BOUNDS ON THE AVERAGE RECURRENCE INTERVAL OF MAJOR EARTHQUAKES ALONG THE HAIYUAN FAULT IN NORTH-CENTRAL CHINA

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ABSTRACT

Evidence of surface rupture has been found in trenches near Caiyuan and Shaomayin along the Haiyuan fault, where a great earthquake occurred in 1920. In addition to the 1920 earthquake, faulting occurred at least once between 2590 ± 190 years and 1525 ± 170 years B.P. in Caiyuan, and there probably was another event since 1525 ± 170 years B.P. The formation and later tilting of fault-related, scarp-derived colluvial wedges in the Shaomayin trench appear to record the occurrence of two pre-1920 events in the last 2200-3700 years, but there could have been three or more events. The average recurrence interval for great earthquakes along the Haiyuan fault probably exceeds 700 years, for the 1920 Haiyuan earthquake is the only major event to have been reported in this area in as many years of recorded history. Using a Holocene slip rate along this fault of 8 ± 2 mm/yr, and 8 m as the average amount of offset associated with past great events that have been determined by our previous studies, the resultant earthquake recurrence intervals would be from 800 to 1400 years. The results from our trenches and the historic record are consistent with this range.

INTRODUCTION

One of the most destructive great earthquakes of this century occurred on the Haiyuan fault in north-central China (Figure 1) on December 16, 1920 (M = 8.7); more than 220,000 people were killed and thousands of towns and villages were destroyed (Lanzhou Institute of Seismology and Ningxia Seismological Bureau, 1980). The average left-slip displacement of 8 m (Zhang Weiqi et al., 1987) and a rupture zone more than 200 km long (Deng et al., 1984) make the 1920 Haiyuan earthquake one of the largest intracontinental earthquakes known, and the largest in the Haiyuan area. Clearly, the Haiyuan fault is an important seismic hazard. The objective of this study was to determine the average recurrence intervals of great earthquakes like the one in 1920.

The historical record is too short to constrain the recurrence interval of earthquakes on the Haiyuan fault. Except for one large aftershock (M = 7.3), only five moderate earthquakes of magnitude greater than 5, and none with a magnitude greater than 6, have occurred in this area since 1920 (Li, 1960). No major earthquake can be associated with the Haiyuan fault in the 700 years preceding 1920, a time during which other minor events were reported in the area within 30 km of the Haiyuan fault. Also, no great earthquakes from the Haiyuan region during the 600 years prior to 1920 were reportedly felt in Xian, located 300 km east of Haiyuan and a major city throughout that period.

The geological record of the late Holocene Epoch provides the best opportunity to study the long-term behavior of active faults. By dating both sedimentary units offset by slip on faults in past events and continuous sedimentary units overlying faults on which lower horizons were displaced, Clark (1972), Sieh (1978, 1984), Weldon and Sieh (1986), and others have obtained bounds on when previous earthquakes occurred and on their recurrence intervals. To study such relationships between sediments and faulting, trenches are usually dug across or near active faults in order to expose these relationships. We excavated two trenches across strands of the Haiyuan fault. This paper reports the analyses of sedimentary units exposed in those trenches.

Ages of sedimentary units were obtained from radiocarbon ages of organic material. All Carbon-14
ages were determined by Beta Analytic Inc., in Coral Gables, Florida, using the traditional half-life of 5568 years. These ages (Table 1) were then corrected using calibrations based on tree rings; we used Stuiver's (1982) calibration for the A.D. time scale and Klein et al.'s (1982) calibration for older radiocarbon dates.

If slip on faults occurs primarily during earthquakes, then the average, long-term rate of slip on the fault can be used to constrain the average recurrence interval (e.g., Wallace, 1970). If slip occurs in steps of roughly equal amounts, as would be the case if segments of faults ruptured during "characteristic earthquakes" (Schwartz and Coppersmith, 1984; Swain et al., 1980), then the recurrence interval given by the quotient of average slip to the average long-term rate of slip can be a reasonable assumption (e.g., Sieh and Jahns, 1984). At the least, the product of the average slip rate and the average recurrence interval provide a reasonable estimate of the average displacement during major earthquakes. In addition to the evidence of the recurrence interval of large earthquakes revealed by the trench logs, we also use the late Holocene slip rate on the Haiyuan fault (Zhang Peizhen et al., 1988) as a constraint on the average recurrence interval.

