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DOCUMENTED EARTHQUAKE FAULTS IN IRAN

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GEOLOGICAL SURVEY OF IRAN

Abstract

Recent Iranian earthquake faults are presented and briefly discussed. These faults are: Nozad 1493 earthquake fault, Bozqush 1879 earthquake fault, Dorud 1909 earthquake fault, Baghan-Germab 1929 earthquake fault, Salmas and Derik 1930 earthquake faults, Torud 1953 earthquake fault, Garun 1958 earthquake fault, Ipak 1962 earthquake fault, Dasht-e-Bayaz 1968 earthquake fault, and Mishan 1972 earthquake fault. In addition to the above mentioned documented earthquake faults, a few other cases which were reported as probable earthquake fractures are presented and discussed (Khaf 1336 earthquake fault, Tabriz 1721 earthquake faulting, Tash 1890 earthquake faulting, Londeh 1929 earthquake faulting, Bahabad 1933 earthquake faulting, Chahak 1941 earthquake faulting, and Farsinaj 1957 earthquake fissuring). Finally, earthquake ground deformations of secondary nature, such as Qir 1972, are discussed.

Field studies of most earthquake faults in the country provide data on an active NNE–SSW tectonic compression. Due to the fact that the earthquake faults constitute reactivated existing Quaternary geological faults, great care should be taken during the country's future development, where sites near the active faults are involved.

1. INTRODUCTION

A review of the seismic history of Iran demonstrates that the country is probably one of the most earthquake-prone in the world. Considering the intricate structural pattern and the young, partly Recent tectonics so characteristic of Alpide Belt countries in the Middle East, this is not surprising. In most parts of the country seismicity can be directly related to the reactivation of faults, and most seismic activity originated along the active faults. Many belts of major faults and abnormal tectonic contacts are characterized by seismic unrest producing earthquakes.

Slip movements along active faults may either occur violently, and generate earthquakes, or gradually in a process called fault-creep. The large earthquakes and abrupt surface movements may sometimes occur on fault segments where part of the strain is being relieved by small earthquakes and tectonic creep. Consequently, the presence of creep or widespread small earthquake activity cannot be considered a safeguard against larger and more catastrophic earthquakes.

An earthquake fault is a ground fracture formed in association with a shallow earthquake, usually by reactivation of a pre-existing geological fault. It can provide information about both the mechanism of seismic energy released during an earthquake and the accompanying regional strains.

The small number of earthquake faults known in Iran may result from the lack of adequate macroseismic documentation. It should be noted that most known earthquake faults in Iran are over 40 km long, and that all were associated with destructive events of magnitude greater than seven. It therefore seems likely that shorter surface breaks have occurred in Iran during earthquakes of smaller magnitudes, but that these earthquake faults have passed unreported or even, in desert areas, unnoticed.

In most earthquake faulting cases in Iran fault directions and displacements indicate present day NNE–SSW compression. A predominantly NNE direction of plate motion has been postulated for Arabia, towards Iran, on the basis of fault plane solutions for recent earthquakes.

2. IRANIAN EARTHQUAKE FAULTS

In this study Iranian earthquake faults are presented in alphabetical order. Figure 1 shows the location of the known earthquake faults in Iran (see also the Seismotectonic Map of Iran, and the Generalized Fault Map of Iran).

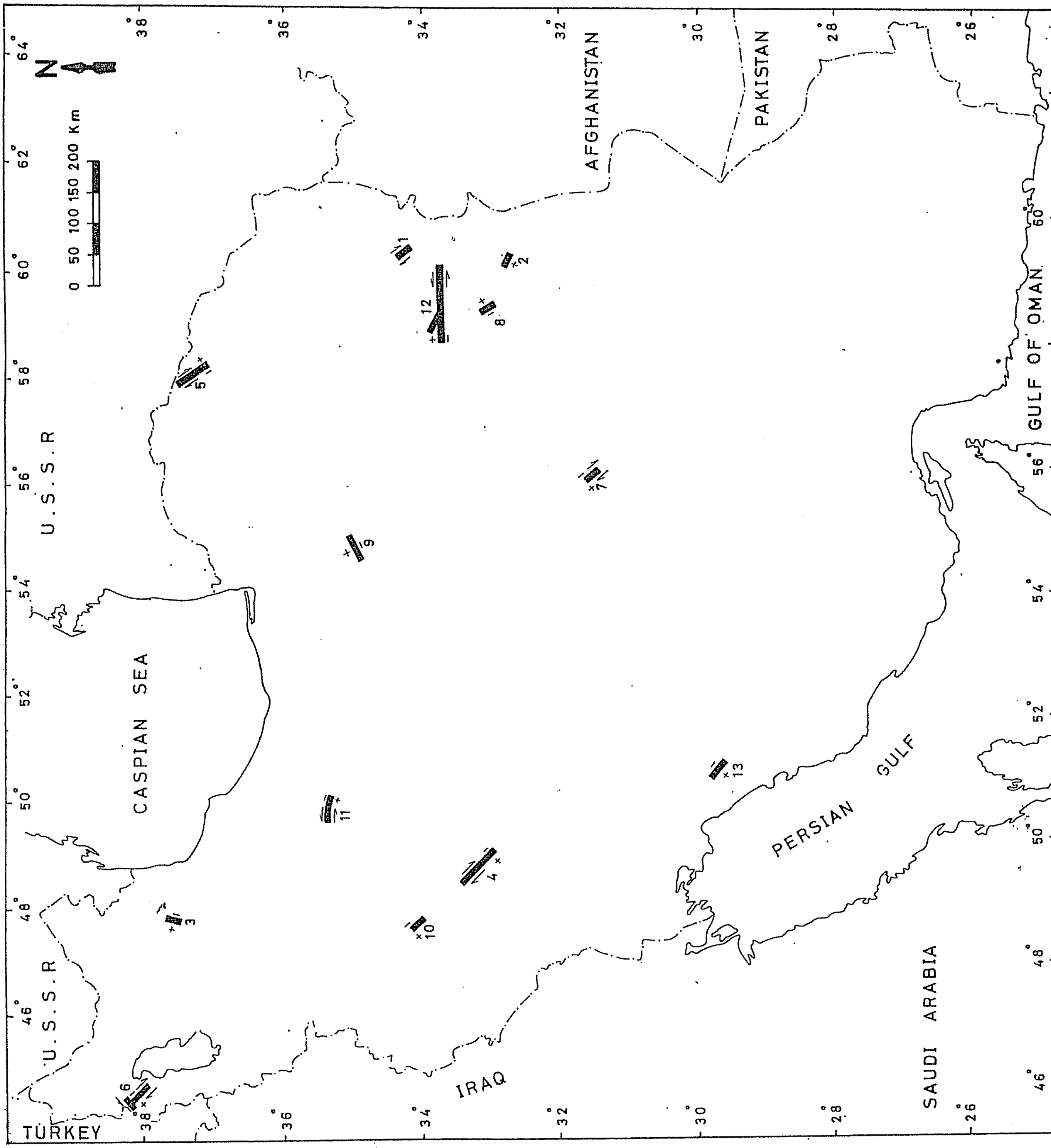
2.1. Baghan-Germab 1929 Earthquake Fault

The Baghan-Germab earthquake fault was associated with the Baghan-Germab destructive earthquake which occurred at 15 h,37 m,36.2s GMT on 1 May 1929 in the Koppeh Dagh Ranges (northeastern Iran) with a magnitude of 7.1. The preliminary macroseismic epicentre was located at 37°. 8'N and 57°. 8' E and the relocated epicentre (Nabavi 1972) at 37°. 92'N and 57°. 60'E.

General aspects of the earthquake and its associated fault were studied in detail by Tchalenko (1975) ; a preliminary note was given by Tchalenko, Braud and Berberian in 1974. The following has been taken from Tchalenko (1975).

"A surface fault over 50 km long was associated with the earthquake (Fig. 2). It extended from Suqeh in the SSE to the Iran-U.S.S.R. frontier in the NNW, following one of the faults of the Quchan-Bakharden Zone. In Soviet Turkmenia, extensive ground fissuring but no clear fault scarp was observed in the Germab and Kurkulab regions. I mapped two sections located towards the ends of the earthquake fault, near Baghan and near Kakeli, and traced the intermediate section with the help of 1:50,000 aerial photographs, press reports and field interviews. Even though a more complete study is required, the Baghan and Kakeli sections described below serve to illustrate some characteristics of the earthquake faulting which took place in 1929.

Fig. 1. (Facing Page) Location of known earthquake faults in Iran.
1. Khaf 1336, 2. Nozad 1493, 3. Bozqush 1879, 4. Dorud 1909, 5. Baghan-Germab 1929, 6. Salmas and Derik 1930, 7. Bahabad 1933, 8. Chahak 1941, 9. Torud 1953, 10. Garun 1958, 11. Ipak 1962, 12. Dasht-e-Bayaz 1968, 13. Mishan 1972.



N
0 50 100 150 200 Km
U.S.S.R
CASPIAN SEA
AFGHANISTAN
PAKISTAN
GULF OF OMAN
PERSIAN GULF
SAUDI ARABIA
IRAQ
TURKEY
U.S.S.R

(P. 144A)

In the field, the earthquake fault trace is marked by a saddle morphology and a slight discolouration of the top soil. The 1929 scarp, still visible in places, appears as a rounded topographical step up to 2 m high with the NE side uplifted. Suitable markers for measuring horizontal movements were not found during my brief investigation. North of Baghan, two qanats supplying the village were damaged by fault movement.

In the southeast, the fault trace can be followed through the villages of Kalateh Shafti and Suqeh, which were both destroyed, but not beyond Suqeh into the Atrak valley (Fig. 2). Northwest of Baghan, the trace follows N 345° up to the Karganli stream bed, then takes a more general N 330° direction. Its linearity through the mountain range suggests a nearly vertical fault plane at depth. The fault passes near the villages of Zakaranlu, Barzow, Chalkanli, Palkanlu, Kalateh Nazar Mohammad and Kakeli. Between the latter two, it crosses a col in Lower Cretaceous limestone and its trace can be followed as a darker zone through the wheat fields. Evidence was found there of a quasi-instantaneous opening and closing of the earthquake fault fracture at surface. The transactions of the Kheyrabad Meteorological Station (quoted in Gorshkov 1941) record that "a fracture appeared along a path, and that the ground opened and then closed again in such a manner that in one place the ears of a donkey were found sticking out of the ground; the donkey was dug up, but the man leading it could not be found". In July 1972, R.Aryan and I were able to clarify this story in conversation with Haji Mohammad Qulieh Rezai in Kakeli who had been involved in the rescue attempt. The young man who had been killed was apparently walking at some distance from the donkey. He was struck by a falling rock, and it was the donkey alone which fell into the crack which then closed up on it. There is every reason to believe that the substance of this account is factual; if so, it may be added to the other known cases of living creatures falling into, and being crushed by, an earthquake ground fracture, i.e. at San Francisco in 1906, at Fukui (Japan) in 1948 (Richter 1958), and at Tabriz in 1641 (See Paper 8).

Beyond Kakeli the fault trace passes through Bagh and possibly Zeydar. It is unlikely that it extended in 1929 into Soviet territory as the Russian sources are very thorough on ground deformations and do not mention anything on the subject.

In Turkmenia the Bakharden-Quchan Zone crosses the Mergen Ulya stream near Germab and Kurkulab, and then bends into the Main Fault Zone. The ground fracture which occurred in these two villages seems to have been exclusively due to slumping and landslides. In Germab, fractures with vertical displacements of 20 cm were observed near the banks of the Mergen Ulya and Sakiz Ab streams, and the water-table rose by several metres with respect to the ground surface. Many streams temporarily increased their output. In Kurkulab fissures were also observed along the Mergen Ulya and one of its smaller tributaries, the Tunchi. At one point where these fissures crossed a road, Nazarevsky (1930) noted: "Here occurred a displacement of the road to the left." He does not mention this again in his 1932 report, and it is not clear from the text whether these fissures were any different from the slump scarps which he describes at other localities. Fissures up to 15 m in length were also reported at the Kheyrabad Meteorological Station, and in the mountains many tracks were blocked by rockfalls and landslides.

The 1929 earthquake fault of Baghan resulted from reactivation of a post-Pliocene

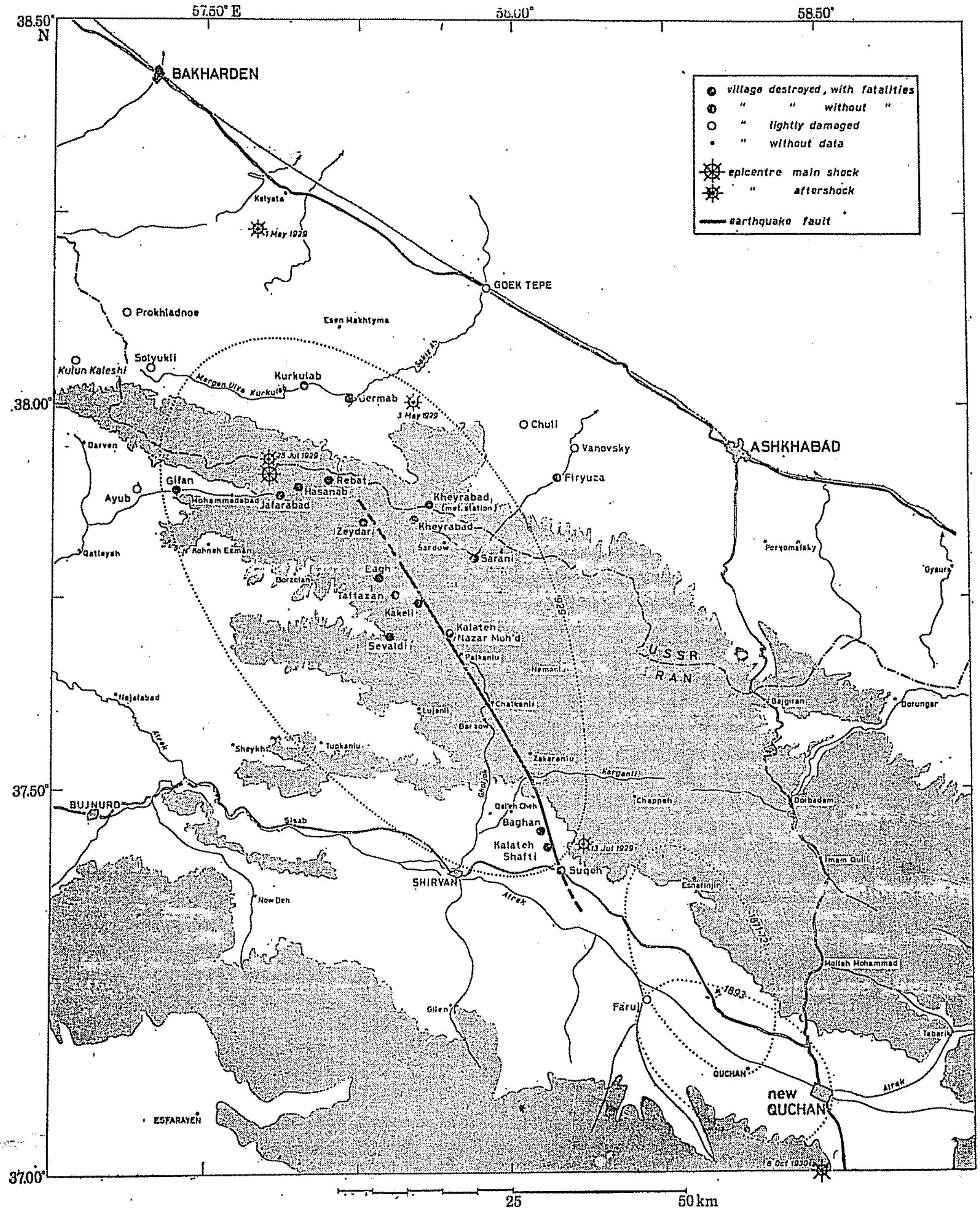


Fig. 2. Baghan-Germab earthquake of 1 May 1929. Dotted line indicates approximate limit of severe destruction. Shaded area is region above 1500 m. Roads shown are as in 1971. The Quchan earthquakes are shown for reference; the sizes of their epicentral regions are not directly comparable to the 1929 region (after Tchalenko 1975).

fault zone which extends from Bakharden (U.S.S.R) to Quchan (Iran). This zone forms part of a fault system which dissects the late Alpine folds of the Koppeh Dagh and consists of NNW dextral and NE sinistral strike-slip faults and minor E–W thrusts. This system is consistent with a NNE–SSW direction of tectonic compression. Quaternary horizontal displacements on some of the individual faults amount to several kilometres, and several have been shown to be active. In the north, the Bakharden-Quchan fault zone bends into the Main Koppeh Dagh fault, which marks the southern edge of the Turan plate. In the south the fault zone crosses the Atrak River near Quchan, which was devastated at least three times by earthquakes during the 19th century."

