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A newly discovered major fault of the 1976 Tangshan earthquake in China

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In the field investigations of the great 1976 Tangshan earthquake in China, several large subsidence areas with remarkable boundary fissures were reported as phenomena of the seismic event. Recently a re-interpretation of aerial photos taken immediately after the quake revealed that the areas were controlled by a giant fault of about 40 km in length; and subsidences were brought about by the movement of the fault during the shock, not being a consequence of soil liquefaction as suggested in some of the investigations. This discovery has been confirmed by the results of fine geophysical explorations carried out by the Jidong Oilfield Company, PetroChina. The newly discovered fault, named Fuzhuang-Xihe fault, is much longer than the one prevailingly accepted as the seismic fault of the Tangshan earthquake. Moreover, the former seems to be a normal fault, while the latter is regarded as a strike-slip one.

Introduction

The 1976 Tangshan earthquake of China, M7.8, was a deadliest disaster in the 20th century. Taking place in Tangshan, a densely populated city, it claimed more than 240,000 lives. A vast amount of phenomena related to the event were observed and documented (Liu, 1985; Housner & He, 2002). A nearly 8 km long intermittent surface fissure zone was located passing through the city and was regarded as the seismo-generic fault of the earthquake (Guo, S., 2002; Yang, 2002a); however, some scientists hesitated to accept the suggestion because the fault did not seem to be great enough for such a strong earthquake. The right-lateral displacements of the fissure zone were considered to indicate the strike-slip of the fault (Chen et al, 1979; Zhang et al, 1989). For a long period of time, studies were focused on the fissure zone, paying minor attention to areas beyond the city. There were field surveys reporting large subsidence areas with remarkable boundary fissures produced by the quake, but no special papers have been published on them.

We began our investigations with locating the subsidence areas on aerial photographs taken immediately after the main shock, and came up with the surprising discovery of the previously unknown giant seismic fault of the earthquake (Figure 1).

Field investigation reports

Many researchers conducted field investigations soon after the disastrous earthquake (Wu, 2002; Du et al, 2002; Guo, W., 2002). Wu (2002) reported a huge slumping area, with a clear scarp on its southeast side, in Xihe Commune of Fengnan County, about 30 km southwest of the Tangshan City, and described it as striking N40–50°E, being 500 m wide and 4 km long. The area was filled with water after the earthquake. Du et al (2002) mentioned another even larger subsidence zone in the Yangjiapo Commune, further southwest of the Tangshan City. The strike of the zone was N80°E, the drop was over 3 m, and the fissure zone extended for about 7 km. Guo, W. (2002) made a similar description of the same area and mentioned a Fuzhuang village in the area, which subsided dur-

ing the earthquake and was quickly flooded. The water was so deep that boats were sailing on it. We went there twice to study the subsidences. In the southern part where the flood plain was close to sea, there were many salt pools. During our investigations, we were told by villagers that when subsidence occurred during the main shock, sand-boils were observed almost everywhere in the area and the subsided places were soon filled with water coming from nearby broken pools. Village survivors ran to the boats in the fear that the whole area might sink into the sea. The subsidences still remained despite of 28 years of re-shaping, and could be found as salt pools, fishery ponds or deserted farmlands. We saw boundary fissure zones only on the southeast side of the area, and gained an impression of a normal fault.

Aerial photographs

Ten thousands of aerial photographs were taken a few days after the main shock of the Tangshan earthquake (Zou & Zhang, 2002). Recently we re-examined the photos aiming to locate the subsidence areas. The photo over the Xihe slumping area (Figure 1, Photo 4) obviously shows in dark colour a subsidence area with sharp boundaries, resembling a fault, on the southeast. The photo is actually a mosaic of several smaller photos and the neat edges of the patches can be easily distinguished by different tones of grayness. The dark color of subsidence is due to the water filled. The photo over Fuzhuang shows as well a subsidence area and a fault on the southeast (Figure 2, Photo 2). In order to confirm that the fault of the Fuzhuang subsidence is linking to that of the Xihe subsidence, we have examined all the adjacent photos, and found more subsidence areas and boundary faults (Figure 2; Photos 1, 3, 5, 6). The regularity is that each of the subsidence areas has only one clear boundary fault on the southeast. Pieced together in a map (Figure 1), the boundary faults are found virtually the fragments of a giant fault, about 30 km long, which we refer to as the Fuzhuang-Xihe fault.

Geophysical explorations

Detailed geophysical exploration for oil was carried out in 1993 by the Jidong Oilfield Company, PetroChina over most part of the concerned area. We were very fortunate to be able to use the results to confirm the existence of the Fuzhuang-Xihe fault. Figure 3 shows that the fault is located where the clear boundary of the Xihe subsidence passes by. It reaches a depth of at least 2500 m, which is the limit of the exploration. The fault appears to be normal with the northwest wall, i.e., the subsidence area, dropping along the northwest-dipping fault plane. The evident dislocation cuts through the strata of old geologic ages as well as the newest deposits. What is more, according to the seismic interpretation, the Fuzhuang-Xihe fault extends northeastwardly for about 40 km, i.e. 10 km longer than the length we suggested from the aerial photos.

Figure 1 Map showing the newly discovered Fuzhuang-Xihe fault (solid curve) and the previously inferred seismic fault (dashed line) of the Tangshan earthquake. Dotted square shows the Fuzhuang-Xihe area where fine geophysical explorations were carried out by the Jidong Oilfield Company, PetroChina. Numbered small squares (1–6) are the subsidence areas identified from aerial photographs (see Figure 2). Aftershocks (circles) are plotted for reference.