We first discuss results from trenches near Caiyuan and near Shaomayin (Figure 1), and then we consider the contraints imposed by the slip rate.

**Trench in Caiyuan**

Two strands of the Haiyuan fault overlap each other at Caiyuan so that a small pull-apart basin, about 700 m in length and 300 m in width, has formed (Figures 1 and 2). Slip on both strands apparently occurred during the 1920 earthquake. Fault scarps associated with the 1920 earthquake can still be seen on the northern strand but the southern strand has been modified by human activity. Between these two major strands that bound the pull-apart basin, another short fault strand developed almost parallel to the overall trend of the main fault. Slip on this strand was manifested by a series of mole tracks and tension cracks. Although each of the three strands in the Caiyuan area may not have ruptured during all events that have occurred in the past along this fault, we chose to trench in this area because the sediments were known to contain organic material needed to date layers of sediment displaced by past events.

Trenches were dug across all three strands, but only one yielded a discernible stratigraphy containing organic material. A trench across the southern strand did not yield a simple stratigraphy. In one of two

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**Table 1**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Location</th>
<th>Measured Carbon 14 Age (years before 1950)</th>
<th>Corrected Date (years before 1950)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFB4CY1</td>
<td>Caiyuan</td>
<td>1610 ± 70</td>
<td>250-600 AD**</td>
</tr>
<tr>
<td>HFB4CY2</td>
<td>Caiyuan</td>
<td>2510 ± 100</td>
<td>825-450 BC**</td>
</tr>
<tr>
<td>HFB4SMY1</td>
<td>Shaomayin</td>
<td>4540 ± 80</td>
<td>3775-2890 BC**</td>
</tr>
<tr>
<td>HFB4SMY2</td>
<td>Shaomayin</td>
<td>4780 ± 80</td>
<td>3820-3300 BC**</td>
</tr>
</tbody>
</table>

One sigma uncertainties are given for ages.
**Corrections based on Klein et al.'s (1982) tree-ring chronology.
trenches across the zone of mole tracks in the middle of the pull-apart basin, the fault was exposed, but almost all sediment was found to be black mud. The lack of any definable stratigraphy made it impossible to detect evidence for multiple offsets. In the other, which crosses a large mole track, we could not recognize a fault trace in the layers of cobbles. The only trench amenable to identifying the occurrence of past earthquakes was dug adjacent to the northern strand. The Quaternary deposits exposed in that trench consist of alluvium, colluvium, fine-grained sand and silt, reworked loess, and stream channel deposits (Figure 3).

OLDER COLUVIUM (Unit A). The oldest lithologic unit exposed in the trench is colluvium. It consists of poorly sorted, bouldery gravel. Most of the boulders and detritus are schist of the pre-Ordovician Haiyuan group exposed in Nanma Shan, some of them are granite from east of the pull-apart basin. (See Burchfiel et al. (1989) for the Quaternary geology of this area.) There are some irregular masses or blocks (A2) of loess within the gravel, some of which seem to have been dragged down along with what appear to be faults (such as the lower parts of fault F3 and F4 in Figure 3).

OLDER REDEPOSITED LOESS (Unit B). A layer of redeposited loess overlies the Older Coluvium. The loess is not homogeneous; angular pebbles commonly 1 or 2 cm in diameter are abundant in some parts but absent in others, and regions with differing abundances of pebbles appear to be separated from one another by faults.

OLDER ALLUVIUM (Unit C). A sequence of well-laminated silt, sand, and clay with some coarse sand and pebble layers or zones was found at the base of the southern part of the trench and directly overlies the layer of redeposited loess. The sequence itself becomes coarser northward in the trench and probably was deposited by a wide stream. The corrected radiocarbon age of organic material taken from a layer of black clay about 0.4 m above the bottom of the trench (HF84CY2 in table 1) is 2590 ± 190 years before present (1950).

STREAM CHANNEL DEPOSITS (Unit D). Stream erosion excavated a channel in the fine-grained sand
and silt, which later was filled with well sorted gravel and coarse sand (D1 + D2). In the plane of the trench, the channel deposits are about 1.5 m wide and less than 0.5 m thick. Cobbles with diameters of about 5-10 cm lie at the base of the channel deposits and grade upward into coarse sand. Beds of this well layered sediment dip about 20° south.