2.2. Bahabad 1933 Earthquake Faulting (along northern segment of the Kuh Banan fault)

The Bahabad earthquake of 28 November 1933 occurred in the Bahabad valley in eastern Central Iran. It took place at 11 h 09m 26 s GMT at 32°. 0' N, 56°. 1' E with magnitude of 6.25 (ISS). The relocated data (Nabavi 1972, in Ambraseys 1975) give 11 h 09m 24s GMT at 32°. 1'N, 56°. 0'E. Estimated focal depth was 27 km (STR) (Fig. 3).

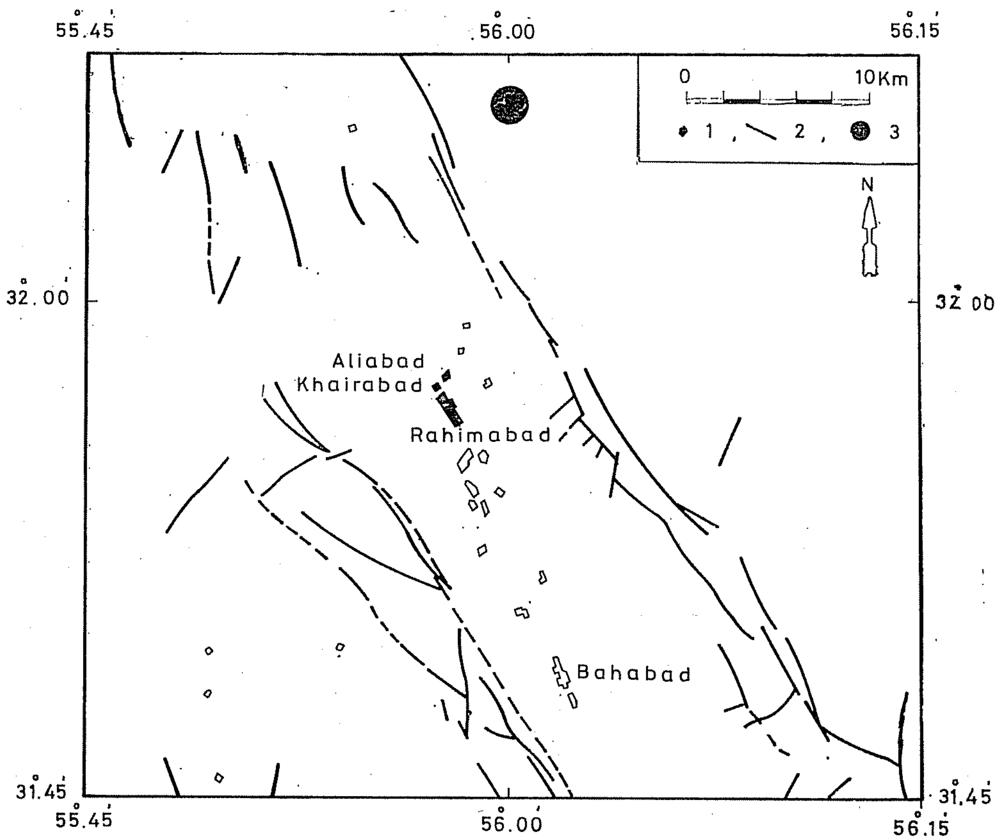


Fig. 3. Epicentral region of Bahabad 28 November 1933 earthquake.
1. villages destroyed, 2. faults, 3. instrumental epicentre.

According to Kumel (1941), "around Aliabad (12 km north of Bahabad, in Bahabad valley) a ground fracture was associated with the earthquake; during this earthquake three villages were destroyed in Dareh Boland-e-Bahabad, these are Aliabad (Mola Ali Reza), Rahimabad and Khairabad; the ruined Aliabad village can be seen near the new village; four people were killed in Aliabad". Huckriede et al. (1962) add that in 1940 a strongish earthquake occurred in Bahabad, and that in April and May 1960 two other shocks occurred in Aliabad. Ambraseys (1975) quotes a statement to the effect that the Bahabad earthquake of 1933 was associated with faulting of more than 12 km.

The Bahabad valley is situated in the eastern part of Kuh Banan fault (See Berberian, Paper 3) and the earthquake was most probably associated with reactivation of the Kuh Banan fault.

2.3. Bozqush 1879 Earthquake Fault

The Bozqush earthquake fault in Azarbaidjan (southwest of Ardebil, NW Iran) was associated with the Bozqush destructive earthquake of 22 March 1879. According to Ambraseys (1974), the destructive earthquake ruined the region between Nir and Mianeh (Fig. 4). The earthquake occurred at 03:42 and it was preceded and followed by many shocks. Official damage reports indicate that 21 villages were totally destroyed and 54 were severely damaged; most of this destruction occurred on the east and south-east slopes of the Kuh-e-Bozqush where 922 people were killed, together with 2,660 sheep, 1,125 oxen, 124 horses and 55 camels. In Ardebil the shock ruined some houses, killing three people. Half of Nir was destroyed; at Saganchi 50 people were killed and the village ruined. Gharashiran was totally destroyed and more than 100 people killed. In Dashanli all houses were ruined and 50 people killed. Meshkidjik was levelled to the ground and no one survived; more than 1000 animals were killed. In Armudagh only two people survived and the village was totally destroyed; the same thing happened at Sarighamish. In Tark the collapse of houses and landslides killed about 500 people, and at Munagh 600 more were buried under the ruins. Half of Dursun-Hadjali and Hadili was destroyed and about 1000 people perished in the region of Mianeh, Dizaj and Yengidjeh. The shock was strongly felt in Tabriz and Zanjan. At Lenkoran, 110 km from the epicentral area, the shock caused chimneys to vibrate visibly and produced some panic. Further away, at Belyasuvar, 160 km distant, the shock was very strongly felt. At Ordubad, 200 km away, the shock was so strong that a few houses cracked. At Shusha, 220 km distant, the earthquake was distinctly felt. Aftershocks occurred at about 04:00, 17:00 and 21:00; they continued up to the 2nd of April.

The whole epicentral area of the Bozqush 22 March 1879 destructive earthquake was investigated by Berberian and Lotfi in July 1975. During a careful investigation they found the first evidence of an earthquake fault associated with the Bozqush destructive earthquake of 1879 (Fig. 4). This discovery is significant for seismotectonic study of the area. Casualty and destruction information about the earthquake had been gleaned from historical documents, but no attempt made at detailed seismotectonic investigation of the epicentral area.

One kilometre north of Sarighamish, on the eastern section of the Garmi river, the southern segment of Bozqush earthquake fault was discovered. The existing length

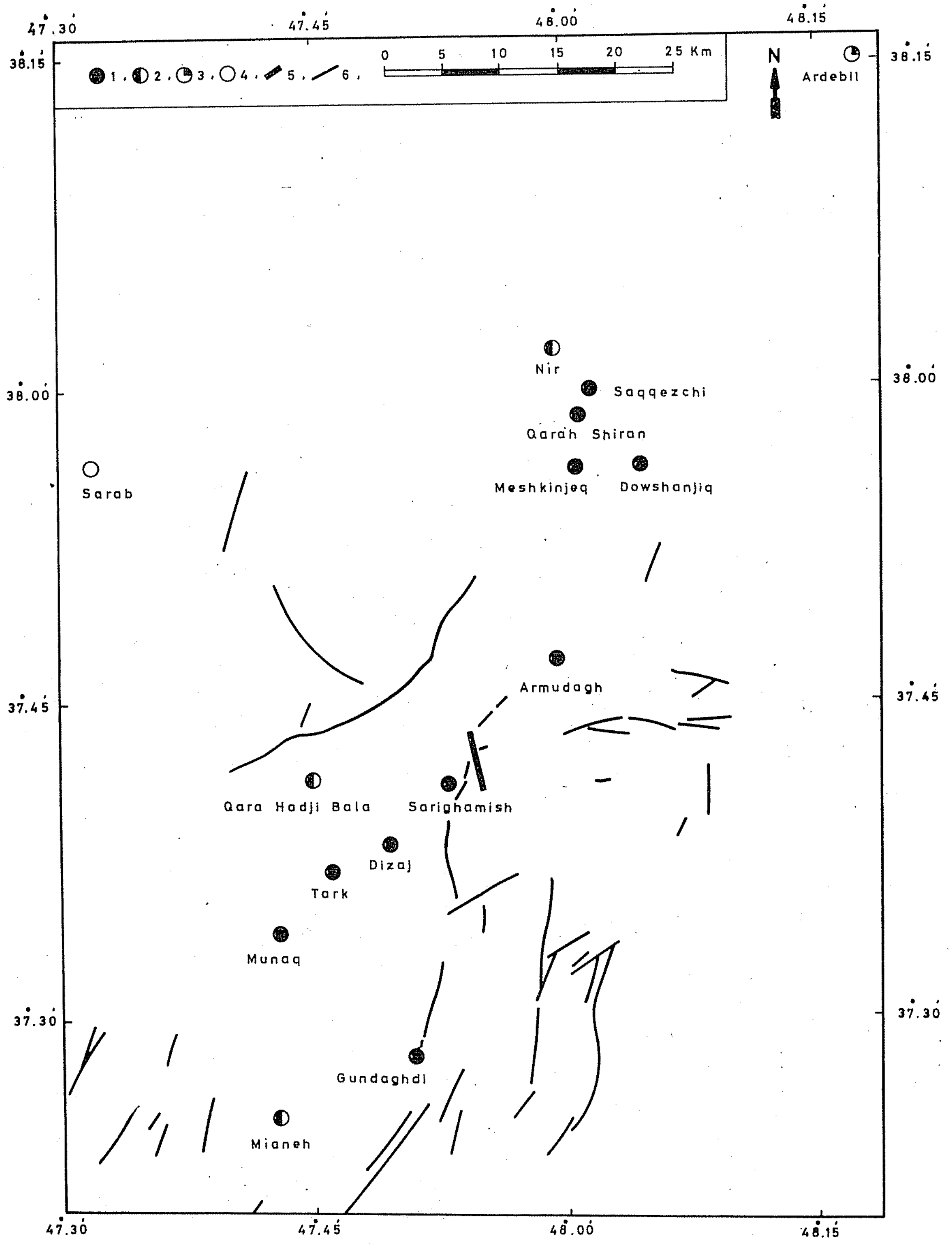


Fig. 4. Epicentral region of Bozqush 22 March 1879 earthquake.
I. villages completely destroyed, 2. half destroyed, 3. partly destroyed, 4. severely felt with slight damage, 5. earthquake fault, 6. fault without specification (after Berberian and Lotfi)

of the earthquake fault is 2 km, the northern extension of the fault goes into the Garmi river and is now covered by alluvial deposits.

The Bozqush earthquake fault is a Quaternary geological fault reactivated during the 1879 destructive earthquake. It is a high angle reverse fault with approximate strike of N 170°E and dip of 75°W. The western block, which is composed of silicified allunite-bearing breccia of Miocene age, is thrusted over the Quaternary alluvial deposits (Figs. 5 and 6). The fault has a gauge zone 3 m thick, indicating the first phase of the geological fault movement in Quaternary. Just along the main fault line 10 cm of very fresh sheared zone is visible, formed during the reactivation of the fault in the 1879 earthquake (Fig. 7). The amount of vertical movement during geological times and during the earthquake is difficult to estimate, because there is no evidence of Miocene rocks below the 6 m alluvial deposits east of the fault. No evidence of horizontal movements can be seen.

A few old men in Tark village remember hearing the story of the 1879 disaster from their grandfathers. During the earthquake of 1879 the Dash Masjed (stone mosque, tomb of Khajeh Kavus) of Tark, which is 870 years old, was partly destroyed (the

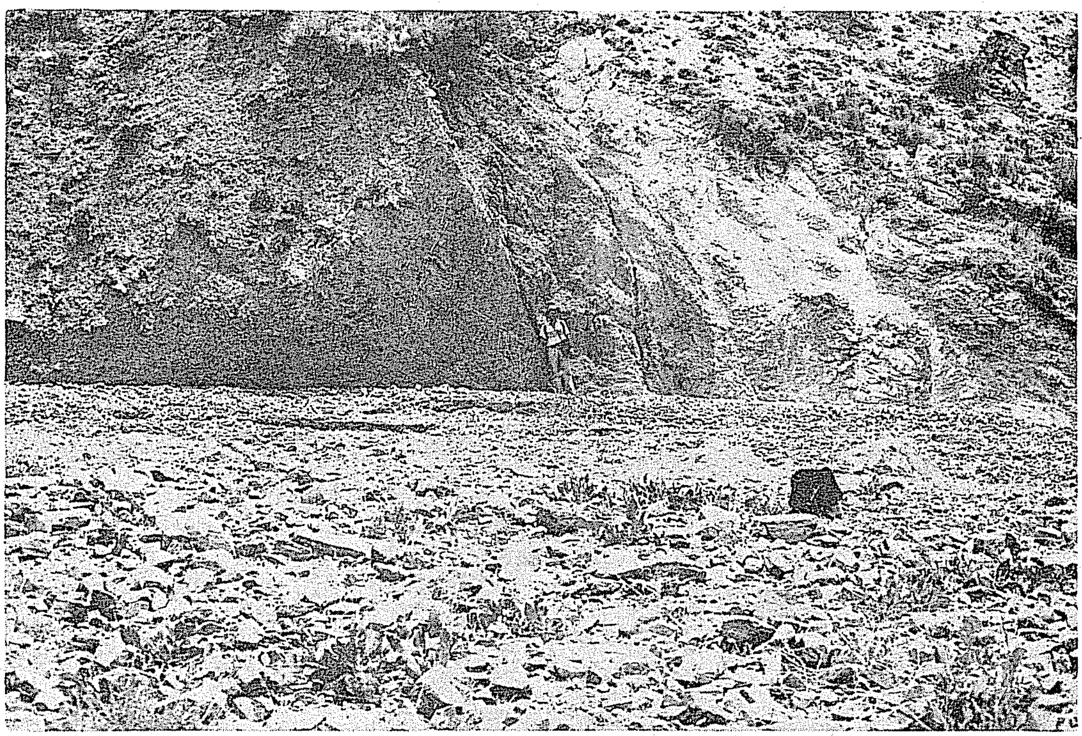


Fig. 5. Bozqush earthquake fault of 22 March 1879. The western block of Miocene age (right) is thrust over the eastern Quaternary alluvial deposits (left).

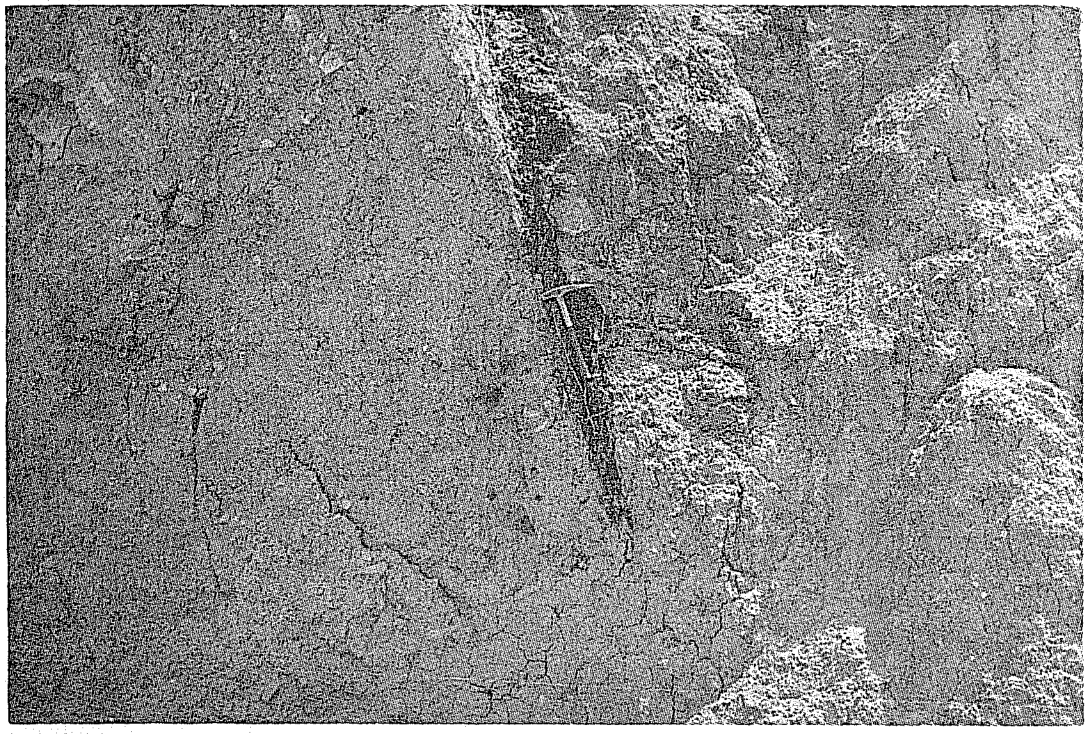


Fig. 6. Bozqush earthquake fault.

