Surface faults associated with the Qayen, northeast Iran, earthquake of May 10, 1997

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Abstract

The length of the surface fault that caused the Qayen earthquake of Ms=7.1 on 10 May, 1997 at 12:27 (local time) is 110 km. The major fault has the trend N30°W but changes its orientation to N25°E at the northern end. The right-lateral displacement was 1.7 m (average) and 2.1 m (maximum). A living tree was torn in tow by the fault displacement. The northern 30 km of the surface fault overlap the fault that caused the 1979 earthquake. This fault length of 110 km is longer than would be expected from the magnitude of the event (Ms=7.1).

Introduction

The Qayen, northeast Iran, earthquake (Ms 7.1) of May 10, 1997, caused severe damage including loss of about 1500 human lives. The epicenter (preliminarily determined at 33.65°N/59.74°E by the U.S. Geological Survey; 33.95°N/59.91°E by the Earthquake Research Institute of the University of Tokyo) is situated in the north of the Sistan collision zone, which separates the central Iranian block on the west from the Afghanistan block on the east (Stocklin, 1968; Berberian, 1981; Jackson and Mckenzie, 1984; Jackson et al., 1995). Quaternary activity of this 700 km long collision zone is evident even on small-scale Landsat imagery.

We made a field reconnaissance from June 18 to 25, 1997, and observed surface ruptures and other geologic effects associated with this earthquake. Air-photo interpretation over the epicentral area was also made in order to reveal the behavior of the fault zone in the recent geologic past.

Observations

Figure 1 shows the overall trace of, and the distribution of slip on, the surface rupture zone associated with the Qayen earthquake of May 10, 1997. The following descriptions are in the order of locations from the north to the south.

The northern-most portion of the surface rupture zone of this earthquake overlaps the southeastern segment of the 1979 earthquake (Ambraseys and Melville, 1982). The overlapping segment is about 30 km long from Boneyabad to Fandokhit. According to some villagers in Kerizan, surface faulting occurred again in 1997 exactly on the same trace that was associated with the 1979 earthquake.

The surface rupture zone of the 1997 earthquake crosses the road that extends westward from Kerizan (Figures 1 and 2), where 1.8 m of right slip and 0-0.3 m of vertical slip (with the west side upthrown) were observed. About 2 km northwest of Estand, a dirt road is offset right-laterally by 2.1 m and vertically by 0.3 m with the west side upthrown. Fault plane was observed along the surface rupture zone about 1 km west of Estand (Figure 2, Photos 1 and cover page). Unconsolidated, horizontally stratified alluvium on the east possibly of early to middle Quaternary age is in fault contact with altered andesitic rocks on the west. The fault plane strikes N23°W and dips nearly vertical. Striations on the fault plane are almost horizontal, indicating that the fault is dominantly strike slip. About 0.5 km south of this exposure is a tree whose trunk has been pulled apart into two pieces by surface faulting (Photo 2). The amount of right slip here is 1.4 m. Since the surface ruptures are distributed over a wide zone at this location, the amount of slip in total would be larger.

Near Bohnabad the surface rupture zone changes its strike locally from NNW to NNE (Figure 2). Compressive surface ruptures were observed at this bend in fault trace (Figure 3, Photo 3). Figure 3 is a plane-table survey map originally on a scale 1:100, showing apparent horizontal...
separations that were caused principally by horizontal shortening on the surface fault. Here, artificial banks striking NW show right-step separations of 0.6-1.6m, whereas a channel perpendicular to these banks does not show a significant horizontal separation. This indicates that the direction of horizontal slip (shortening) is ENE, almost perpendicular to the local strike of the surface fault; the amount of horizontal shortening here is estimated at 0.4-0.9m, and the amount of vertical slip is 0.2-0.3m with the west side upthrown. One might have expected extensional, instead of
compressive, fractures at this bend, since the general sense of slip on the surface rupture zone is dominantly right slip. It seems possible that a large landslide block (3 km long and 2 km wide; see Figure 2 for topographic expressions) exists on the west of this bend and moved northeastward in the earthquake to cause compressive deformation at its toes.

From Bohnabad down to Malekabad, the surface rupture zone follows the eastern foot of the mountain range (Figure 4), and is dominantly right slip with a minor component of vertical slip (west side up). Two km north of Old Abiz, surface faulting occurred just on a preexisting fault (high angle reverse), where Cretaceous sandstone on the
Photo 1. Fault plane moved in 1997 (above) and a close-up of horizontal striations on it (below). See Figure 2 for location.

Photo 2. A tree completely torn in two by faulting. See Figure 2 for location.
Fig. 3. Plane-table map of surface faults, west of Bohnabad Village.
1, tension crack with or without strike slip; 2, compressive fracture (with teeth on the upthrown side).

Photo 3. Surface ruptures caused by horizontal shortening that were observed only locally in the old Bohnabad Village. Right step separation of banks caused by horizontal shortening whose direction is oblique to the banks (above); a reverse fault scarplet (below).
Fig. 4. Topographic map of the central part of the surface rupture zone associated with the 1997 earthquake. See Figure 1 for location and Figure 2 for legend.

west is in fault contact with Neogene (possibly middle to early Quaternary) conglomerate on the east. Figure 5A shows a geomorphological map of the Abiz-Nedeh area. In this area, an active fault cuts a series of Quaternary alluvial fans, and offsets small gullies and streams right laterally by several tens of meters. The surface faulting occurred exactly
on this preexisting fault (Figure 5B, Photo 4). These indicate that the surface fault of 1997 has moved repeatedly in recent geologic time with the same sense of slip.