YOUNGER ALLUVIUM OR COLLUVIUM (Unit E). These deposits rest unconformably on the fine sand and silt (Unit C) and on the stream channel deposits (Unit D). They consist of poorly sorted cobbles, gravel, and coarse sand. The irregularity of the upper surface of the deposit suggests deep (0.5 m) erosion after the deposition of this unit.

DARK SOIL (Unit F). A layer of dark soil overlies Unit E. The dark soil is composed mainly of loess and silt. Some small pebbles are mixed within the soil, but because they are smaller and rarer than those in the alluvium or colluvium beneath it, the soil does not appear to be an altered zone of Unit E. The contact between Units E and F, in fact, is quite sharp. A sample of organic material (HF84CY1 in Table 1) collected from the dark soil gave a corrected radiocarbon age of 1525 ± 170 years B.P. (Table 1).

YOUNGER REDEPOSITED LOESS (Unit G). Almost the entire ground surface of the Caiyuan pull-apart basin is underlain by redeposited loess containing only a few small pebbles and with thicknesses varying from nil to 1 m.

FAULTS. Several faults, which we labeled from F1 to F4, were revealed in the trench, but they all did not rupture during the 1920 earthquake because they do not displace the youngest sediment layers. The surface rupture of the 1920 earthquake may have occurred along faults F3 and F4; there seems to have been drag of the loess blocks A2 and of Unit B along these faults (Figure 3), and these faults can also be correlated with two scarpes present at the surface. It is also possible that the surface rupture of the 1920 earthquake, or part of it, is located about one meter northeast of our trench, and if so the trench did not intersect it (Figure 4). We did not have permission to excavate the road just north of the trench. The curved trace and the multiplicity of scarpes made defining the actual 1920 fault break in this area difficult in 1982 to 1985.

Both faults F1 and F2 can be recognized by the juxtaposition of the Older Redeposited Loess and younger units. The upper surface of the older loess has clearly been offset. The apparent offset of the contact between Units B and C is about 300 mm at fault F1 and about 700 mm at fault F2. The contact between...
Recurrence Interval Along Haiyuan Fault

Fig. 5. Photograph of the stream cobbles from the channel exposed in the northwest wall of the trench at Caiyuan. The white dashed line marks the trace of the fault F2 (see Figure 3). The vertical separation of 200 mm along this fault is clear in this photo. (The knife is about 100 mm long and is located at D in Unit D1 of Figure 3.)

the stream channel deposits D2 and Unit E are separated by only about 200 mm along fault F2 (Figure 5). All of these separations could be due to strike-slip displacement, and the different amounts for different layers cannot be taken as evidence of multiple offsets.

Because older loess (Unit B) is juxtaposed along faults F1 and F2 against the fine-grained sand and silt (Unit C), slip on these faults must have occurred after the formation of Unit C, and therefore more recently than 2590 ± 190 years B.P. It appears that the ground surface was not offset or warped by slip on faults F1 and F2 in association with the 1920 earthquake, and therefore that the offset of Units C and D did not occur in 1920. The lack of any apparent continuation of faults F1 and F2 into Unit F might suggest that slip occurred before 1525 ± 170 years B.P., but the coarse texture of Unit E and the lack of a well defined stratigraphy in Unit F allow for the possibility that faults F1 and F2 pass into Unit F. Thus, the evidence from the exposures in the northwest wall of the trench imply that slip occurred on these faults since 2590 ± 190 years B.P. and before 1920, but this evidence does not yield a more precisely defined interval.

To constrain the timing of slip on faults F1 and F2, we examined in detail the southeast wall of the trench (Figure 6). The chaotic loess, the alternating sand, gravel, and gritty layers, and the dark loess in Figure 6 correspond to Units B, D, and F in Figure 3. The transition from the well bedded and well sorted gravel of Unit E is not sharp, and we abstain from distinguishing them in Figure 6. Layers of well sorted (clean) sand, interbedded with layers of small pebbles between the chaotic pebbly loess and a large cobble are clearly offset by fault F1 (Figure 6). Above the cobble, neither the sand nor the gravel layers are obviously cut by fault F1, but the coarse, poorly sorted gravel could be cut by faults that are difficult to recognize. Note that on upward extrapolation, fault F1 lies close to a steep contact of the gravel unit and the dark loess (Figure 6). We could not determine whether fault F1 continues through the gravel and offsets the dark loess because of the lack of stratigraphy in the dark loess.

