 deaths and 78 injuries. The intensity in the epicentral area of this earthquake reached a degree of IX [29]. The rupture of the 1955 event was confined to the SE section instead of the whole fault [30]. The latest research shows that the magnitude of the 1955 Kangding earthquake is estimated to be M7.0 from the surface rupture length and average displacement of the SE section [5]. Nevertheless, the relationship between the SE section and the NW section remains unclear based on the current research.

The ZDTF exhibits both left-lateral strike-slip and dip-slip activity. While most previous studies on the slip rate have focused on the SE section, many scholars have studied the horizontal slip rate of the ZDTF. Chen et al. [32] measured ages in the Zheduo Mountain pass and Zheduotang village and found a 5 mm/yr horizontal slip rate. Li et al. [4] obtained slip rates of 5.8–6.7 mm/yr at Zheduotang village, 4.3 mm/yr east of Kangding Airport, 6 mm/yr at the Zhedu Mountain pass, and 4 mm/yr at the Ertaiziadaoban landform (Figure 2). In addition, a 30 m vertical offset was found west of the Zhedu Mountain pass, and the vertical slip rate of the fault was estimated to be 1.8 mm/yr [32]. In one of our previous studies, we found that the slip rate along the SE section is not uniform and attenuates toward the north. Fortunately, the high slip rates of the ZDTF have produced many clear offset markers, so we can research the fault activity and seismic hazard characteristics of the ZDTF by measuring these offsets.

3. Data and Method

3.1. Data Acquisition. This study mainly uses high-resolution remote sensing satellite images (Pléiades, 0.5 m × 0.5 m pixel resolution) and high-resolution DEM data (Pléiades, vertical precision of 0.2 m) (Figure 3) to analyze typical faulted landforms. The high-resolution Pléiades constellation belongs to the French company Astrium. It is composed of two identical satellites, Pléiades 1 and Pléiades 2, launched and started commercial operation on December 17, 2011, and December 1, 2012. Both satellites have an ultrahigh-resolution of 0.5 m and a swath width of 20 km at nadir. Considering the resolution and vertical precision of the DEM data, the horizontal and vertical offsets have centimeter precision.
We purchased Pléiades stereo satellite images, including programming data and archived data, covering an area of approximately 200 km² to generate a DEM for the ZDTF. LiDAR360 software, independently developed by Beijing Green Valley Technology Co., Ltd., is employed to process the stereo satellite images into a DEM. As shown in Figure 3, the final DEM effectively restores the landforms along the ZDTF.

3.2. Offset Marker Identification and Measurement. First, the surface traces of the ZDTF are mapped by conducting a field investigation and interpreting the satellite imagery. The signs for identifying the fault include fault ridges and the left-lateral offset of landforms, such as rivers, terraces, fans, moraines, and crests. Second, typical faulted landforms (including gullies, terrace ridges, linear ridges, and moraine ridges) are visually identified using high-resolution remote sensing images and DEM [33]. Then, the offsets along the fault are measured and systematically interpreted. The tools mainly include ArcGIS software, Global mapper software, and LaDiCaO_z_v2 (an offset measurement tool based on the MATLAB programming language [34]), extensively used to measure fault offsets worldwide.

For horizontal offsets, we use ArcGIS software to draw a trend line of offset landforms along the fault, project the trend line onto the fault, and use restoring measurements to obtain the minimum, optimum, and maximum offsets (Figure 4). The uncertainty in the displacement depends mainly on the shape and sinuosity of the linear landform, the location of the fault trace, and the angle between the linear landform and the fault trace. Based on the measurement quality, we classify the offsets of the offset markers into grades 1, 2, and 3 from best to worst (Figure 5). Grade 1 implies that the offset markers on both sides of the fault exhibit low sinuosity and intersect with the fault orthogonally or at high angles. Grade 2 indicates that the offset markers with moderate sinuosity obliquely pass through the fault. Grade 3 denotes offset markers with high sinuosity or a poorly defined fault trace.