Fig. 7. A close up view of the Bozqush earthquake fault.

kiln-brick dome, the upper part of the walls, and two minarets) (Fig. 8). The earthquake fractures can be seen now in the stone windows of the mosque (Fig. 9). There is an inscription on the stone above the eastern gate of the mosque indicating that the rebuilding of the mosque was completed in 1282 (A.H.S.?).

It seems that all the strain energy stored along the zone was released during the Bozqush destructive earthquake of 22 March 1879, as very few shocks have occurred since the earthquake.

2.4. Chahak 1941 Earthquake Fault

The Chahak Fault, which has a trend of NNW–SSE, is situated near Chahak, SW of Qaen and south of Dagh-e-Mahmudabad in eastern Central Iran (see the Seismotectonic Map). A destructive earthquake occurred on 16 February 1941 in the Chahak area at 16 h 38 m 59 s GMT at 33°. 3'N, 58°. 7'E (ISS) with a magnitude of 6.25 (GR). The relocated data (Nabavi 1972 in Ambraseys 1975) give 16h 39m 03s GMT at 33°. 30' N, 58°. 87'E. The earthquake killed 600 people, destroyed 2500 houses and was strongly felt at Birjand (Ambraseys, Moinfar and Tchalenko 1972). Ambraseys (1975) quoted to the effect that the Muhammatabad (Chahak) earthquake of 1941 was associated with faulting.

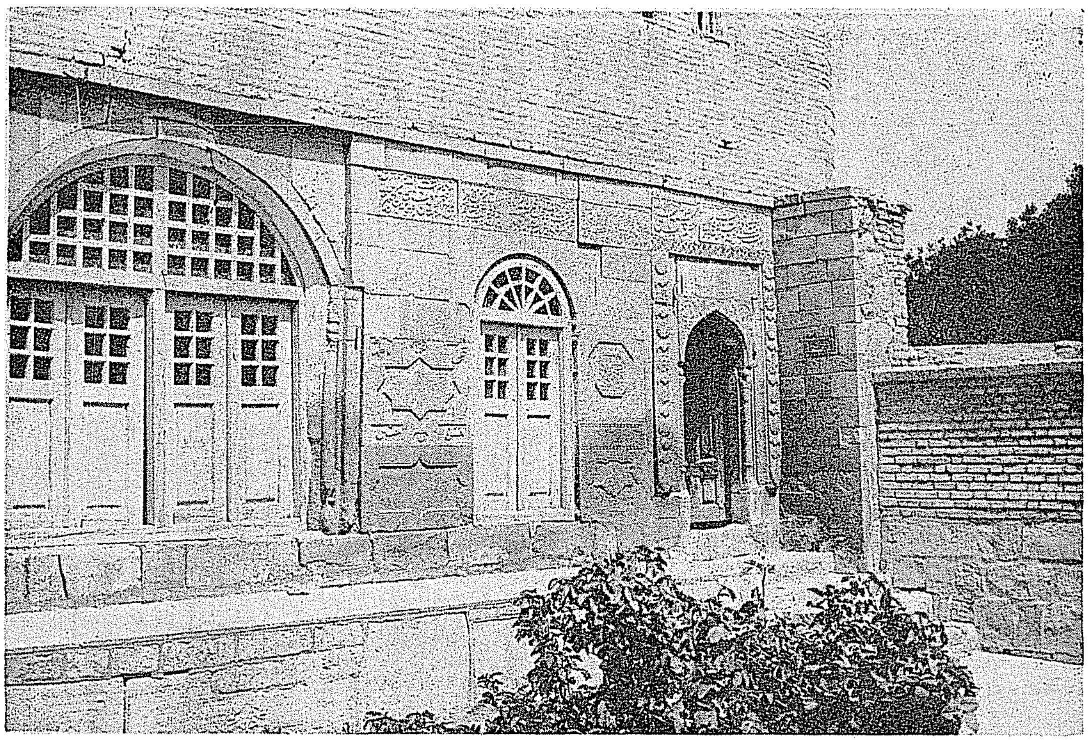


Fig. 8. Dash Masjed (stone mosque) in Tark village. The 870 years old mosque was partly destroyed during the Bozqush destructive earthquake of 22 March 1879 (photographed in 1975).

5.2. Dasht - e - Bayaz 1968 Earthquake Fault

The Dasht-e-Bayaz earthquake fault runs almost along 34°N between 58°E and 60°E (see the Seismotectonic Map). The Dasht-e-Bayaz earthquake of 31 August 1968 was associated with a set of surface fractures over a length of 80 km (the earthquake fault, Figs. 10 to 12) caused by reactivation of a fault (the geological fault), and extensive non-tectonic deformations.

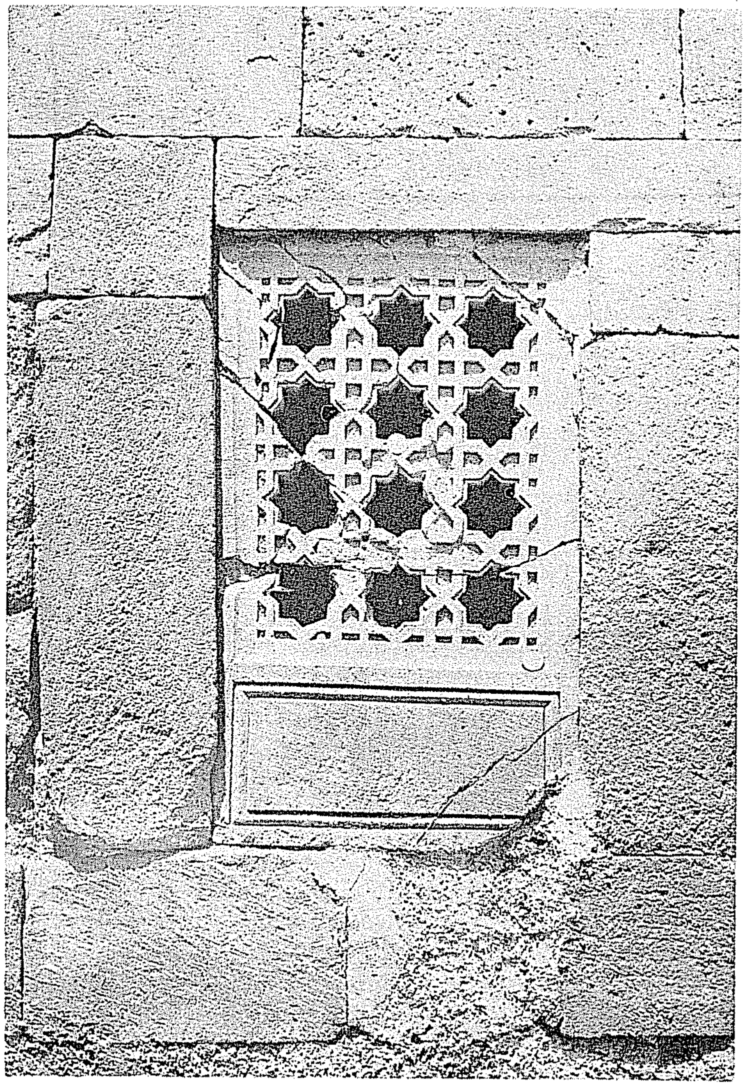


Fig. 9. The Bozqush earthquake fractures in the stone window of the Tark Dash Masjed (stone mosque).

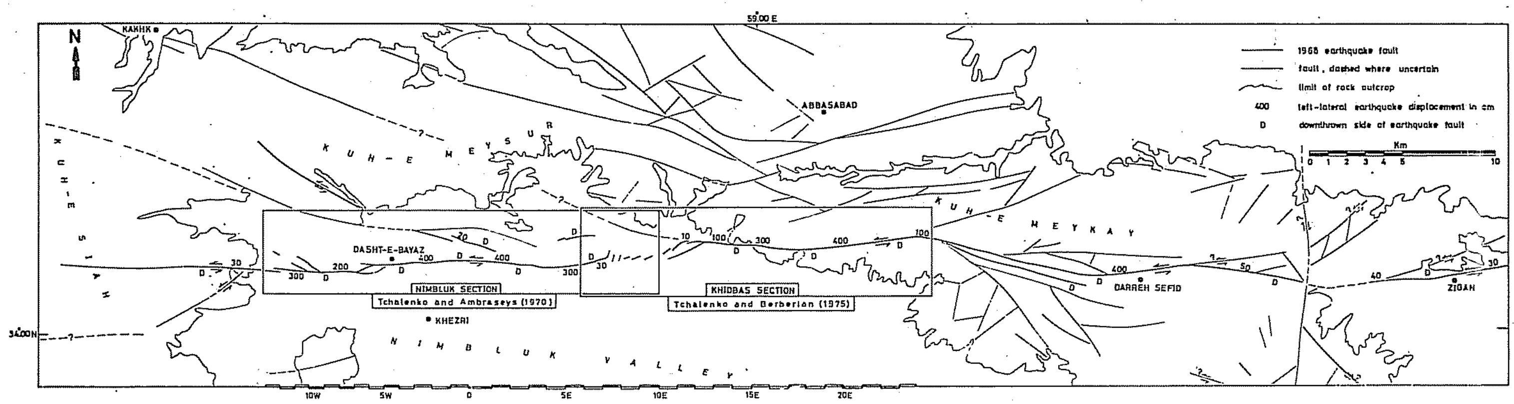


Fig. 10. Dasht-e-Bayaz earthquake fault. Faults after Ambraseys and Tchalenko (1969), Tchalenko and Ambraseys (1970), Behzadi (1972, unpublished), and Tchalenko and Berberian(1975).

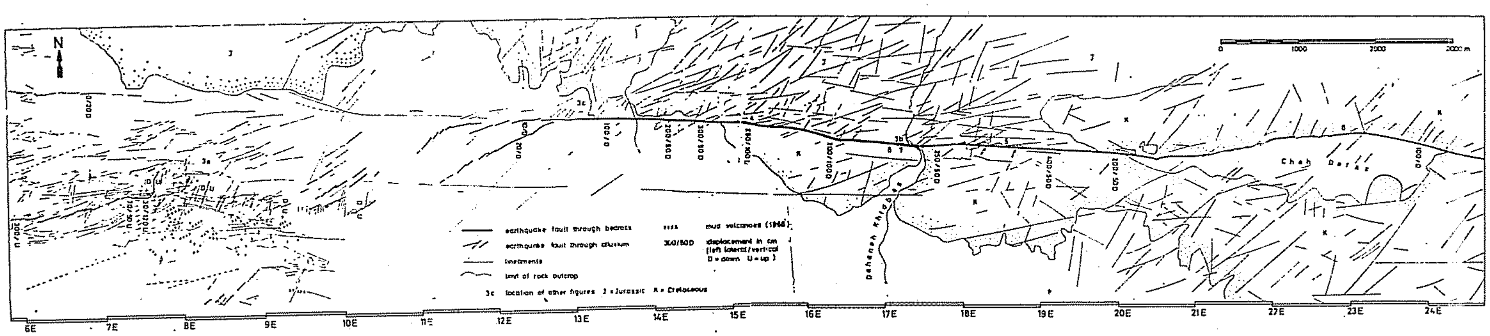


Fig. 11. Khidbas section along Dasht-e-Bayaz earthquake fault. Chainage is in kilometres and is a continuation of the one used in Tchalenko and Ambraseys (1970); (after Tchalenko and Berberian 1975).

Fig. 12. Aerial photograph of Dasht-e-Bayaz earthquake fault break, NW of Miam.

The Dasht-e-Bayaz destructive earthquake occurred at 10h 47m 37.4s GMT, on 31 August 1968, in the Khorassan province of east Iran, a region known to have been seismically active since at least the ninth centrury A.D. Its epicentre was located at lat. 34°. 10'N, long. 58°. 96'E (Niazi 1969), with a focal depth of about 15km and a magnitude of 7.2 averaged from several determinations. The main shock and strongest aftershock (lst September 1968) destroyed or severely damaged about 12,000 housing units and killed more than 10,000 people. It was felt over an area of about 40,000 sq.km.

The general aspects of the Dasht-e-Bayaz earthquake and its fault were studied by several investigators immediately after the event (Ambraseys and Tchalenko, 1968, 1969a, 1969b; Bayer, Heukroth and Karim 1969; Crampin, 1969; Eftekhar-Nezhad, Haghipour and Davoudzadeh 1968; Gansser 1969; Niazi 1968, 1969; Sobouti 1969; Tchalenko and Ambraseys 1970), and more recently (Berberian 1973; Sobouti 1972; Tchalenko and Ambraseys 1973; Tchalenko and Berberian 1975).

Tchalenko and Ambraseys (1970) analysed the fractures formed along the part of the fault that crossed the alluvium of Nimbluk valley. The recent movement was left-lateral (maximum 4m) with a small vertical component (1m south side relatively down), (Fig. 10.)

Tchalenko and Berberian (1975) examined the Khidbas section (18 km long eastern segment) of the fault in detail, where the fault passes through hard rock (Fig.11). They compared the 1968 earthquake fractures with structures caused by earlier tectonic deformation, and affirmed that the ground displacements accompanying the earthquake coincided precisely with the pre-existing east-trending fault trace. The bedrock displacement occurred along new tension fractures that strike on average at N50°E, as well as long reactivated pre-existing structures. Earlier tectonic deformation also produced tension fractures (post-Pliocene), conjugate shears (Pliocene), and tension joints (pre-Pliocene), all of which are consistent with N47°E to N55°E tectonic compression. This trend for the compression axis is in accordance with the results of the observations of Niazi (1969) and McKenzie (1972) on their fault plane solutions.

The study of Tchalenko and Berberian (1975) covered the three following points:

1 – The 40° to 45° angle measured between the major principal stress direction indicated by the earthquake fractures and the fault.

2 – The apparent constancy of the stress field direction during the three early phases and the 1968 deformation.

3 – The "gap" and "anti-Riedel" structure shown by the overall fault trace, which, they suggest, are characteristic of situations of kinematic restraint and are associated with a non-uniformly propagating rupture.

It should be noted that the main E–W trending fault of Dashte-e-Bayaz has a rotational movement and is not a real wrench fault (Berberian 1973).

A network of 4 strain-metres installed in underground qanat tunnels close to the Dasht-e-Bayaz 1968 earthquake fault detected an eastward propagating creep with a velocity of 200 mm s^{-1} (King et, al. 1975).

2.6. Dorud (Silakhor) 1909 Earthquake Fault

The Dorud earthquake faulting was associated with the Silakhor (Dorud) destructive earthquake which occurred at 02h 48 m 18s GMT on 23 January 1909 in the upper Ab-e-Dez valley in the Silakhor district of the Zagros mountains (southwestern Iran). The body-wave magnitude of the event was 7.4. Maximum destruction was confined to the southeastern part of the valley, between the village of Zargina and the small town of Dorud, with the preliminary macroseismic epicentre (taken as the centre of the area of maximum destruction) located at about 33.° 5'N and 49°.0'E (Fig. 13). It caused between 5000 and 6000 deaths in 130 villages, devastated an area of at least 3000 sq. km, and was associated with a fault-break over 40 km long. The aftershocks continued for almost six months.

The general aspects of the Silakhor earthquake and its fault (Dorud) were studied for the first time in detail by Tchalenko and Braud (1974), Gidon et al. (1974), and then by Ambraseys and Moinfar (1973). A preliminary note was made by Tchalenko, Braud and Berberian in 1974.