Figure 2 Aerial photographs of the subsidence areas. Dark color of subsidence is due to the water filled after the areas subsided. Note that each of the areas has only one clear boundary fault on the southeast. Arrows point to the fault. Locations of the numbered subsidence areas (1–6) are shown in Figure 1.

Figure 3 Contour map of the top of Ordovician stratum and geological profile along A-A' based on detailed geophysical explorations over the Fuzhuang-Xihe fault area (dotted square in Figure 2). Geophysical interpretations show that the fault extends for about 40 km to the northeast. The fault is normal, cutting through strata of old geologic ages as well as the newest deposits. W1 and W2 — wells.

Discussions

Aerial photos had been studied by some researchers (Zou & Zhang, 2002) and a quite detailed damage map of the 1976 Tangshan earthquake was published by the Earthquake Research Institute of China Earthquake Administration (1985) based on the aerial photos. The fissure zone of the Yangjiapo subsidence is identified in some publications, although not highlighted, and is attributed to soil liquefaction (Du et al, 2002; Yang, 2002b).

When a long fissure zone appears after an earthquake, water plays a significant role in its explanation. If there has no water, one would suggest a fault, e.g. the inferred seismo-generic fault passing through Tangshan City. When water gets involved, fissures as well as subsidences may probably be explained as the results of soil liquefaction. In our case, it is water that helps indicate the subsidences and the faults on the aerial photos. Otherwise it would be much more difficult to identify the Fuzhuang-Xihe fault 28 years after the Tangshan earthquake.

Liquefaction may take place when pore pressure rises in a saturated sandy soil as the strength of the soil is reduced so that the soil cannot bear as much as before. This phenomenon can be well explained with the laws of effective stress (Nur & Byerlee, 1971; Robin, 1973). Complication, however, is introduced as seismic shaking is taken to be the reason for the sudden increase of pore pressure (Martin et al, 1975; Seed, 1979; Castro, 1987). Ground shaking may produce pore pressure rises here and there, but there are yet other causes. When a block of strata falls, probably along a fault, it will compress underground water so that the pore pressure will increase to drive the water upwards out. This ought to be a reasonable mechanism to account for the soil liquefaction as well as the sand boils in the slumping wall of a fault.

In the case of the Fuzhuang-Xihe fault, subsidence does not seem to have resulted from liquefaction due to the sudden tectonic movement, but from the movement itself. Unlike some previously

reported focal mechanisms (i.e., Qiu Q., 1976; Zhang et al., 1980; Butler et al., 1979), which suggested a vertical fault with rather pure right-lateral strike slip for the main shock of the Tangshan earthquake, the latest Harvard centroid-moment tensor resolution given by Ekström & Nettles (1997) indicates a dip of 43 degrees to the northwest and a significant normal component of slip for the seismic fault of this event. Probably it is this normal component of slip that, in agreement with our discoveries, accounts for the subsidence and the related liquefaction.

A slope in topography has been suggested to account for the so-called liquefaction-induced lateral spreading, something like landslide, which brings about ground fissures as well as subsidences (Varnes, 1978; Ishibara et al, 1991). But it cannot be applied to the case here because the slope, if there is any, is opposed to the required as the region is actually on a piedmont towards the sea on the south. In fact, the Fuzhuang village had been a highland relative to its adjacent southeast area (Guo, 2002).

Conclusions

According to Guo S. (2002), there is a Ninghe-Changli fault whose western portion is at about the location of the Fuzhuang-Xihe fault. However, the new activity of Ninghe-Changli fault is described as that the southeast wall subsided vigorously in Tertiary and Quaternary. This is not in agreement with the movements as observed from the Fuzhuang-Xihe fault. The newly discovered Fuzhuang-

Xihe fault of the Tangshan earthquake, as can be seen in Figure 1, appears to be about 40 km long. The close relation of the fault to the earthquake is further demonstrated by the aftershock sequence plotted in the figure. Obviously, the fault as a whole strikes about the same direction as the zone of aftershocks. It roughly bounds the zone on the southeast.

Our new discoveries are not only challenging the widely accepted idea about the role of soil liquefaction in seismic damage, but also denying the prevailing explanation for the generation of the great 1976 Tangshan earthquake. As the Fuzhuang-Xihe fault seems to be a co-seismically active normal fault, the explanation that a right-lateral strike-slip fault produced the earthquake turns out to be rather unreasonable. We stress here that the aerial photographs were taken immediately after the main shock, therefore the subsidences and the faults could not have resulted from the M>6 aftershocks that took place much later over the Ninghe area. Further studies on the real cause of the Tangshan earthquake need to be carried out in accordance with the discoveries.

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Hutchison 'Young Scientist' Fund

William Watt Hutchison, "Hutch" to his many friends around the world, was a Scots-born Canadian geologist who served Canada and the IUGS in myriad dynamic and creative ways. Most notably, he served as the IUGS Secretary General (1976–1980) at a pivotal time in its history, and as IUGS President (1984–1987). The same boundless energy, enthusiasm, skill in communications, and ability to foster teamwork that characterized his work with the IUGS also carried him to preeminent scientific administrative positions in the Canadian Government, where he served as Director General of the Geological Survey of Canada and as Assistant Deputy Minister of Earth Sciences. His distinguished career was terminated in 1987 by his untimely death at the age of 52, following a painful struggle with cancer.

One of Hutch's last wishes was to establish under IUGS auspices a memorial foundation intended to promote the professional growth of deserving, meritorious young scientists from around the world by supporting their participation in important IUGS-sponsored conferences. The first 3 beneficiaries of the **Hutchison "Young Scientist" Foundation** attended the 28th International Geological Congress (IGC) in Washington, D.C., in 1989.

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