For vertical offsets, we use Global mapper software to obtain terrain contours across the steep ridges of the fault on different geomorphic units, linearly fit the slopes on both sides of the ridges, and finally project two separate lines onto the fault traces to estimate the amount of vertical offset. To acquire a more reliable displacement distribution, we use the rules from Bi et al. [35]. First, to reduce the measurement...
uncertainties, we aim to select profiles at sites that have experienced relatively little erosion or degradation. Gullies that intersect the geomorphic surface at an oblique angle are avoided. Second, when selecting profiles, we ensure that all data for the profile are derived from the same geomorphic surface. Third, we use the root mean square error of the fitted line as the offset measurement error. All faulted landforms are manually measured, each measurement is performed at least three times, and the average of all measured values is used as the final offset value.

There are unclear offsets in the DEM, such as moraine and talus. We identify these features throughout the high-resolution satellite images and employ ArcGIS to measure the offsets. For typical faulted landforms clearly displayed in the DEM, the LaDiCaoz_v2 code is used to measure and restore the offsets. The amount and the quality of each offset measurement, together with a reconstructed slip map, can be obtained from the DEM using the LaDiCaoz_v2 code [11]. A triangular probability is used to represent each offset measurement, and its error, where the triangle’s height is
the probability of the optimal offset and the width is the measurement uncertainty defined by the maximum and minimum values [13]. The triangular probability areas of the grade 1, 2, and 3 offsets are 1, 0.75, and 0.5, respectively. Then, the COPD for all offsets is calculated by stacking the offset measurements weighted by an assigned quality rating through the R program [9, 10, 12, 36].

The offset probability peaks are used to identify single- and multievent cumulative offsets, recognize paleoearthquake surface rupture events, and characterize the fault slip.
behavior. Each clear peak probability represents the cumulative slip associated with a different number of past earthquakes [9, 10, 12, 36].

4. Results

A total of 74 linear geomorphological markers are identified with different left-lateral offsets (Figure 6(a)), and the maximum, optimum, and minimum offsets of each offset marker are measured (see Table a). The proportions of the offset markers of grades 1, 2, and 3 are 55.6%, 23.6%, and 20.8%, respectively. In addition, a total of 135 vertical offset geomorphological markers are identified (Figure 6(b)) (see in Appendix A). The geomorphological markers near Duoriagamo village, Ertaiizidaoban, and the Zheduo Mountain pass are remarkably well preserved because of the sediment and location. Next, we introduce the measured horizontal and vertical offsets through a few typical examples.

4.1. Horizontal Offsets

4.1.1. North of Duoriagamo Village (site 1). Site 1, the northernmost tip of the ZDTF, is located approximately 2 km northwest of Duoriagamo village. Field investigations and UAV images show that the fault is represented by beheaded rivers, river terraces, left-lateral alluvial fan offsets, and other typical faulted landforms (Figure 7(a) and 7(b)). In the northwestern part of the site, two river terraces, T1 and T2 (Figure 7(a), 7(c), and 7(e)), are offset by the ZDTF. These offset markers were measured based on the method in Section 3.2 (Figure 5). The offsets of the T1 terrace are 8.1 + 1.0/-0.9 m, and those of the T2 terrace are 17.1 + 1.1/-0.8 m (Figure 8(c)). In addition, there are two stages of alluvial fans in the southeastern part of the site (Figure 8(b), 8(d), 8(f)). The fans are faulted, resulting in left-lateral offsets of 21.7 + 1.8/-2.1 m. The offsets of younger gullies are between 3.3 m and 4.6 m. Thus, this fault has been active since the late Quaternary. Seven linear landforms with different left-lateral offsets are measured in this area. The minimum offsets are 3.3 + 0.5/-0.3 m, and the maximum offsets are 21.7 + 1.8/-2.1 m. Preliminary analysis can distinguish three levels of offsets: (1) 3.3–4.6 m; (2) 8.1 m; and (3) 17.1–21.7 m. The minimum offsets, namely, the values of (1), should be the coseismic offsets of the most recent event. The (3)-
③-level offsets, deemed cumulative offsets, are approximately two and five times as large, respectively, as the ①-level offsets of the most recent event.