A qanat (subsurface water channel) 1.2 km south of Nedeh is offset right laterally by 1.0 ± 0.3m; any significant vertical slip was not observed here. A highway 0.75 km northwest of Malekabad is offset right laterally by 1.4m without significant vertical slip (Figure 4). According to some villagers, the ruptured portion of the highway was covered with asphalt soon after the main shock, but was rup-

Fig. 5. (A) Map showing geomorphic surfaces along the active fault, by interpretation of aerial photographs on a scale 1:60,000. See figure 1 for location. 1, mountainous area; 2, hills and dissected terraces (early Pleistocene); 3, alluvial fans of middle to late Pleistocene age; 4, alluvial fans of late Pleistocene (to early Holocene?) age; 5, Holocene flood plain; 6, offset stream; 7, active fault (dotted where surface rupture appeared in 1997). (B) Topographic profile across the fault scarp and on an alluvial fan. See Figure 5A for location.
tured again with a small amount of offset (5-10 cm) in association with a large after shock. West of Malekabad, the surface rupture zone follows a preexisting fault scarp in alluvium (Photo 5).

Farther south, the rupture zone passes through mountainous areas. About 3.5 km north-northwest of Ardekul, surface faulting occurred on a preexisting fault that separates Cretaceous limestone on the west from Eocene flysch on the east. The fault plane strikes N20°W and dips 83°W; striations on it plunges slightly north (4°N). The amount of right slip here in 1997 is 1.2m.

East of, and subparallel to, the surface rupture zone of the 1997 earthquake is a preexisting active fault, which is traceable for at least 18 km from the point 7.5 km north-northwest of Ardekul down to Ahangaran. Although no lines of evidence for surface faulting in 1997 were observed along it, this fault marks the boundary between mountainous areas on the west and the wide Quaternary basin on the east.

According to our air-photo interpretation, this fault cuts Quaternary alluvial fans with the west side upthrown, and right laterally offsets stream channels systematically. At a point 4.5 km northeast of Ardekul along this fault, a 15m high terrace shows remarkable flexure toward the northeast; alluvial sediments underlying the terrace also show progressively greater dips with decreasing distance from the flexure scalp. This flexure is likely to have been caused by a west-dipping thrust fault (with a right slip component) underlying soft alluvium. Thus, the Quaternary movements of the Sistan collision zone as a whole is likely to be transpressional; significant slip partitioning may exist among subparallel faults in this zone.

From Ardekul to Zeydan, the rupture zone passes through rugged and inaccessible areas; we therefore checked surface ruptures at only a few places south and southwest of Ahangaran (Photo 6).

About 7 km west-southwest of Zeydan (33°10.7N/
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Photo 5. Surface ruptures just on the foot of a preexisting fault scarplet, west of Malekabad. See Figure 4 for location.

Photo 6. Surface rupture across the mountain slope along a preexisting fault, west of the Ardekkul Mountains.
Photo 7. Open clacks arranging in left-step echelon at the foot of a mountain, in the southernmost segment of the surface rupture zone. Detail map is shown in Figure 6.

Photo 8. Open clacks and thrusts on the western foot of the Ardekal Mountain. Location is south of Photo 7. Detail map is shown in Figure 7.
a small closed basin (sag pond) is formed on the east of the surface rupture zone (Figure 6, Photo 7), suggesting repeated movements of the fault. The amounts of right slip and vertical slip here in the 1997 earthquake are about 1.0m and 0.5-1.0m, respectively. About 0.8km south of this location (33°10.2’N/60°13.8’E), a small stream channel is offset right laterally by about 2.2m (Figure 7, Photo 8); this value may contain much error because the offset reference is not suitable for precise measurement.

**Summary and Conclusion**

The rupture zone associated with the Qayen earthquake of May 10, 1997, is 110km long, striking NNW-SSE, and dominantly left lateral (1.0-2.1m right lateral) with minor component of reverse slip. Other important characteristics of the surface faulting are summarized as follows:

1. Surface faulting occurred on pre-existing faults. According to our air-photo interpretation and field observations, these pre-existing faults have evidence for repeated movements in the late Quaternary.

2. Small amounts (1.0-2.1m) of slip on the surface fault were not in proportion to its total length as long as 110 km. This indicates that the stress drop due to this earthquake was low, in comparison with stress drops due to intraplate earthquakes in Japan. The Qayen earthquake of 1997, therefore,
is of interplate nature rather than intraplate nature.

3. The northern-most portion (ca. 30 km long out of 110 km) of the rupture zone associated with the 1997 earthquake overlaps the surface rupture zone of the 1979 earthquake (Ambraseys and Melville, 1982). These two surface faulting events occurred exactly on the same trace. However, the maximum amount (2.1m) of slip was observed on the overlapping segment, not on the main segment, of the 1997 surface rupture zone.

4. There exists a possible sequential rupturing from the
North to the South along the Sistan collision zone. Two surface faulting events (1979 and 1997) have ruptured the northern 110 km of the collision zone; but there still remains a 600 km of segment that has not ruptured in historic time. Thus, we should pay attention to future earthquakes that could be generated by slip on the southern segment of the collision zone.

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