As already stated, contemporary descriptions of ground deformation (Shtelling 1910) suggest that faulting occurred during the earthquake. The eroded fault scarp is clearly visible now on the ground and on aerial photographs, and can be followed in a N35°E direction from Kalangona to Dorud and Sarawand. The small town of Dorud, situated at approximately the mid-point of this trace, may be conveniently used to distinguish a southeastern section contained in the Shotorun Kuh mountains, from a northwestern section contained in the Silakhor Valley (Fig 14). In the alluvium of the Ab-e-Dez Valley it appears as a rectilinear topographical step along which the north-eastern side is downthrown by at least 1m (Fig. 15). Horizontal displacements have so

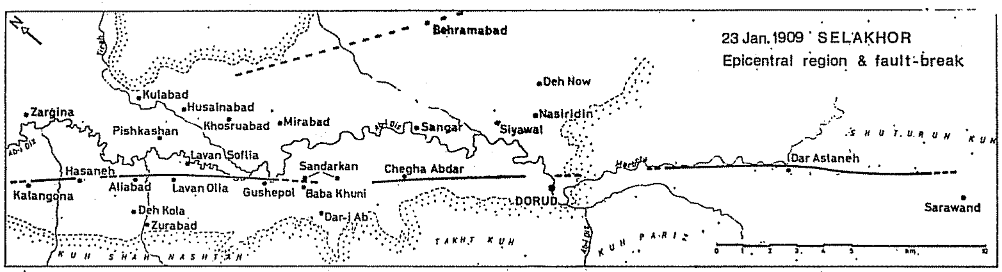


Fig. 13. 1909 Silakhor (Dorud) earthquake. Villages in the epicentral region and identified segments of the earthquake fault-break (dashed where trace is uncertain). Sketch map based on field mapping and 1:50,000 aerial photographs (after Tchalenko and Braud 1974).

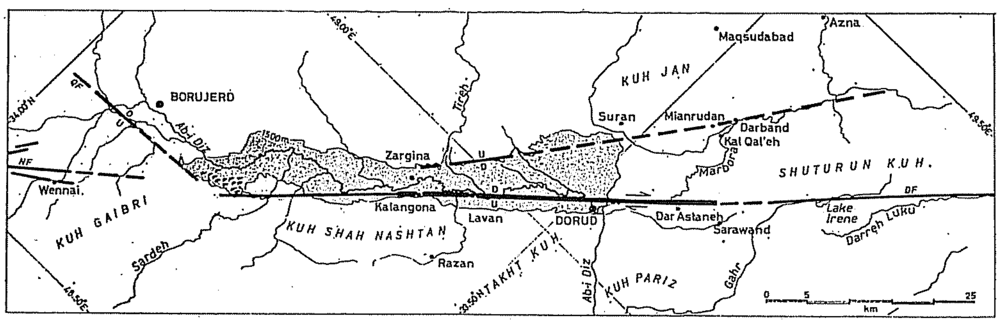


Fig. 14. Dorud Fault. The 1909 earthquake fault scarp is shown by the thicker line. Shaded area is region below 1500m. Fault movement: U (up) D (down). DF: Dorud Fault, NE: Nahavand Fault, QF: Qaleh Hatam Fault (after Tchalenko and Braud 1974).

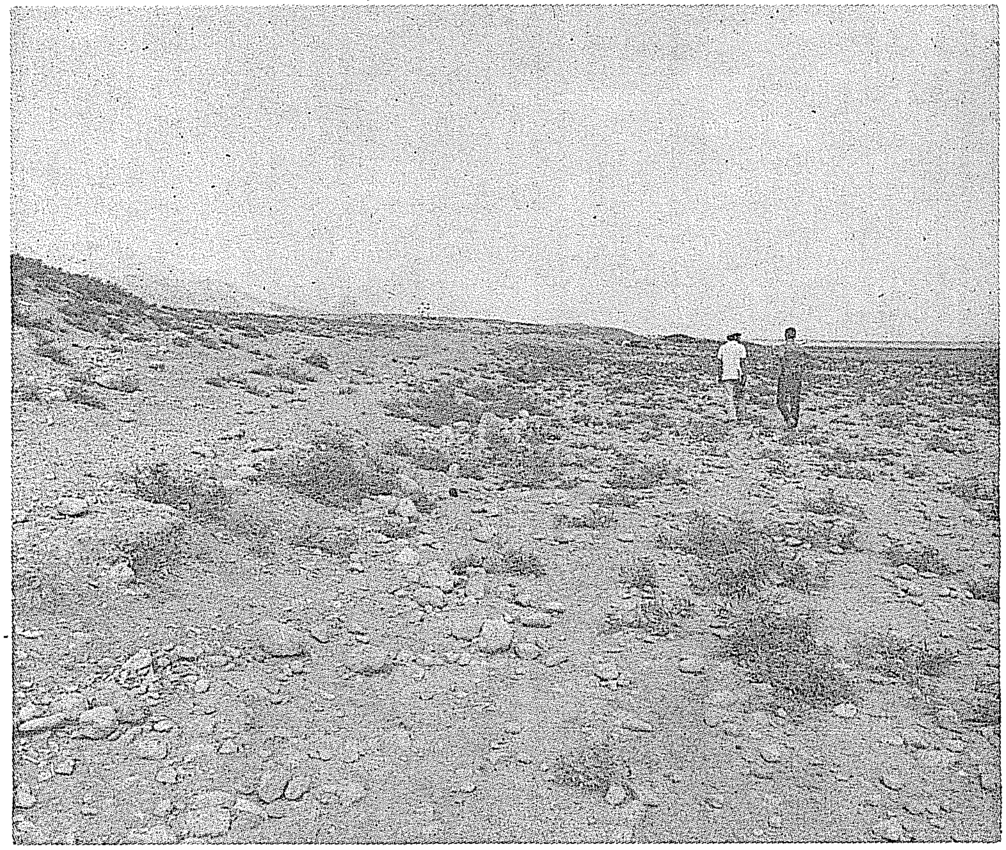


Fig. 15. 1909 Silakhor earthquake fault. Eroded fault scarp in the Silakhor Valley between Lavan Olia and Aliabad. Typical scarp height is now one metre but must have been greater before erosion. Looking NW (after Tchalenko and Braud 1974).

far not been determined. In places such as Kalangona the topographical step is several metres high, probably as a result of previous fault movement, while a number of small springs mark the fault throughout the valley. The linearity of the fault trace along its entire length from the mountains in the southeast to the alluvial valley in the northwest indicates that the fault plane at depth is vertical. Southeast of Dorud, the earthquake fault enters the mountain range where it can be seen to coincide with a well marked pre-existing geological fault.

Detailed geological mapping has shown that the earthquake fault was formed by reactivation of a much larger NW–SE structure, called the Main Recent Fault. This is a major wrench fault in the northwestern part of Zagros. It is later than, and quite distinct from, the post-Pliocene Main Zagros Reverse Fault which is considered to mark the northeastern edge of the Arabian Plate. The Main Recent Fault probably results from the latest NNE motion of the Arabian Plate with respect to Central Iran, and is at present seismic to the northwest of the 1909 epicentral region, but in the southeast no data have yet been found to establish its activity (Tchalenko and Braud,1974; Tchalenko et al. 1974).

Gidon et al. (1974) described stratigraphic marker-beds truncated and displaced along the Main Recent Fault (Dorud segment) in a right-lateral sense by at least 10 km, and possibly as much as 60km.

Analysis of the visible surface scarp and of the occasional feature, man-made or natural, which crosses the Dorud fault showed that the 1909 earthquake displacement of about 1m does not appear to have been followed by any significant creep movement (see also Dorud Fault, Paper 3).

2.7. Farsinaj 1957 Earthquake Fissuring

The Farsinaj earthquake of 13 December 1957, of Magnitude 7, was associated with some fissuring in alluvium northeast of Sahneh, along Sahneh Fault (Fig. 16) (Tchalenko and Braud 1974). According to Ambraseys et al. (1973) and Ambraseys (1975), there is some evidence that the Farsinaj earthquake or perhaps some of its larger aftershocks were associated with ground deformations, which in some places aline with, and elsewhere define, structural trends, or coincide with Recent faults. There is insufficient evidence, however, to show conclusively that these deformations were of tectonic origin. Their significance lies in the fact that they have been found in the vicinity of, or alined with, pronounced structural trends and Recent faults. Ambraseys (1975, case No. 20) put an earthquake fault of about 10 to 20km along with ground deformation of small amplitude.

2.8. Garun 1958 Earthquake Fault

The Garun Quaternary fault, situated NW of Borujerd and Nahavand, was reactivated during the Nahavand (Firuzabad) earthquake of 16 August 1958 (see Garun Fault, Paper 3 and the Seismotectonic Map).

2.9. Ipak 1962 Earthquake Fault

The Ipak earthquake fault is situated in the southern part of Eshtehard (SW of Tehran) with N100°E trend, at Ipak; the Buyin Zahra earthquake of 1 September 1962, of average magnitude 7.25, originated on this active fault (Fig 17).

The Buyin Zahra (Qazvin) destructive earthquake occurred at 19h, 20m, 38.7s, GMT, on the 1 September 1962 in the southern Qazvin area (SW of Tehran). Its epicentre was located at 35°. 6'N and 49°. 9'E (U.S.C.G.S), with a focal depth of about 20km, and a magnitude of 7.25 averaged from several determinations. The earthquake killed 12,225 and injured 2,776 people. It damaged beyond repair 21,310 houses (294 villages) and killed 35% of the livestock in the area. The maximum intensity of the shock did not exceed IX on the Mercalli scale.

Several hundred aftershocks were recorded by Iranian stations but only a few by foreign seismographic centres. On the 2nd of September one aftershock was recorded with a magnitude of 4.75, 40km to the west-southwest. On the 13th of September a shock of 5.5 magnitude located over 10km to the northeast of the epicentre occurred, and was felt in Qazvin, Tehran and, curiously, along the Caspian shore. The activity

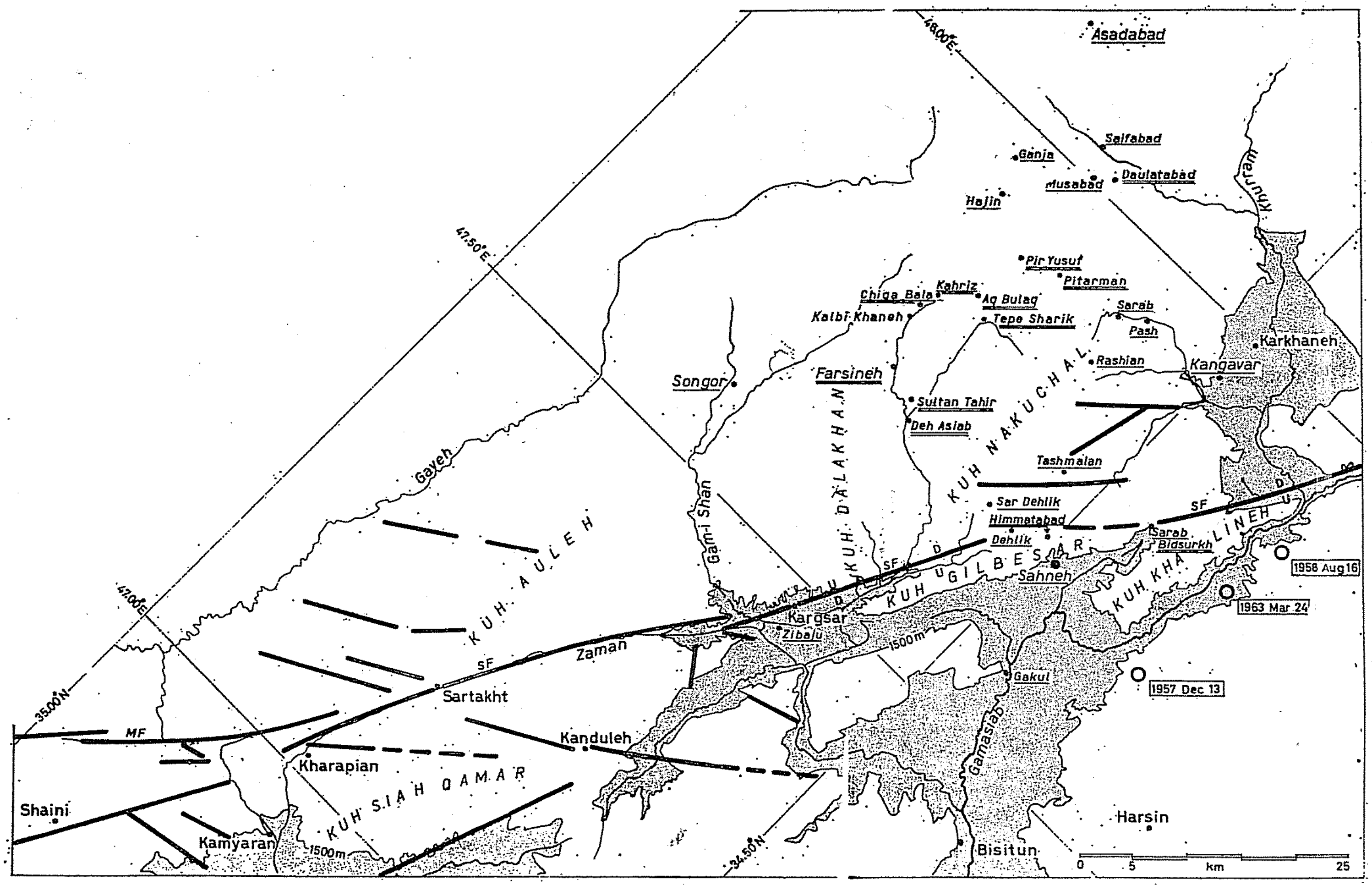


Fig. 16. Sahneh Fault and villages destroyed by the 1957 earthquake. Shaded area is region below 1500m. Fault movement: U (up) D (down). SF: Sahneh Fault (southeastern, central and northwestern sections); MF: Morvarid Fault. Villages in italics and underlined once were severely damaged by the 1957 Farsinaj earthquake; those underlined twice were destroyed and had people killed. Instrumental epicentres shown are for 1957 Farsinaj, 1958 Nahavand and 1963 Karkhaneh earthquakes (after Tchalenko and Braud 1974).

of aftershocks decreased strongly after the 15th of September and died about the middle of November 1962 (Ambraseys, 1963).

The earthquake was associated with a surface faulting about 100km long, with upward vertical movement of the southern block and a small left lateral horizontal component. The earthquake faulting was from Ipak, south of Buyin Zahra, to Dakhrajin 6km west of Ab-e-Garm in the west (Figs. 17 and 18). Besides faulting, extensive non- tectonic deformations occurred (Ambraseys, 1963). The fault-plane solution for this earthquake is in close agreement with field observations, if the south-dipping plane is chosen (Petrescu and Purcaru 1964; McKenzie 1972). The slip vector then strikes N 55°E and the horizontal component of the compressional axis lies at N 38°E.

The general aspects of the Buyin Zahra earthquake and its fault (Ipak) were studied immediately after the event (Ambraseys 1962, 1963; Abdalian 1963; Mohajer and Pierce 1963; Mohajer 1964; Saraby and Foroughi 1962; Institute of Geophysics 1963; Gansser 1969), and more recently by M. Berberian (1971 and 1972; Paper 9).

Berberian (1971) examined the young pre-existing joint pattern along the Ipak fault in detail. He stated that the Ipak 1962 earthquake fault occurred along a pre-existing geological fault and compared the 1962 fractures with structures caused by earlier tectonic deformations. The youngest tension joints related to the stress responsible for young movements (post-Pliocene) of the geological fault strike on N 28°E to 86°E; the principal local stress acted in a N 56°E direction, which gave a left-lateral post Pliocene movement to the geological fault (see also Paper 9, this volume).

2.10. Khaf 1336 Earthquake Fault

This fault is situated west of Khaf town in the east of Iran (see the Seismotectonic Map). It has been included on geological maps as a 70km Quaternary fault with NW-SE direction. Ambraseys (1975), on the evidence of historical documents, reported that the 20th October 1336 destructive earthquake of Khaf was associated with faulting.

2.11. Londeh 1929 Earthquake Faulting?

The Londeh earthquake of 15 July 1929 occurred at 07h 44m 07s GMT, at 33°. 7'N, 49°.4'E with a magnitude of 6.25 (ISS) and estimated focal depth of 65km (STR). The relocated data (Nabavi 1972, in Ambraseys 1975) give 07h 44m 14s GMT, 32°. 18'N, 49°. 72'E. According to Wilson, "seven distinct shocks in 24 hours occurred in the Masjed Soleyman area, 31m east of Shustar; the first shock was at 10.47am (local time), minor tremors felt later. Minor damage to plant and property. Movement SE–NW; village of Andarkah damaged and nine lives lost." Ambraseys (1975, case No. 39) put a doubtful earthquake faulting of 1km long in the area associated with the 15 July 1929 earthquake.