The steep contact between the coarse gravel (top of Unit D, or Unit E) and the dark loess (Unit F) is not likely to have formed at the earth's surface, because mass wasting would have destroyed it shortly after it formed. Largely for this reason, we suspect that fault F1 passes through the coarse gravel and into the overlying dark loess. Therefore we infer that slip on F1 occurred after 1525 ± 170 years B.P., but obviously the evidence for this is not conclusive.

The trace of fault F2 displays features similar to those observed for F1. It also displaces sand and

Fig. 6. Trench log on southeastern wall of the trench in Caiyuan, with 1-meter grid, showing the continuations of faults F1 and F2. The dark loess, gravel layer, and the chaotic pebbly loess correspond to Units B, D, and F in Figure 3, respectively.
gravel layers just below the dark loess. The contact of the unsorted gravel and dark loess above F2 also is irregular. Thus, the offset on fault F2 also could have occurred after the formation of, at least, the lower part of the dark loess, but again the evidence is not convincing.

A third fault, labeled fault F5 (Figure 6), was recognized on the southeast wall but not in the northwest wall. This fault displaces a clean sand layer beneath the gravel, but it clearly does not offset the gravel. Both the gritty layer and a silty lens that overlie fault F5 have not been offset. If offset along fault F5 occurred during a major earthquake, it occurred after the deposition of the chaotic pebbly loess but before the formation of the gravel layer, and therefore between 2590 ± 190 and 1525 ± 170 years B.P.

Finally, note that the Stream Channel Deposits (Unit D) in Figure 3 and the sand and gravel layers in Figure 6 dip south. The steep dips cannot be ascribed to depositional processes; for instance, deposition on a point bar is not likely to be as steep and, moreover, would dip northeast, not southwest on this side of the valley. The dip is almost surely due to tilting, but this tilting cannot be associated with slip on fault F5, because the unconformably overlying layers are also tilted. Moreover, the tilted layers lie between faults F1 and F2 (Figures 3 and 6). The absence of clear surface deformation above the localized tilting implies that it occurred before 1920. This tilting probably occurred when slip on faults F1 and F2 last occurred and since 1525 ± 190 years B.P.

In summary, the trench at Caiyuan is located at the northern border fault of a pull-apart basin; and even though there are two other strands of the fault that have surface ruptures formed during the 1920 earthquake, we believe the trench data reflect the history of the Haiyuan fault because the northern border fault is a continuation of the main fault trace east of Caiyuan. The unconformable deposition on units cut by fault F5 (Figure 6) requires that there was faulting since 2590 ± 190 years B.P., but before 1525 ± 170 years B.P. Slip on faults F1 and F2 clearly occurred since 2590 ± 130 years B.P., but before 1920. The evidence that such slip occurred since 1525 ± 170 years B.P., however, is only suggestive. Units deposited since fault F5 slipped last have clearly been tilted before 1920. Therefore, there appear to have been at least two events since 2590 ± 190 years B.P. and prior to 1920. We suspect that slip on faults F1 and F2 occurred when the tilting occurred. If these faulting and tilting events were associated with major earthquakes, then there definitely was one major earthquake between 2590 ± 190 years B.P. and 1525 ± 170 years B.P. associated with slip on fault F5 and a second probably since 1500 years ago, but before 1920, associated with the tilting and probably with slip on faults F1 and F2.

TRENCH IN SHAOMAYIN

About 700 m east of Shaomayin (Figure 1) a dry stream channel has been offset left-laterally about 30 m where it crosses the main fault scarp (Figure 7). The 1920 surface rupture included the formation of a small graben, but strike-slip displacement of 8-9 m contributed to this 30 m offset of this channel (Zhang Weiqi et al., 1987). Our trench crossed the fault scarp within this channel (Figure 7).

Fig. 7. Photograph showing the 30 m stream offset 700 m east of Shaomayin, the offset associated with the 1920 earthquake, and the location of the Shaomayin trench. The view is to the east-northeast. The stream is in the center of the photo and flowing north on the left side of the photo has been offset about 30 m; its reach upstream from the fault lies to the right of the trench and behind the ridge in the foreground in the lower right of the photo. A fresh face of the opposite stream bank to the left of the trench marks the scarp formed during the 1920 earthquake; the offset of the surface is 8 to 9 m. The trench, in the middle of the photo, was dug across the fault scarp. The fault scarp can also be seen receding across the flat saddle in the upper right of the photo and is marked by an arrow.