4.1.2. South of Ertaizidaoban (site 2). To the south of Ertaizidaoban, the fault is located on the hillside next to National Highway 318. Faulted landforms are clearly observed from the satellite images and DEM, revealing many faulted landforms such as gullies and terraces (Figure 9(a) and 9(b)). We jointly utilize the DEM, images, and field observations to ensure that vegetation does not influence the measurement of horizontal offsets. The fault has caused 37.4 ± 2.3/−1.5 m offsets of the riverbed and 38.2 ± 2.2/−2.1 m offsets of the colluvium (Figure 9(c)). The stream is left-laterally displaced by the ZDTF (Figure 9(d)). Near site 2, we use the LaDiCaoz_v2 code (Figure 10) to measure and reconstruct the offset, and the optimal offset is determined to be 39 m (Figure 9(d)).

4.2. Vertical Offsets

4.2.1. North of Duoriagamo Village (site 1). Displaced landforms are clearly observed approximately 2 km northwest of Duoriagamo village. There are many left-lateral offsets of gullies and rivers. Here, the water permeability varies due to lithological differences. The water flow converges along the fault zone to form a series of swamps. As a result, the fault scarp is obscured, and their inconsistent slopes cover a large area on both sides of the fault. Three typical offset points are selected to measure vertical offsets. The elevation profiles show the fault scarp and the elevation information on both sides of the fault. The vertical offsets measured on lines ①, ②, and ③ are 0.7 ± 0.1 m, 0.7 ± 0.3 m, and 1.1 ± 0.4 m, respectively (Figure 11).

4.2.2. Zheduo Mountain Pass–Zheduotang Village (site 2). The fault traces are prominent between the Zheduotang pass and Zheduotang village. ZDTF is observable, mainly developed in the antilope fault scarp. Similar to the previous profile, the topography rises to the northeast of the fault and descends to the southwest. The vertical offsets in this area are the most prominent. Three points are selected near the Ertaizidaoban landform to measure vertical offsets. The elevation profiles show the fault scarps and the elevation information on both sides of the fault. The vertical offsets measured on lines ①, ②, and ③ are 29.2 m, 12.1 m,
mostly covered by grassland, and there are no detectable

...The terrain within 10–20 km is smooth and is mostly covered by grassland, and there are no detectable coseismic landforms. ① The 30–36 km range is the mountain pass, which rises to a high altitude and is strongly affected by erosion, destroying the offsets of landforms (Figure 14).

The horizontal cumulative offset probability distribution shows that the cumulative offsets of the 2, 3, and 4 most recent seismic events on the SE section are multiples of the offsets of the most recent event. However, this relationship is not easily identified in some places (Figure 15(c)).

According to the COPD, the offset clusters create peaks after performing calculations in the R program. These peaks allow us to recognize the offsets of characteristic and small events. The slip distributions of paleoearthquakes and the horizontal offset probability peaks (Figure 15(b)) show two prominent peaks (P1, P2). Peak P1 is the offset of the most recent event on the SE section, and peak P2 is the cumulative offset. P2 is formed by two offsets, E1 and E2. This phenomenon is mainly caused by slip variability along the fault trace. Small peaks, such as P3 and P5, and the peaks between P1 and P2 are caused by small events. P4 and P5 are caused by offsets E3 and E4 because they are multiples of offset E1 (Figure 15(b)).

5. Discussion

Some offsets measured in this study were not identified during the field investigation because the locations were too difficult to reach. Consequently, the accuracy of the data may be influenced. However, we combined DEM data with satellite images to analyze offset markers, reducing the impact of these missing measurements. This ensures that the measured offsets can reflect the actual activity of the ZDTF.
5.1. Segmentation of the ZDTF. The ZDTF is divided into an NW section and an SE section by Kangding Airport, with separation distances of 16 km and 30 km, respectively. The 1995 Kangding earthquake rupture occurred along only in the SE section (from the airport to Zheduotang village) instead of along the whole fault. In contrast, the fault did not break the surface on the NW section. In addition, according to the paleoearthquake record, the most recent event on the NW section occurred during 3148–5821 BP, and there have been no earthquake events in the past 3000 years [30]. The offset measurements reveal that the average vertical coseismic offsets of the most recent events on the NW section and SE section are approximately 0.6 m and 2.7 m, respectively; likewise, the average horizontal coseismic offsets of the most recent events on the NW section and SE section are approximately 3 m and 4.8, respectively. Therefore, the most recent events on the SE and NW sections were not the same. There is also a gap in the offset distribution between the SE and NW sections.