2.12. Mishan 1972 Earthquake Fault

The Mishan earthquake of 2nd July 1972 occurred at 12h 56m 06s GMT and was assigned a magnitude Mb=5.4. Its focal depth was given as 27km (ISC), but both destruction data and ground fracturing suggest that the event may have been shallower. The epicentre was located at 30°.1'N, 50°. 8'E (NOAA). The general aspects of the Mishan earthquake and its fault were studied by Berberian and Tchalenko (1975; see also Paper 6, this volume).

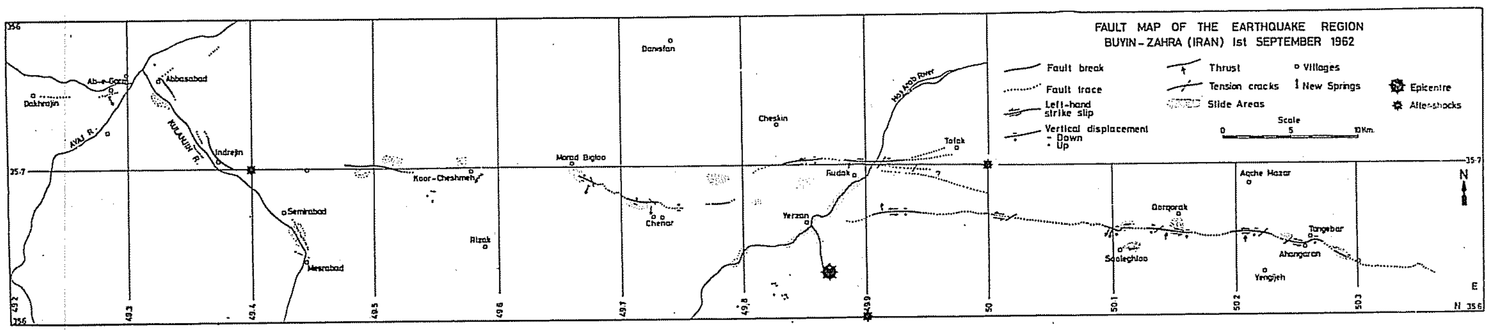


Fig. 17. Ipak earthquake fault trace of 1 September 1962 (after Ambraseys 1963).

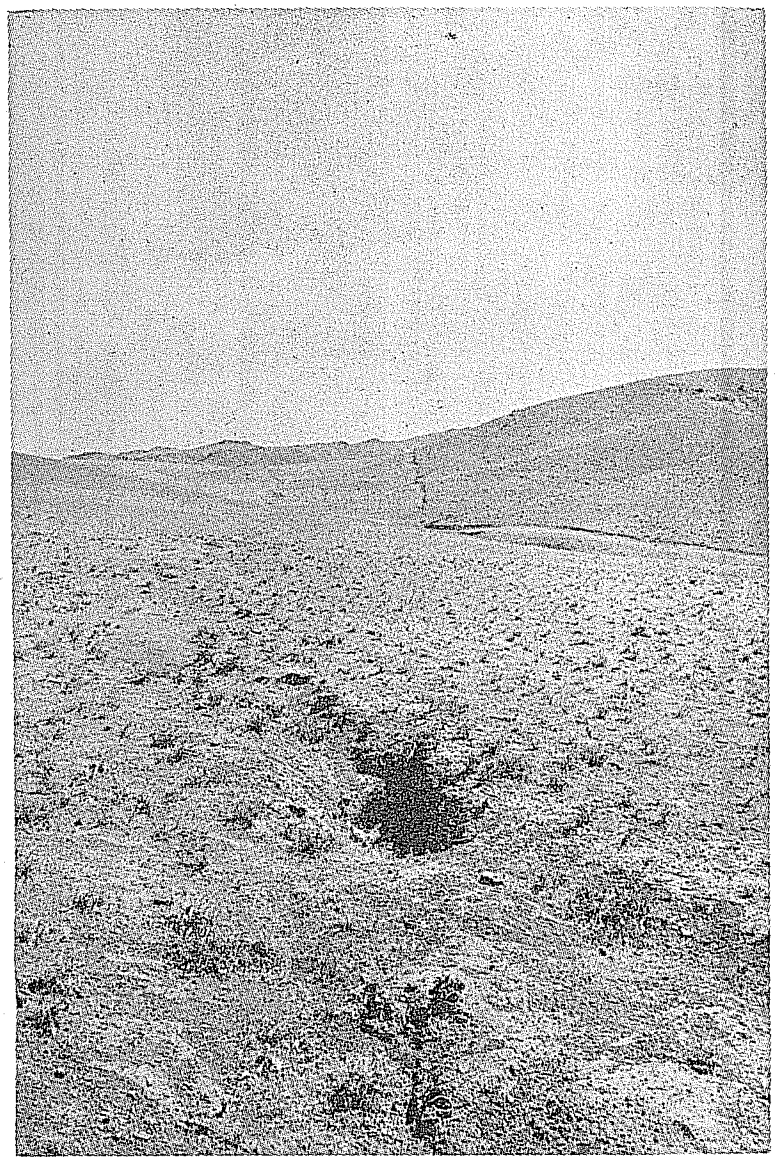


Fig. 18. Ipak earthquake fault north of Ahangaran village, viewed eastwards (photographed in 1971).

About 700 houses were destroyed in Mishan Markazi and a few surrounding villages (Fig. 19). There were no fatal casualties, as in summer the inhabitants were not living in their houses. Damage estimates were as follows:

Mishan Markazi:	50%	houses destroyed,		50%	houses damaged	
Mishan Sofla:	30%	»	»	70%	»	»
Bidkarz:	20%	»	»	80%	»	»

Talkhab, Talkhab Qarakhan, Talkhab Gharib, Qaleh Kohneh, Neza Olia

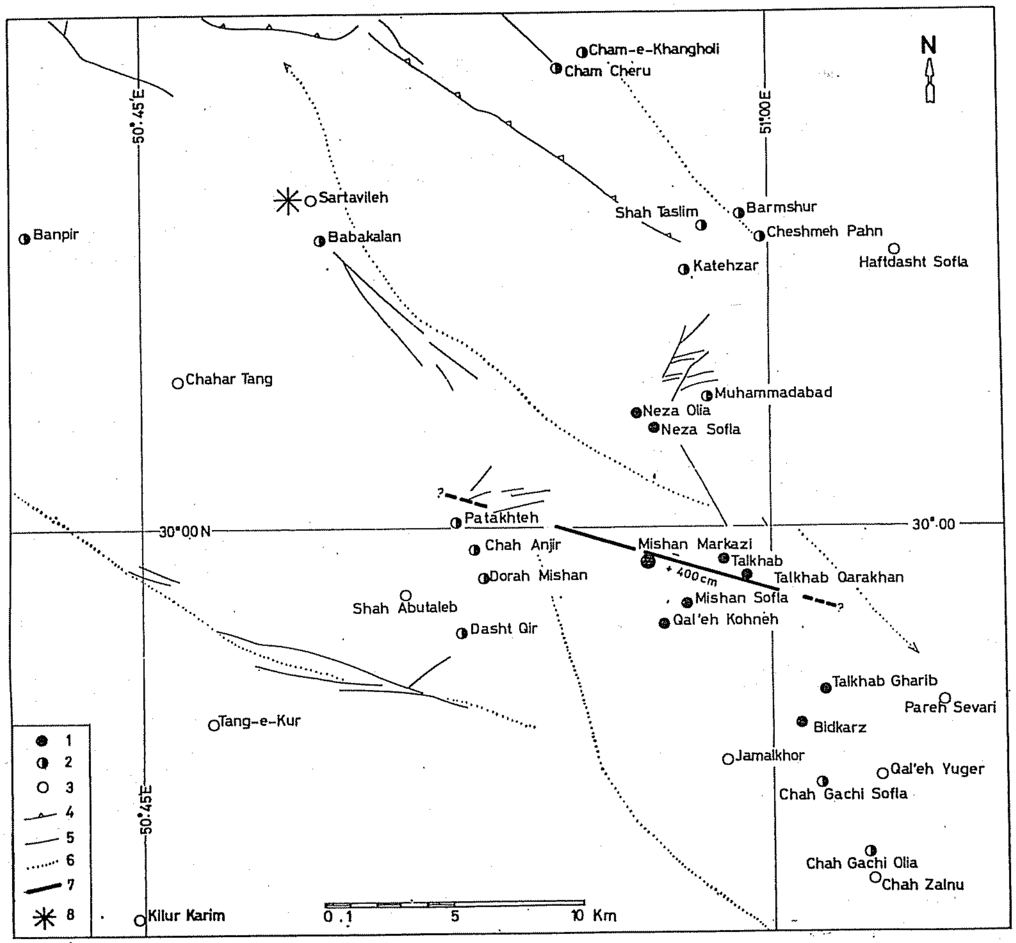


Fig. 19. Mishan earthquake of 2 July 1972. 1. village in which all houses were damaged and some destroyed, 2. village in which many houses were fissured, 3. village in which shock was strongly felt, 4. thrust fault, 5. other faults 6. anticlinal axis, 7. 1972 earthquake fault, 8. instrumental epicentre (Berberian, Tchalenko, Paper 6).

and Neza Sofla: some houses were destroyed and most others damaged. Other villages in which houses were only fissured are shown in Fig. 19.

The shock was felt in the ports of the Persian Gulf between Bandar Shahpur and Bushehr, as well as in Shiraz.

The earthquake was accompanied by a ground fracture (Fig. 20). The fracture, which was studied in the Mishan Markazi-Mishan Sofla region, cuts through the Gach-

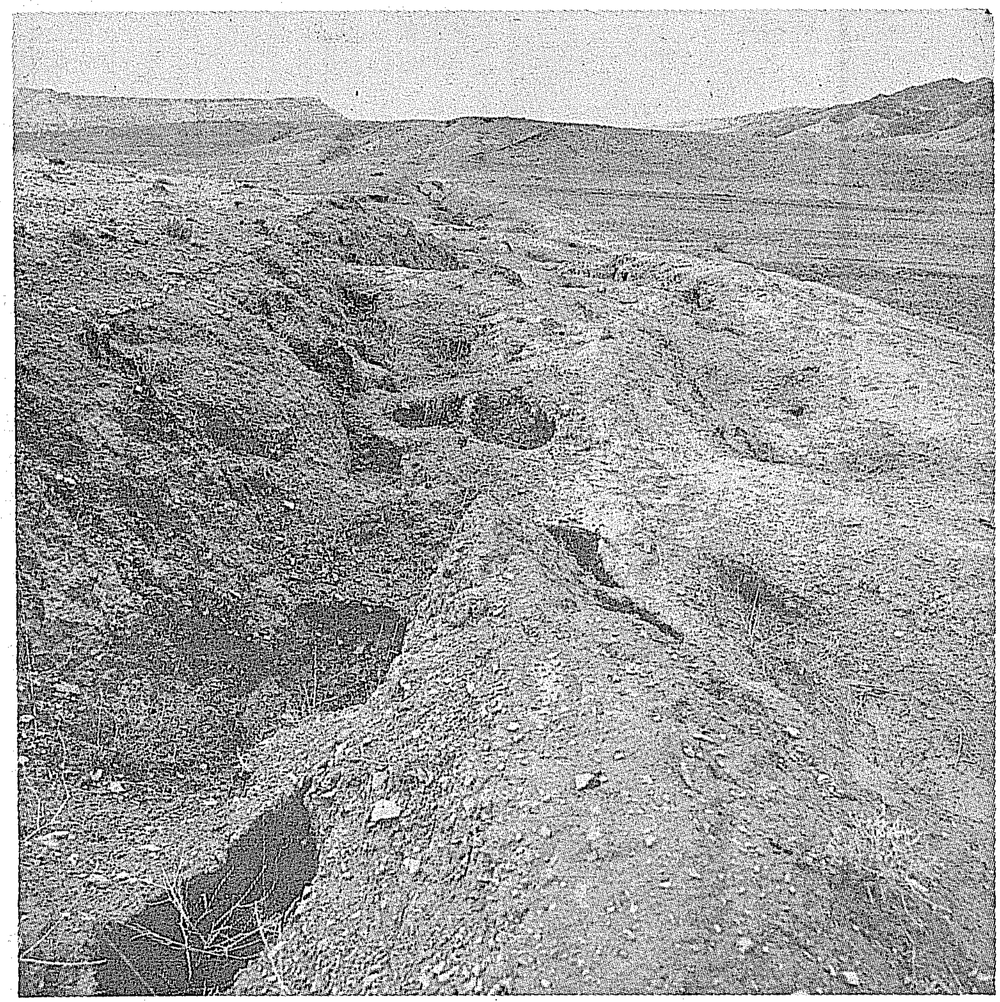


Fig. 20. Mishan earthquake fault scarp near Mishan-e-Sofla. Total vertical displacement is here about 3m. Note the open fissures at foot of scarp. Looking west.

saran Formation (Fig. 21). Here the earthquake fracture is characteristic of normal faulting along a fault striking N 110°E with a dip of 84–90°N. The northern block was downthrown by a maximum of 4m, and the scarp presented many tension features: open fissure at base, parallel open fissures, etc. Degradation of the scarp since 1972 was essentially by erosion, with no indicating of slips. Local inhabitants confirmed that the scarp appeared at the time of the main shock, and that they had seen it extending from the Ghah Anjir region to a location north of Bidkarz, a distance of about 10km.

Fig. 21. Mishan earthquake fault scarp near Mishan-e-Sofla. Looking west (Photographed in 1974)

2.13. Nozad 1493 Earthquake Fault

The Nozad fault is situated in the eastern part of Birjand (NE of Sarbisheh) with NW–SE direction. The fault is situated at the contact of the Paleocene flysch and the northeastern plain. Sargaz, Mask, Moghdan, Kalateh Mazar, Nimehrah, Khonikbaz, Nozad, Chak, Takhrij and Tashman villages are situated along the fault line.

According to Tate (1910, p.29; and Rouzat-ol-Jannat), "on the evening of the 10th January 1493, a destructive earthquake occurred in Nozad-Mask area; in the village of Nozad and Mask much damage was wrought, houses were levelled to the ground and a very large number of human beings lost their lives; between Mask and Nozad a fissure appeared in the earth several miles in length, the traces of which are still visible in a narrow long glen or ravine."

The fault has been mapped as a major, 30km long, Quaternary fault by Stöcklin et al. (1972), and Shahbeig and Salehi (1973, unpublished sheet of Sarbisheh) (Fig. 22). According to these maps the northeastern part of the fault (the plain) is downthrown. Ambraseys (1975) reported this fault as an earthquake fault associated with the 10 January 1493 earthquake, after studying the historical documents.

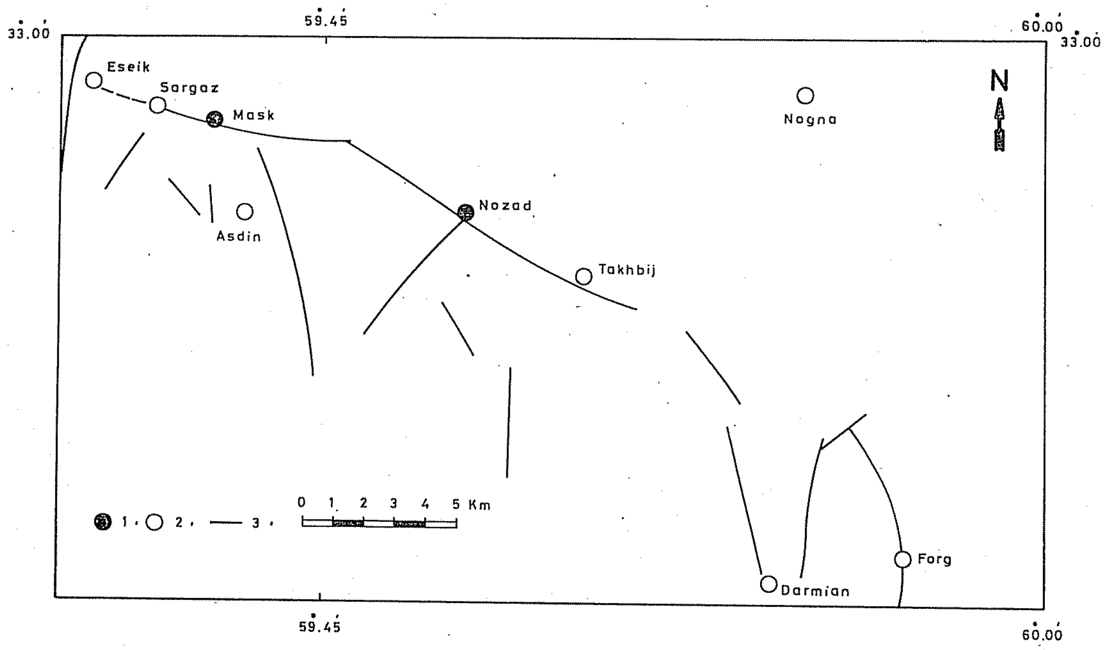


Fig. 22. Nozad fault and epicentral region of 10 January 1493 destructive earthquake. 1. villages destroyed, 2. no information available, 3. mapped faults (Stöcklin et al. 1972 and Shahbeig, Salehi, G.S.I., unpublished).