Breccia (Unit A) exposed in the northeastern part of the trench (Figure 8) is mixed with fault gouge. Some bodies within it could be colluvium (A1, A3) and some consist of pebbly sand and silt (A2). We infer the existence of several faults (F2, F3 and F4) within the breccia from the sharp contacts of different bodies within the breccia.

The main lithological unit in the southwestern part of the trench is colluvial gravel (Unit B) (Figure 8), consisting of boulders, cobbles, and pebbles, mostly of mica schist from the bedrock south of the fault. Several clayey silt beds with re-deposited loess (B1) within the gravel indicate that Unit B formed by sedimentary deposition, and unlike breccia in the northeastern part of the trench, no faults could be identified within Unit B. Organic material from one of the clay layers yielded a corrected radiocarbon age of 5540 ± 230 years B.P. (Table 1).
A clayey silt layer with redeposited loess (Unit C in Figure 8) and containing organic material overlies the gravel in the southwestern part of the trench. A sample of it gave a corrected radiocarbon age of 5295 ± 445 years B.P. (Table 1).

A layer of sandy silt (Unit D in Figure 8) covers both Units B and C. This layer could be easily distinguished from the overlying and underlying units by the relative purity of the sand and the almost complete absence of pebbles. In the northeastern part of the trench a unit of similar composition might constitute a continuation of Unit D. This unit does not exist in the middle part of the trench between the fault F1 and F4. Its absence might be due to erosion after uplift associated with surface faulting in the past.

Unit F, consisting of redeposited loess and soil, covers almost the entire surface of the dry stream channel.

Near the fault scarp F5 two wedge-shaped sedimentary units (Units E and G) were found with their thicknesses gradually decreasing away from the fault. The lower parts of each wedge consist of redeposited loess containing angular pebbles and cobbles, and the upper parts are composed of angular cobbles and pebbles in a matrix of sand and loess (Figure 9). We interpret Units E and G as colluvial wedges derived from erosion of the fault scarp to the north.

The fault scarp exposed at the northeast of the trench is the upward extension of fault F5, the fault that ruptured in 1920. The material exposed by the fault scarp consists of angular cobbles and pebbles mixed with sand and loess, which are overlain by redeposited loess and soil. Apparently when the free surface of the fault scarp formed, the loess that lay on the top of the gravel along the scarp became unstable and slumped first to form the base of the wedge; after the loess was eroded away from the top of the scarp, the gravel slumped onto the loess to form the upper part of the wedge.
Swan et al. (1980) and Schwartz and Coppersmith (1984) recognized similar wedge-shaped colluvial deposits along the Wasatch fault zone, and suggested that each such wedge reflects the creation of a steep scarp at the adjacent normal fault. For strike-slip faults, surface faulting does not always cause scarps, and associated colluvial wedges do not always form, because vertical separation of the surface does not occur everywhere along the fault. In our trench the colluvial wedge G is evident only on the southeastern wall of the trench, but not on the northwestern wall, which is 4 m from the southeastern wall. In addition, because an old colluvial wedge can be deformed or destroyed by subsequent faulting, the number of such colluvial wedges is likely to represent a minimum number of surface ruptures on a strike-slip fault.

We associate the colluvial wedge G along the fault F5 with the 1920 earthquake because it overlies the surface layer F and is adjacent to the present free face of the fault scarp formed during that earthquake. The colluvial wedge E along fault F5 is covered by layer F and overlies breccia A and material similar to that of Unit D. The height of this wedge is about 2 meters. It could be associated with a surface faulting event before 1920. The wedge E itself has been tilted down to the northeast, but despite some warping, it still retains a wedge shape. This tilting must have occurred after the event that formed the wedge, and probably before 1920, because the surface layer F above the wedge E does not seem to be tilted by that event. Thus, two events, including the 1920 earthquake, seem to have occurred since the event responsible for Unit E. If the body of sandy silt in the northeastern part of the trench was deposited at the same time or more recently than Unit D on the southwestern side, then these events occurred since 5295 ± 445 years B.P.