Figure 12: Vertical offsets at Ertaiizidaoban. (a) The dashed red line is the fault trace, and the blue lines are the elevation profile survey lines. (b) Terrain elevation profiles along the three survey lines.

Figure 13: Vertical offsets at Zheduotang village. (a) The dashed red line is the fault trace, and the blue lines are the elevation profile survey lines. (b) Terrain elevation profiles from the two survey lines (Y1, y1, Y2, and y2 are the trend lines).
Figure 14: Offset distribution on the ZDTF. (a) Distribution of the ZDTF; the yellow line is the NW section of the ZDTF, and the red line is the SE section of the ZDTF. (b) Horizontal offset distribution (the purple points are measurements in this study, while the orange points are the measurements from previous scholars (data from [4, 5]). (c) Vertical offset distribution (the purple points are the measurements in this study, while the orange points are the measurements from previous scholars (data from [4])); the short black lines in (b) and (c) are error bars.

Figure 15: Diagrams showing the distributions of the (a) horizontal offsets on the SE section and (b) COPD values for the SE section. The x-axis on the COPD plot represents the frequency of the offset set. (c) Along-strike variations in the summed probability density function for multiple measurements within a 2 km bin. The COPD values are derived by stacking individual offset observations. The white curve marked E1 represents the offsets of the most recent characteristic event. The white curves E2–E4 represent the cumulative offsets of the two to four most recent events. The yellow curves represent the cumulative offsets of small events.
5.2. Fault Slip Behavior. Previous scholars measured 19 horizontal offsets in the Kangding Airport–Zheduotang village section. The maximum offset is 50 m, and the minimum offset is 2 m. All offsets are below 50 m, measured by tape near the Zhedu Mountain pass and Zheduotang village [4]. Adding these to the 74 measurements obtained in this work yields 93 horizontal offset data points. Here, we focus on the SE section’s behavior because the activities of the two sections are independent, and the NW section is too short of developing a slip model. Since the ZDTF exhibits horizontal sliding, we only use horizontal offset data when analyzing the fault slip behavior.

The minimum offset in the offset probability peaks represents the coseismic offset of the most recent event. The slip distribution of the most recent event can be constrained by dividing the fault into sections and connecting the minimum offsets in the offset probability peaks of the adjacent sections [9]. The cluster of the maximum coseismic offset is located in the 36–48 km bin with a displacement of ~7.5 m, which decreases to both sides. The coseismic offsets at the northern end of the SE section (20–22 km) cluster at ~2–3 m, while those at the southern end of the SE section (44–46 km) cluster at ~5.5 m, which is consistent with the results of previous research. The average coseismic offset is approximately 4.8 m. According to the above method, we connect the minimum offsets, revealing that the coseismic offset of the most recent event (the 1955 Kangding earthquake) on the SE section changes along the fault trace. An asymmetrical bell-shaped characterizes the slip distribution.

In the binned COPD plot (Figure 15), in the 20–24 km bin, the cumulative offsets of ~11 m and ~15 m are approximately 2 and 3 times as large, respectively, as the coseismic offset of ~5 m for the most recent event. In the 26–28 km bin, the cumulative offsets of ~12 m and ~18 m are approximately 1.7 and 2.6 times as large, respectively, as the coseismic offset of ~7 m for the most recent event. In the 36–38 km bin, the cumulative offset of ~26 m is approximately three times as large as the coseismic offset of ~8 m for the most recent event. In the 42–44 km bin, the cumulative offsets of ~11 m and 17 m are approximately 1.5 times and 2.5 times as large, respectively, as the coseismic offset of ~7 m for the most recent event. Therefore, the accumulated offsets in most fault areas are multiples of the coseismic offset, revealing the characteristic events on the SE section. However, these parts of the fault that experienced relatively small amounts of slip in the large earthquake experienced more frequent moderate displacement events, such as the 2014 M6.3 and M5.8 events. Therefore, the offset distribution characteristics of the ZDTF indicate that the SE section follows a uniform slip model (Figure 16) [6]. Offsets are developed in high-altitude, glaciated terrain and are recorded in ice water streams and glacial ridges, which are readily eroded by glacial meltwater, obscuring lateral offsets. Seasonal glacial meltwater-induced erosion and the limited number of discrete offsets indicate that these offsets (not located on the white connecting lines in Figure 15(c)) were more likely a result of erosion, thereby increasing or decreasing the measured offsets [13].