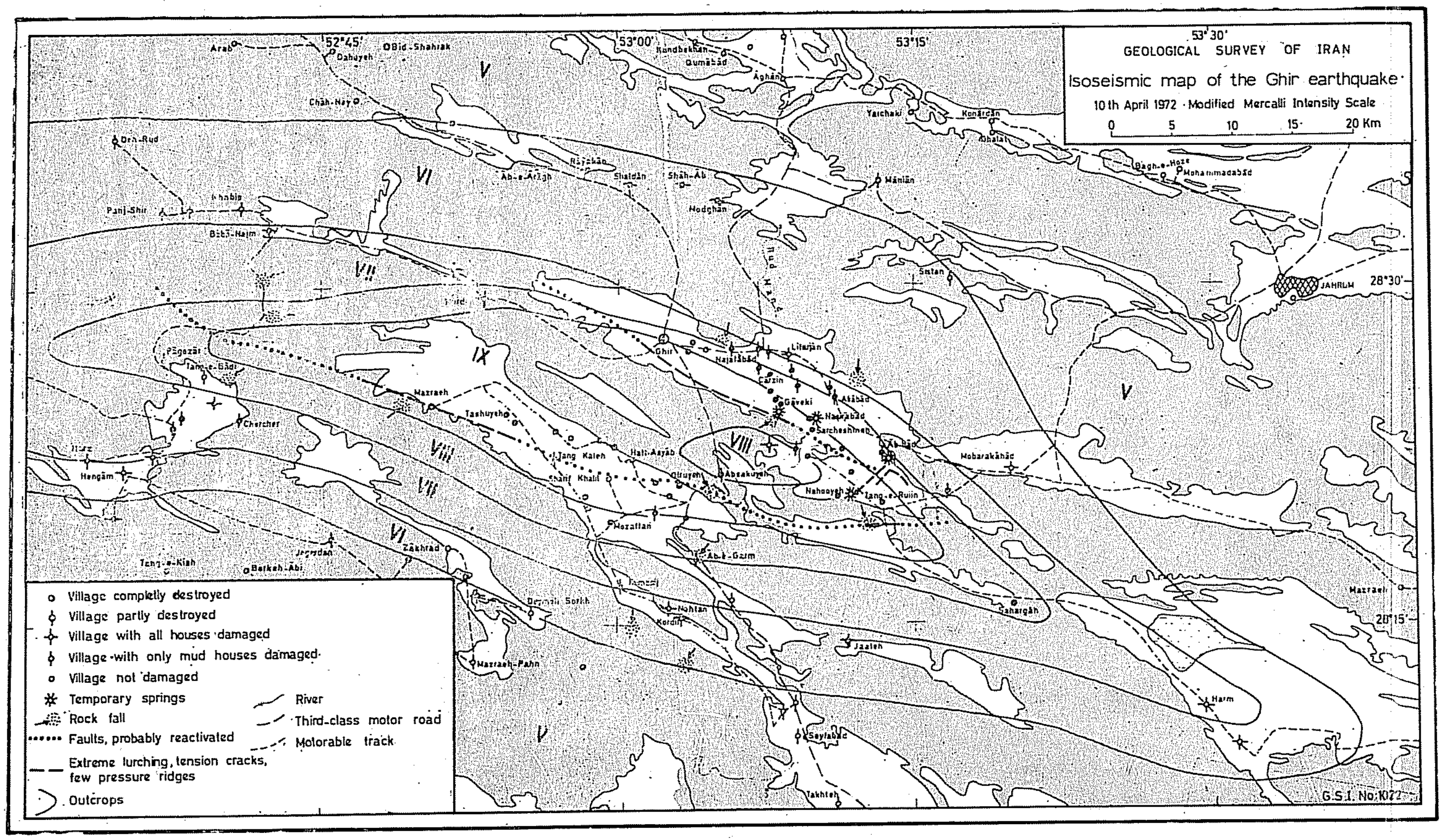


Fig. 23. Epicentral region of the Qir 10 April 1972 earthquake (after Haghipour, Iranmanesh and Takin 1972).

2.14. Qir 1972 Earthquake Ground Deformation of Secondary Nature

The Qir destructive earthquake of 10 April 1972, which killed about 5,000 people and injured about 1,300, destroyed about 5,000 houses in the central part of the Zagros Active Folded Belt (Fig. 23). The earthquake occurred at 02h 06m 52.9s GMT, at 28°.43'N, 52°.79'E, with estimated magnitude of 6.9 and shallow focal depth. The earthquake was associated with minor ground fractures (Figs. 24 and 25) of uncertain tectonic origin (ground deformation of small amplitude and of secondary nature) and rockfalls; many stones thrown up. The long and continuous fractures were extensively developed during the earthquake on the ground (Ambraseys et al. 1972, Haghipour et al. 1972, Dewey and Grantz 1973). Some of these fissures could be clearly related

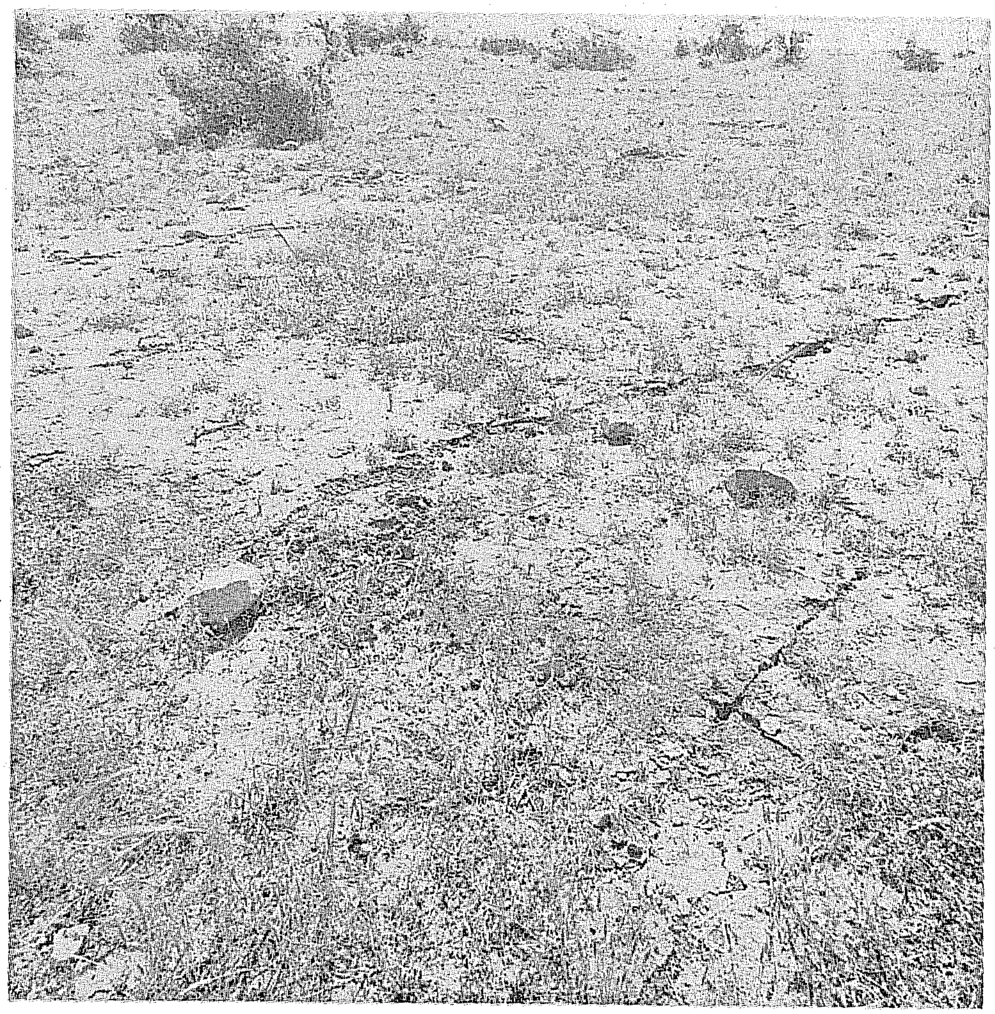


Fig. 24. Ground fractures formed during the Qir earthquake of 1972 (photograph by Tchalenko).

to lurching, differential settling, or collapse of qanats, but others could not (probably of tectonic origin). The evidence is insufficient to distinguish between primary faulting and secondary strain readjustments on pre-existing faults and lines of weakness. According to Ambraseys et al. (1972), it is very probable that the main fracture associated with the Qir earthquake involved formations underlying the Zagros series, and that deep rupturing with a few tens of centimetres relative displacement was absorbed or distributed by the Zagros series and did not reach the surface. Ground features found after the earthquake may or may not reflect features of the causative fracture. Ambraseys (1975, case No.1) put a fracture of secondary nature in Qir area associated with the 1972 Qir earthquake. The length of the fault zone (?) was about 20km with approximate strike of N 120°E.

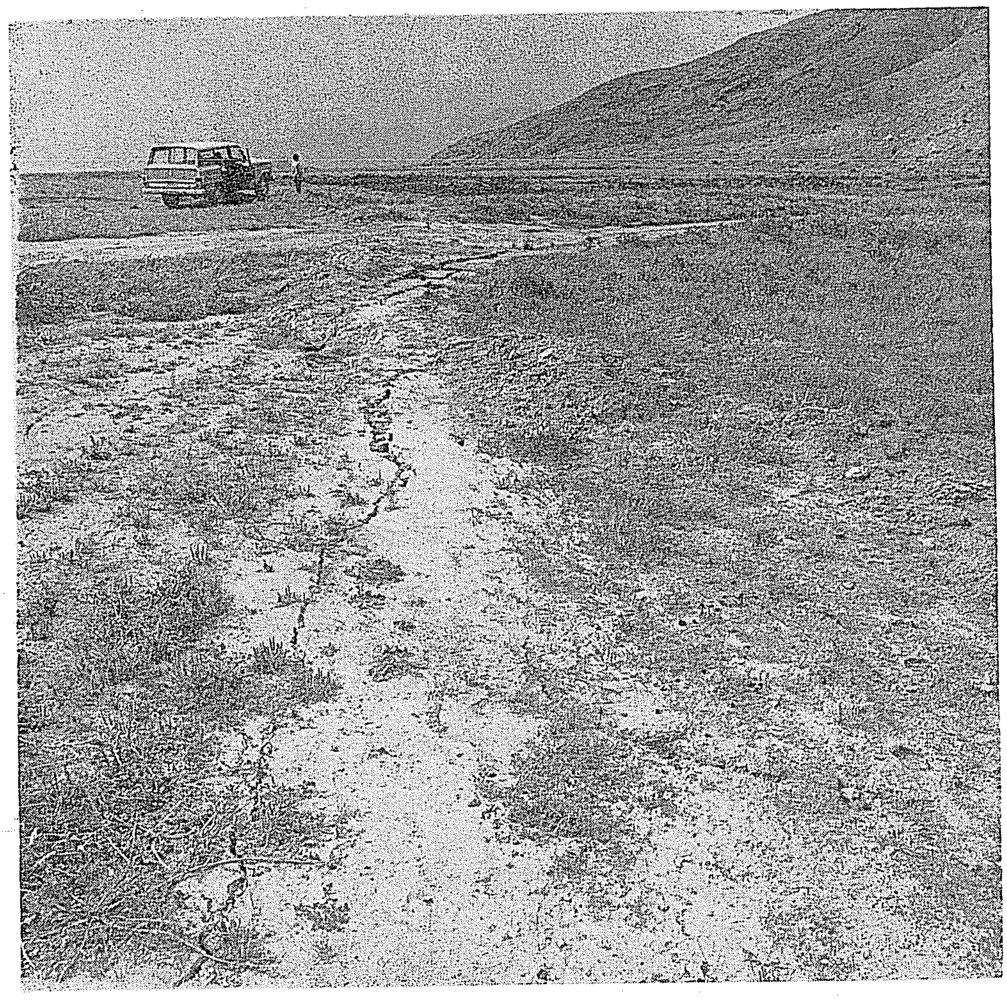


Fig. 25. Ground fractures of Qir earthquake of 1972 (photograph by Tchalenko).

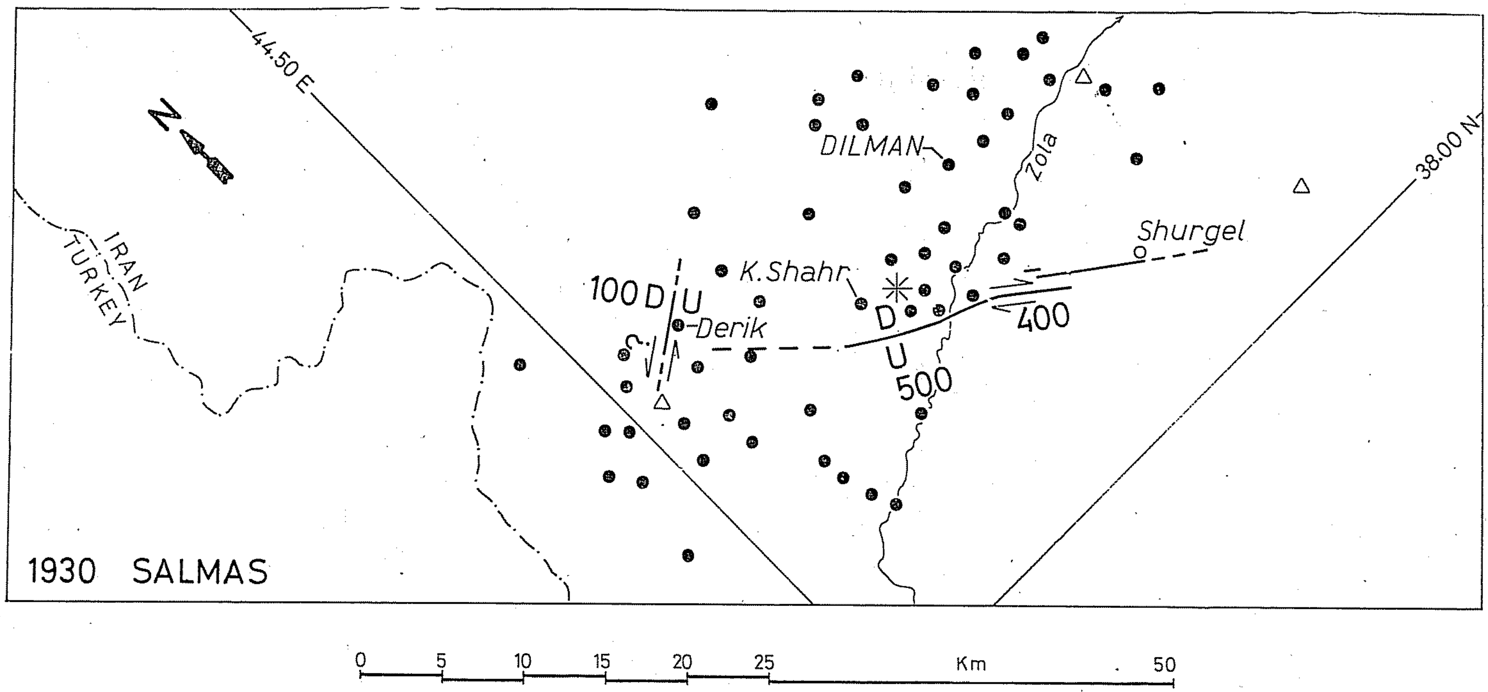


Fig. 26. Salmas (Shahpur-Azarbaidjan) earthquake fault trace and damage distribution. Black line indicates fault trace, dashed where uncertain. Vertical fault displacements during the earthquake are shown by U (up) and D (down) and horizontal displacements by double arrow. Numbers are displacements in cm, with question mark where sense of displacement is known but not the account. Black circles: villages totally destroyed or very severely damaged. Asterisk: approximate centre of area of maximum destruction, taken as macroseismic epicentre. Triangle: new thermal spring created, or existing spring modified, by the earthquake.