The Holocene slip rate provides an additional constrain on the ages of these events. Because the movement of the Haiyuan fault here is mainly strike-slip (Zhang Weiqi et al., 1987), the colluvial wedges could have formed only after the free surface of the fault scarp had been juxtaposed against the dry stream channel north of the fault. If there had been no stream channel, colluvial wedges ought not to have formed, because there would have been no fault scarp with a free surface high enough to provide the scarp-derived colluvium. Thus the ages of these colluvial wedges probably are younger than the entrenchment of the stream channel. The date of the initiation of the stream channel can be estimated from the average slip rate during Holocene time and the total offset of the channel. For a Holocene slip rate of 8 ± 2 mm/year (Zhang Peizhen et al., 1988), for 22 m of pre-1920 displacement, and the initiation of this channel would be 3700, 2750 and 2200 years before 1920 for slip rates of 6, 8 and 10 mm/yr, respectively. Thus the creation of wedge E and the tilting of it, which we assume to be associated with two pre-1920 surface faulting events, probably occurred since 3700 years, and possibly since 2200 years ago.

In addition, fault F1 separates Units A and B, but did not slip in 1920. Among the faults exposed in the trench, only fault F5, which clearly ruptured in 1920, cuts the surface layer (Unit F). The breccia (Unit A) on the northeastern side of fault F1 had been juxtaposed against the gravel (Unit B) and sandy silt (Unit D) before Unit F was deposited. The age of the faulting that juxtaposed these units can only be constrained to be before the formation of layer F and after 5295 ± 445 years B.P., the age of layer D. Since the materials separated by fault F1 are completely different, the strike-slip offset on fault F1 must be at least 2 m, the width of the floor of the trench, and probably more. More than one event is likely to have occurred along fault F1, but we have no evidence to deduce how many events did occur since Unit D was deposited.

In this trench there seem to be three examples of pre-1920 surface faulting. Two of them occurred along fault F5, with one associated with the formation of the colluvial wedge, and with the other associated with the disruption and tilting of it. At least one event must be responsible for the slip on fault F1, but we do not know the relation between that event and the others. Slip on fault F5 could have occurred simultaneously with that along fault F1. Moreover, the ages of these events are poorly known, but all of them must have occurred before 1920. At least one event occurred on fault F1 since 5295 years B.P., the age of material within Unit B. Both events on fault F5 seem to have occurred since 3700 to 2200 years ago, since the stream channel was incised. Taken together these results require an average recurrence interval less that 2600 years, they imply recurrence intervals of 1100 to 1700 years, and the allow shorter recurrence intervals.

DISCUSSION

The maximum left-lateral displacement associated with the 1920 earthquake is 10.2 m, and the average amount is about 8 m (Zhang Weiqi et al., 1987). If the average displacement associated with the pre-1920 event also were 8 m, for a slip rate of 8 ± 2 mm/yr (Zhang Peizhen, 1988), the resulting average recurrence interval for an earthquake with slip of 8 m should be between 800 and 1400 years.

Evidence of surface rupture prior to 1920 has been found in trenches near Caiyuan and near Shaomayin, but neither provides tight constraints on the age of previous earthquakes. We are quite sure that faulting occurred since 2595 ± 190 years at Caiyuan, and probably another faulting event occurred since 1525 ± 170 years, but before 1920.

During the period between 1920 and since 5295 ± 445 years B.P., apparently at least two events occurred near Shaomayin, and there could have been three or more events. Fault-related, scarp-derived colluvial wedges in the Shaomayin trench indicate a minimum of two events prior to the 1920 earthquake and since 2200 to 3700 years ago. The juxtaposition of breccia against gravel along fault F1 in the Shaomayin trench also represents at least one event prior to 1920 and since about 5000 years ago, but we cannot determine if this event can be associated with the formation of tilting the colluvial wedges. The results from both trenches imply that the average recurrence interval be less than 2500 years, probably less than 1500 years,
and possibly smaller. Thus, they are consistent with recurrence interval deduced from the Holocene slip rate.

The recorded earthquake history of the Haiyuan area includes a minor event in 1219, but the only large earthquakes in this area with magnitudes greater than 7 (Li, 1960) occurred in 1920. Furthermore, it is likely that no major earthquake occurred in the 600 years before 1219, because that period corresponds to the Tang and Song Dynasties in Chinese history, during which the city of Xian was the capital and the center of culture. If a great earthquake had occurred in this area, which is only about 300 km northwest of Xian, people in Xian are likely to have known about it and to have recorded it in documents. Thus, the absence of such a record suggests that the previous great earthquakes in the Haiyuan area occurred before 1219, and probably before A.D. 600.

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