5.3. Maximum Potential Earthquake Magnitude of the ZDTF. Horizontal offsets of less than meters or tens of centimeters are easily ignored because of the accuracy of topographic data and unclear geomorphic markers. The offset of the most recent event may be too large. Existing studies have confirmed that an active fault’s size (mainly the length) determines its maximum potential magnitude [37]. Therefore, an empirical formula relating the magnitude to the surface rupture length is used to estimate the potential earthquake magnitude. From the paleoearthquake record and geomorphological analysis, the ZDTF is divided into an NW section and an SE section by Kangding Airport [38] with separation distances of 16 km and 30 km, respectively. Since the rupture behaviors of these two sections are independent, we consider the segmentation of the ZDTF when discussing its maximum potential earthquake magnitude.

5.3.1. Method. We use several empirical formulas relating the magnitude to the length of strike-slip faults to estimate the maximum potential earthquake magnitude of the ZDTF. Formula 1 is derived from 43 historical interplate or intraplate earthquakes. Formula 2 is derived from 23 historical earthquakes that occurred in the Tibetan Plateau. Formula 3 is derived from 56 historical earthquakes that occurred in mainland China and the surrounding areas (Table 1). All the earthquakes mentioned above were caused by strike-slip faults. Given this abundance of earthquake data, these formulas, all of which were constructed via linear regression, are reliable for estimating the potential magnitude of the ZDTF [39, 40]. The formulas are shown in Table 1. We use several empirical formulas for magnitude-horizontal offsets of strike-slip fault to estimate the maximum potential earthquake magnitude. The formulas used are shown in Table 1. Then, we get mean and standard deviation based on the formulas in Table 1. Combining geomorphic features and historical earthquakes can obtain the final potential magnitude [41].

![Figure 16: Uniform model of offsets associated with large-magnitude earthquakes](image-url)
5.3.2. Estimation Results and Discussion. Considering the segmentation of the ZDTF, we use formulas 1, 2, and 3 (Table 1) to calculate the maximum potential earthquake magnitudes. Then the mean and standard deviations are calculated, respectively, (Table 2).

(1) Preliminary Results.

(2) (2) Assessment of the Maximum Potential Earthquake Magnitude. (2)1. NW Section of the ZDTF. The maximum potential earthquake magnitude estimated by the three empirical formulas is 6.2 ± 0.4 (Table 2). The most recent seismic event occurred between 5821 and 3148 yr BP [38]. The horizontal and vertical offsets of the NW section are smaller than those of the SE section. Therefore, the maximum potential earthquake magnitude of the NW section is set at M6.6.

(2)2. SE Section of the ZDTF. This section includes the seismogenic fault of the 1955 Kangding earthquake, but the surface rupture is only 30 km long, and the magnitude estimated by only the surface rupture’s length is less than that M7.5. Liang [3] found a surface rupture near Yajiageng, which was considered to be the surface rupture of the 1955 Kangding event. Because the rupture length of this earthquake may be more than 30 km, the rupture extent needs to be further verified. Yan et al. [5] reevaluated the magnitude of the 1955 Kangding earthquake and reported that the feasible magnitude is M7.0 from the surface rupture length and average displacement. The potential magnitude estimated by the empirical formulas in this study is 6.6 ± 0.4 (Table 2). With COPD, we obtain three characteristic events whose offsets are multiples of the 1955 earthquake, so the four events have similar magnitudes. Based on the above research, the maximum potential magnitude of the SE section is M7.0 when it ruptures independently.