2.15. Salmas and Derik 1930 Earthquake Faults

The Salmas destructive earthquake occurred in west Azarbaidjan (north-western Iran) on 6 May 1930. The main shock was preceded on the same morning by a moderately strong foreshock (Mb=5.4), which killed 25 people and incited a great part of the population to spend the following night out of doors. The main shock of magnitude 7.3, with a normal focal depth, occurred the following night, on 6 May 1930 at 22h 34m 27s GMT and destroyed about 60 villages and 40 old Armenian churches, killing about 2514 people, both in the Salmas plain and in the surrounding mountains. The relocated epicentre (Nabavi 1972) was at 37°. 98'N and 44°. 88'E and its macroseismic epicentre was at approximately 38°.15' and 44°.70'E. The main shock was associated with two surface faults, the Salmas and Derik faults (Fig. 26). The general aspects of the Salmas destructive earthquake and its faults were only studied in detail by Tchalenko and Berberian (1975), and Berberian and Tchalenko (Paper 5).

The Salmas earthquake fault scarp can be seen over about 20km between Shurgel and the region west of Kokhneh Shahr at the southern edge of the Salmas Valley (Fig 27). Its average direction is N 120°E and the maximum displacements during the earthquake were about 4m right-lateral and 5m downwards on the north-eastern side.

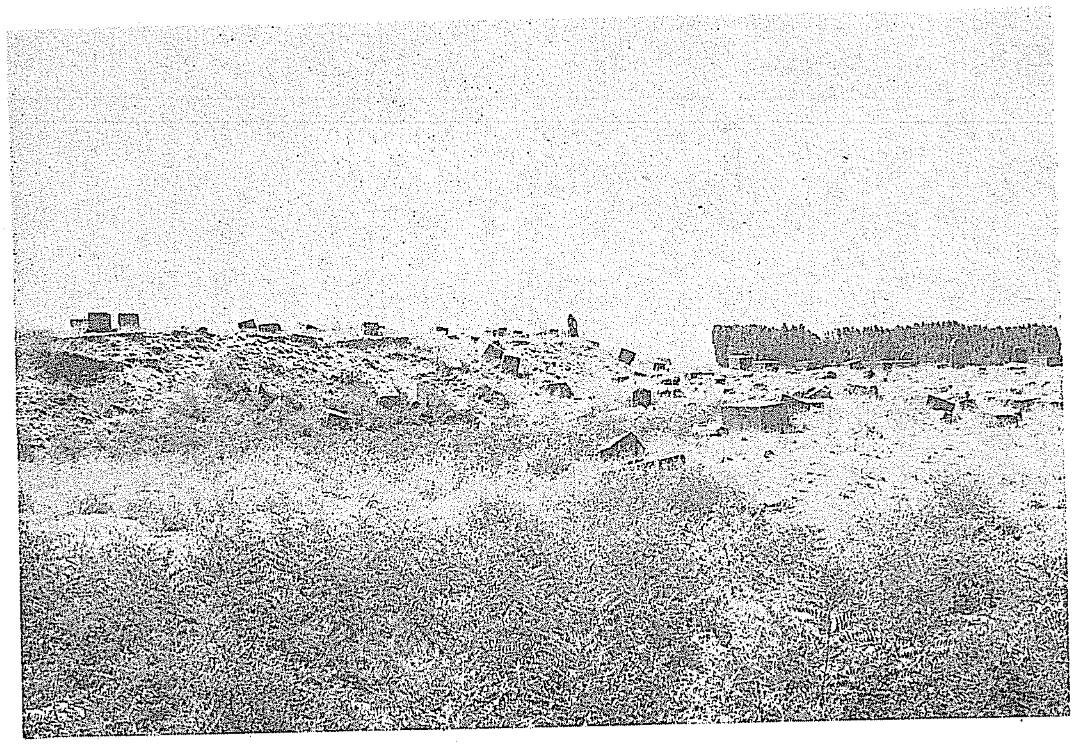


Fig. 27. Salmas earthquake fault scarp of 1930 at Malham cemetery (photographed in 1975).

Survivors of the earthquake describe the fault as extending another 10km to the northwest, but no trace of this scarp can now be seen.

At Derik, a separate earthquake fault, downthrown about 1m to the north-west, extends for roughly 3km through metamorphic rock in a N 55°E direction. The pattern formed by the location of Quaternary and active travertine springs suggests that the corresponding geological fault has a left-lateral horizontal component. At the southwestern end of the Derik fault a thermal spring ceased at the moment of the earthquake, and a new one appeared about 1km further southwest in the same alinement. Other thermal springs appeared, and an existing one at the southeastern end of the main fault segment increased its flow.

The sense of vertical displacement along the main earthquake fault, and observations of waterlogging in the fields of the Salmas Valley, show that the valley subsided during the earthquake. The importance of the dextral displacements, however, and the movement along the Derik fault, indicate a more complex tectonic situation which may be interpreted in terms of a N–S or a NNE–SSW compression.

It should be remarked that the analysis of the visible surface scarp and of the occasional feature, man-made or natural, which crosses the Salmas fault showed that the 1930 earthquake displacement of about 5m does not appear to have been followed by any significant creep movement (see also Berberian and Tchalenko, Paper 5).

2.16. Sangechal 1957 Earthquake Landslides (not faulting)

The Sangechal earthquake of 2 July 1957 occurred at 00h 24m 23s GMT at 36°.14' N, 52°.70'E in the Alborz Mountains, with a focal depth of 10km; the average magnitude given by several stations was 7.3 (Fig. 28). Rothé (1959) states that a fault break was associated with the earthquake. Tchalenko (1974) added that some fault movement seems however to have taken place along the Amir Rud fault zone. On the basis of these references Ambraseys suggested that the Sangechal earthquake was associated with earthquake faulting (case No. 21, in Ambraseys 1975).

The author checked the whole epicentral area of the 1957 earthquake with particular attention to the faults of the area, in 1975. I interviewed as many survivors as possible in the epicentral area and carefully checked all the faults, for instance Amir Rud Fault, Keler Rud Fault, Mangol Fault, Nur Rud Fault, in addition to the landslides and other ground deformations. No evidence of reactivation of the Quaternary geological fault, or formation of a new fault, was found. Certainly no surface faulting was associated with the Sangechal 1953 earthquake, and the ground fissures observed in 1957, adduced by Ambraseys as earthquake faulting were "large scale landslides."

2.17. Tabriz 1721 Earthquake Faulting?

The Tabriz destructive earthquake of 26 April 1721 killed 8,000 people, and the city was totally destroyed (Wilson 1930). According to Brydges (1834), "between the camp and Bosmeech (Basmenj), we passed over ground which some years before had been rent by a succession of earthquakes, in the most extraordinary manner, and on the left hand of the road, I was shown a mountain riven at that time from top to bottom." Ambraseys (1975, case No.67) put a questionable earthquake faulting of 2km in the Sahand area, along North Tabriz Fault (see Berberian and Arshadi, Paper 8).

2.18. Tash 1890 Earthquake Faulting?

The Tash destructive earthquake of 11 July 1890 (south of Gorgan, NW of Sahrud; in Alborz Mountains) destroyed around five villages and killed 121 people; many villages were damaged in addition to Bastam, Shahrud and Gorgan towns. The earthquake caused large masses of rocks to open up and rock falls occurred in the narrow valley of Tash(Ambraseys 1974). Sieberg(1932,p. 815) adds that at Tash the earthquake was associated with ground fractures and rockfalls. Ambraseys (1975, case No. 51) put a questionable earthquake faulting 5km long associated with 1890 earthquake in the Tash area.

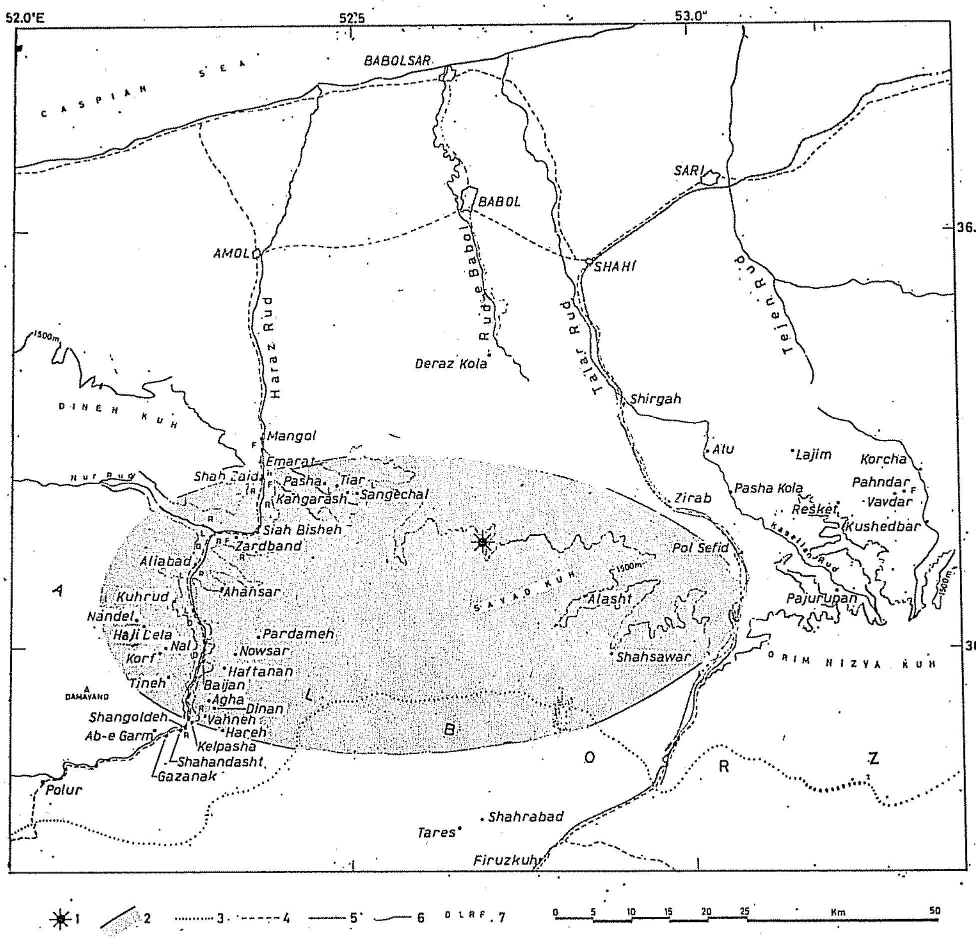


Fig. 28. Epicentral region of the Sangechal 1957 earthquake.
1. instrumental epicentre, 2. approximate limits of the region of total destruction, 3. median Alborz drainage divide, 4. major road, 5. railroad, 6. principal river, 7. D: damaged bridge or tunnel, L: landslide, R: rockfall, F: ground fracture; only villages and towns for which macroseismic data are available are shown on the map (after Tchalenko 1974).

2.19. Torud 1953 Earthquake Fault

The Torud destructive earthquake of 12 February 1953 occurred at 08h, 15m, 29s GMT (USCGS) in Torud, an old desert village situated at the northeastern border of the Great Salt Kavir. Its epicentre was located by USCGS at 35°N and 54°.5'E and relocated by Nowroozi (1971) at 35°. 40'N and 55°. 08'E. The focal depth was normal, with a magnitude of 6.25 (Fig. 29).

Torud and seven other villages (1,800 houses) were destroyed, three others damaged, and 920 people were killed. The villages destroyed are alined in an ENE direction and are situated along a notable Quaternary fault. This earthquake was the object of a detailed study by Abdalian (1953); Gansser (1969) gives a short description of this earthquake. The casualties and destruction caused by 12 February 1953 earthquake are summarized in Table 1:

Table 1:* Casualties and destruction of the 12 February 1953 Torud earthquake:

Village	Killed	Injured	Destruction
Bidestan (with 330 inhabitants)	11	15	Partially destroyed (85 houses).
Hosseinian	–	4	damaged.
Mehdiabad (with 15 families)	2	?	partially destroyed.
Moalleman	–	?	damaged.
Sadfi	?	?	partially destoyed.
Satveh (with 120 families)	8	10	partially destroyed.

Total from press reports: 919 killed, 500 houses destroyed.
Total from Abdalian (1953): 930 killed, 1800 houses destroyed.

* Data from Abdalian (1953), press reports, 1970 interviews (Tchalenko, unpublished report) and Parham (1972).

The earthquake was accompanied by ENE–WSW surface faulting (Torud Fault) with a maximum vertical throw of 140cm, as well as fissuring in cultivated fields, cliff falls in partially cemented surface material, and slumping in desert flats. On the Torud plain just south of the fault scarp, the earthquake fractured the soil with upwelling of gypso-saliferous mud. Along these east-west running fractures downthrowing to the north was visible, but no horizontal displacement could be observed (Abdalian 1953, Huber and Stöcklin 1956, Gansser 1969).

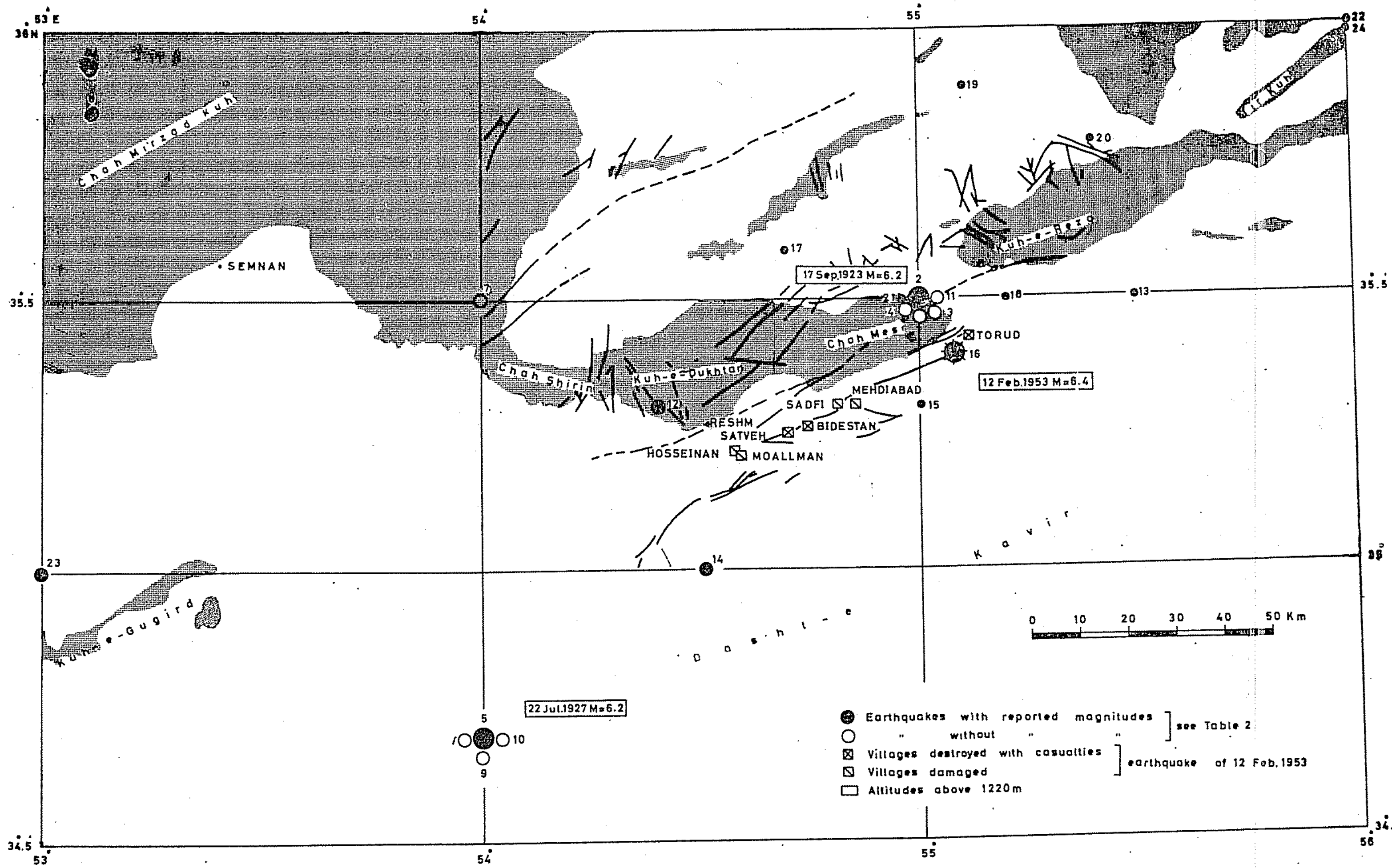


Fig. 29. Epicentral region of Torud 12 February 1953 earthquake (after Tchalenko, unpublished; faults after Torud Quadrangle map, G.S.I., 1976).