The rupture behaviors of the NW section and SE section are clearly independent based on previous research. However, because the two sections may rupture during the same event in the future, so the maximum potential magnitude in the ZDTF is M7.2.

5.4. Seismic Hazard Analysis. Previous studies indicate that the date of the most recent seismic event (ET1) in the NW section is between 5821 and 3148 yr BP, while ET2 occurred in 13060–10745 yr BP, ET3 occurred in 13687–11420 yr BP, and ET4 occurred in 41443–13715 yr BP [49]. Because the most recent seismic event occurred many years ago and the maximum potential earthquake magnitude is estimated to be 6.6, there is a risk of major earthquakes recurring in the future.

The average recurrence interval of a fault can be estimated by dividing the coseismic offset by the slip rate [43]. The average recurrence interval of the SE section has been approximately 500–2000 yr over the past 5000 years [4]. Previous scholars obtained a left-lateral slip rate of 5.5 ± 1 mm/yr for the SE section [4, 32, 44]. The average coseismic offset of the SE section is approximately 4.8 m, and the average recurrence interval is estimated to be 752 ± 137 yr. The most recent seismic event on the SE section was the Kangding earthquake in 1955, only approximately 65 years ago. Therefore, there is a low risk of a >M7.0 earthquake recurring in the next 100 years.

Table 1: Empirical magnitude formulas selected for the ZDTF.

| Number | Formula | Fault type | Applicable area | Source |
|--------|---------|------------|-----------------|--------|
| 1      | \[M = (5.16 ± 0.13) + (1.12 ± 0.08) \times \text{lg} \ L\] | Strike-slip fault | Worldwide | Wells and Coppersmith [39] |
| 2      | \[M = 5.92 + 0.88 \times \text{lg} \ L\] | Strike-slip fault | Qinghai-Tibet Plateau | Deng et al. [40] |
| 3      | \[\text{lg} L = (-2.45 ± 0.17) + (0.61 ± 0.03)M\] | Strike-slip fault | Mainland China | Cheng et al. [42] |

Note: \(L\) denotes the surface rupture length.

Table 2: Preliminary estimates of the maximum potential earthquake magnitude. The mean and standard deviation are calculated by formulas 5.1 and 5.2, respectively.

| Section | Surface rupture length (L) | Formula number | Maximum potential earthquake magnitude | Mean ± standard deviation |
|---------|---------------------------|----------------|----------------------------------------|--------------------------|
| NW section | 16 km | 1 | 6.5 ± 0.2 | 6.2 ± 0.4 |
|          |      | 2 | 6.6     |     |
|          |      | 3 | 6 ± 0.6  | 6.1 ± 0.2  |
|          |      | 1 | 6.9 ± 0.2 |     |
| ZDTF    | SE section | 30 km | 2 | 6.7     | 6.6 ± 0.4 |
|         |            |      | 3 | 6.5 ± 0.6 |     |
|         |            |      | 1 | 7.1 ± 0.2 |     |
| Whole fault | 46 km | 2 | 6.7 | 6.9 ± 0.3 |
|          |      | 3 | 6.8 ± 0.6 |     |
6. Conclusion

The ZDTF is dominated by left-lateral strike-slip activity, although it also exhibits dip-slip motion. Measurements reveal that the SE section and NW section have different offset distributions, and the SE section displays uniform slip behavior. The maximum potential earthquake magnitudes of the two sections are preliminarily estimated, and the corresponding averages are obtained through empirical formulas. Based on these results, we report a final maximum potential earthquake magnitude for the NW section of M6.6, and that of the SE section is M7.0. The NW section is at a notable risk of a large earthquake recurring in the future, while the SE section has a low risk of a >M7.0 earthquake recurring in the next 100 years. Thus, if these two sections rupture during the same event in the future, the maximum potential earthquake magnitude of the ZDTF is M7.2.

Data Availability

All the data are in the main manuscript and supplemental files (Appendix A).

Conflicts of Interest

The authors declare no conflicts of interest relevant to this study.

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Supplementary Materials

Appendix A. Offset table. It includes all the horizontal and vertical offsets measured along the ZDTF in this article. (Supplementary Materials)

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