As mentioned above, the Torud earthquake was associated with fault movement along an ENE fault zone (reactivation of Torud fault) (Figs. 30,31). One of the planes of the fault-plane solution given by Shirokova (1962) shows a strike direction which corresponds well with the earthquake fractures observed in the field, and indicates a steep south-dipping reverse fault, the southern block being upthrust with a small right-lateral horizontal component over the northern block. The slip vector then strikes N 135°E and the horizontal component of the compressional axis lies N 40°W.

The earthquakes recorded instrumentally since 1908 are listed in Table 2 on page 178 (after Tchalenko, unpublished report).

The earthquake of 17 September 1923 is still remembered by some of the older inhabitants of Torud. Although all the houses of the village were badly damaged during this earthquake, no casualties occurred.

It many be noted however that the unusually high number of 12 February 1953 earthquake causalties in Torud, compared with other villages affected, does not necessarily indicate that the epicentre was located at Torud. The village of Torud was situated on a small cliff of partly cemented Quaternary alluvial material, highly ravined by stream erosion and further under-mined by man-made caves and semi-troglodyte habitations.

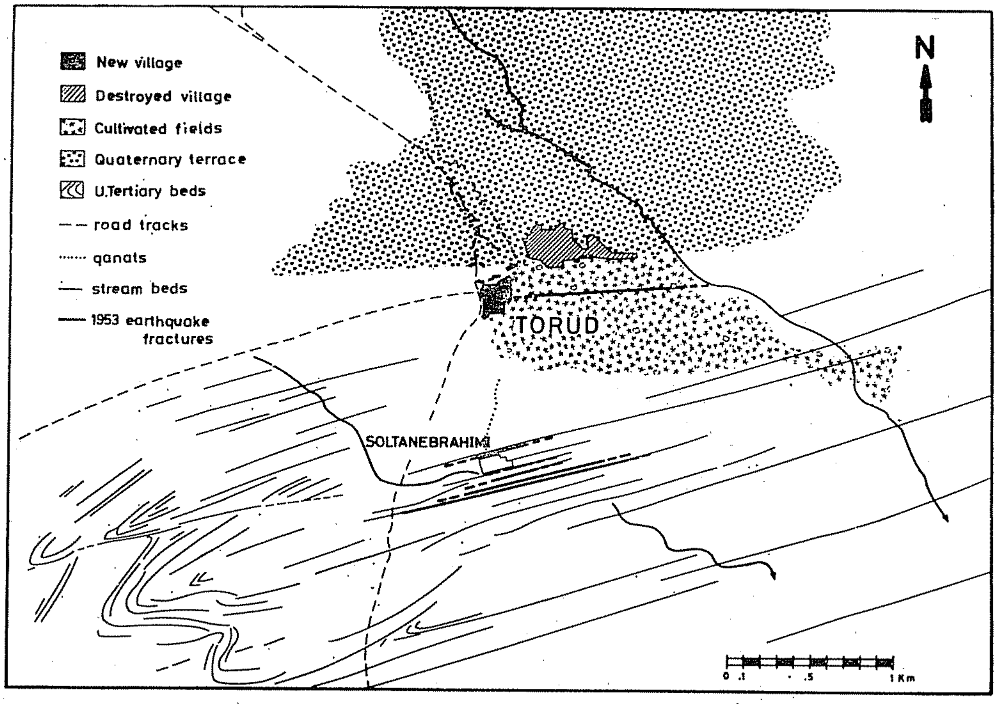


Fig. 30. Torud earthquake faulting (after Tchalenko, unpublished; see also Fig. 31).

Table 2: Instrumentally recorded earthquakes in Torud area:

No	Date	Time GMT	Long.	Lat.	Mag. Mb	Focal Depth km	Source
1.	10–23 Jan. 1908	–	35.5	55.0	–	–	WIL
2.	17 Sep. 1923	070914	35.5	55.0	6.5	–	GR-ISS
	»	»	37.2	57.2	6.0	14	CCP-RU-CP
3.	3 Jul. 1924	080830	35.5	55.0	–	–	ISS
4.	3 Jul. 1924	081850	35.5	55.0	–	–	ISS
5.	22 Jul. 1927	035454	34.7	54.0	–	–	ISS
	»	035510	34.5	53.0	6.3	–	GR
	»	035510	34.5	53.5	–	–	PER
6.	22 Jul. 1927	083730	34.7	54.0	–	–	ISS
7.	22 Jul. 1927	203308	35.5	54.0	–	–	ISS
8.	23 Jul. 1927	201746	34.7	54.0	–	–	ISS
9.	23 Jul. 1927	224018	34.7	54.0	–	–	ISS
10.	27 Jul. 1927	204142	34.7	54	–	–	ISS
11.	29 Jul. 1927	113312	35.5	55.0	–	–	ISS
12.	14 Apr. 1928	131644	35.3	54.4	5.2	–	CP
	»	131633	35.5	55.0	–	–	ISS
13.	13 May 1929	063200	35.5	55.5	4.5	12	CCP-RU
	»	»	38.4	57.7	4.5	–	CP
	»	063232	38.4	57.7	–	–	ISS
14.	6 Apr. 1939	040802	35.0	54.5	5.6	–	ISS-PER
	»	»	35.5	54.5	5.6	–	GR
15.	18 Mar. 1942	061000	35.3	55.0	4.5	12	CCP-RU
16.	12 Feb. 1953	081529.9	35.4	55.08	–	0	NOW
	»	081531	35.8	55.0	6.4	0	ISS-REC
	»	081531	35.3	55.2	6.2	0	CP
	»	»	35.2	55.0	–	–	MOS
17.	13 Feb. 1953	043628	35.6	54.7	4.5	–	CP-CCP
18.	1 Apr. 1953	022435	35.5	55.2	4.0	–	CP
19.	11. Jul. 1953	152508	35.9	55.1	4.5	–	CP-CCP
20.	24 Jul. 1953	053056	35.8	55.4	4.5	–	CP-CCP
21.	24 Jul. 1953	162930	35.5	55.0	4.7	–	CP-CCP
22.	22 Aug 1955	121905	36.0	56.0	4.7	–	CP-CCP
23.	16 Mar. 1957	004342	35.0	53.0	–	–	USA-ISC
	»	004348.2	34.91	52.87	–	46	NOW
	»	004342	34.5	52.5	5.0	–	BCIS
	»	»	35.0	52.5	5.0	–	MOS-ISS
24.	28 Nov. 1965	224946	36.0	56.0	4.0	–	Z5

Fig. 31. (Facing Page) Aerial photomosaic of Torud region. For definition see Fig. 30. Scale, 1:20,000

(P.178A)

This foundation material fractured and collapsed during the shaking. Other villages with lesser damage, such as Bidestan, were built on open ground and hence cannot be directly compared to Torud. Furthermore, there are no villages to the east, north or south of Torud, and it is impossible to estimate intensities in these regions (Tchalenko, unpublished report).

Only one immediate aftershock of the Torud earthquake was instrumentally located (13 February 1953), even though the inhabitants and press reports mention many more. During the following months and until July 1953, four more shocks were recorded. Since then the inhabitants have not felt any tremors and seismological networks have not recorded any shocks originating in the region.

The 1953 earthquake fractures

(The following has been taken from an unpublished report by Tchalenko).

"The few available reports on the ground fractures associated with the earthquake are slightly contradictory. This may be due to the fact that, as these features were never mapped, different authors were referring to different sets of fractures. From the descriptions given, it is also difficult to estimate how uniform the displacements were along the features described. We were fortunate enough in locating Mr. Ali Ahmadi from Torud who claims to be the person holding a frying pan and whose head emerges from the crevasse in Abdalian's photograph (Abdalian, 1953; Fig. 4). With his help and the 1:20,000 aerial photographs (Fig. 31) we were able to relocate and assess the tectonic significance of the principle earthquake fractures (Fig. 30).

The ground ruptures nearest to the village of Torud had a slightly north of east direction, parallel to, and about 200m south of, the Quaternary terrace cliff. From the description given by the inhabitants, the trace was about 1km long, extending from the eastern edge of the modern village, through the cultivated fields and up to the stream bed. The villagers refer to a single rectilinear open gap but do not mention relative displacements of the sides. It seems that these are the fault steps shown in Gansser's Fig. 2, described as being east-west with down-faulting to the north and without horizontal displacements, and attributed by him to a lurching effect. These fractures are no longer visible in the cultivated field (Fig. 32), but a disturbed zone still remains there where they crossed the path leading south from Torud. No indications could be found to extend this feature either westward beyond the modern village, or eastward into the recent gravel fans. Abdalian does not refer specifically to these fractures, but seems to classify them as one of the various secondary ground effects caused by shaking.

As mentioned in a previous section, the high rate of casualties in Torud was partly caused by cliff falls in the Quaternary Terrace material on which the village is built. These slightly cemented deposits of silty clay are dissected by erosion and undermined by cave dwellings. They dip by a few degrees to the north, a fact which led Huber and Stöcklin (1956) to postulate that they had been tilted by recent earthquakes, and Gansser (1969) to assume a drag effect on a fault coinciding approximately with the southern edge of the terrace. A fault at the cliff-edge would explain the unusual east west termination of the Quaternary terrace, but recent fan deposits make it impossible to substantiate such a structure by field evidence. The cliff material at Torud is certainly prone to collapse even under moderate shaking, and the presence of a fault through the village is not required to explain the extensive earthquake damage.

The most intense ground disturbance, referred to specifically only by Abdalian, occurred about 1km southwest of Torud at the small farm of Soltan Ebrahimi (Figs. 33 and 30). Here the Miocene beds outcrop in an eroded ENE anticlinal system. These lagunar deposits, known as the Upper Red Formation by the geologists working in Iran, are formed of mudstones with varying contents of silt and sand, and a high concentration of gypsum and rocksalt. Beds of various hues of pink, red-brown and green, intercalated with nearly pure gypsum and rocksalt layers, are easily distinguish-

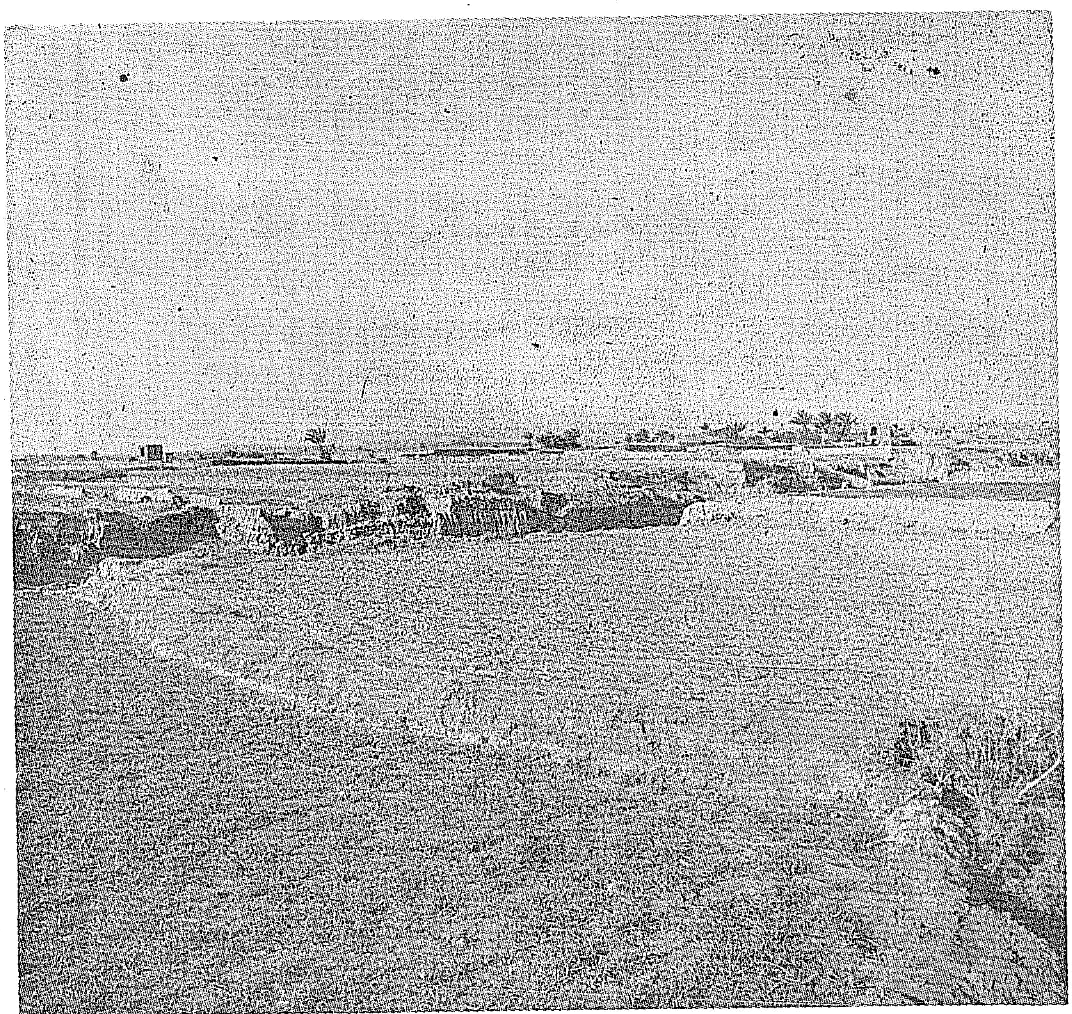


Fig. 32. Cultivated fields east of New Torud as in 1971, looking W. The 1930 earthquake fracture cut this field (photograph by Tchalenko).

able on aerial photographs. The outcrops at Soltan Ebrahimi are part of the southern flank of an ENE anticline, the hardest layers forming low topographical ridges. In Abdalian's description the earthquake fractures followed the strike of the beds over several kilometres, with a principal fracture 15m wide showing a south-facing scarp 20 to 140cm high, and other parallel and equally "principal" fractures. Ground displacements must indeed have been very severe here as they are still clearly visible seventeen years after the event. The northernmost of these fractures visible today borders the northern limit of the farm crossing the qanat line which was disrupted during the earthquake. At this location the terrain is nearly horizontal, ruling out collapse by shaking of any natural ridge; this is probably Abdalian's 15m wide zone, with the scarp now removed by erosion. Further south and over a distance of 150–200m, several other parallel ENE fracture zones, generally located near the ridges formed by the outcrops of the harder beds, show signs of violent disruption. These zones can be followed over a length of about 1km, beyond which the outcrops take their more usual undisturbed appearance.

Aerial photographs of the Soltan Ebrahimi region show several examples of disharmonic folding in the Miocene beds, especially west and southwest of the farm. A distinct ENE fault can be traced westwards in the continuation of the zone disrupted by the earthquake fractures described above (Fig. 33). This fault would have 200–300m of left-lateral displacement, and also probably a vertical displacement, even though a detailed field study would be necessary to confirm these movements. Another, less distinct, fault runs south of the farm in a NE direction. Further south, Huber and Stöcklin located a ENE glide plane separating two stratigraphic units of the Miocene formations.

A quick search in the regions to the northeast and southwest of Torud did not reveal any other signs of earthquake effects. From interviews with the elder inhabitants of some of the villages damaged by the 1953 earthquake (Bidestan, Hosseinian), it does not seem that ground fractures occurred anywhere else, nor that qanat systems were sheared or distorted.

Detailed mapping of the ground fractures soon after the 1953 earthquake would undoubtedly have produced a much more extensive fracture map, and accurate displacement measurements may have thrown some light on the actual movements. Nevertheless, even with the limited information at hand, the overall fault movement associated with the earthquake can be deduced with some degree of certainty.

The fissures in the cultivated fields south of Torud seem to have been of lesser importance, and possibly of a secondary nature, when compared to the fracture zones at Soltan Ebrahimi. These zones are strictly parallel to the strike of the Miocene beds and in continuation of a clearly distinguishable fault. It seems most likely that this fault moved during the earthquake and caused the intense desplacements still visible to-day at Soltan Ebrahimi. It would be wrong to interpret these displacements purely as bedding plane slip; faults in these extremely plastic Miocene beds, having further reduced shear strengths along the gyspum-rocksalt layers, bend the strikes locally into their direction, with the result that anticlinal axes, bedding and fault strike are generally all parallel to each other. This structure is evident from the aerial photographs (Fig. 31).

On the larger scale of the Torud-Reshm fault zone, the syncline-anticline axes and many of the small faults of the Miocene beds are broadly parallel to the direction of the fault zone. The folding and faulting of these beds is interpreted here as being imposed by the tectonics of the fault zone. Continued activity of this fault zone to-day, situated under a thick cover of sediments, causes movements along small faults in these sediments.

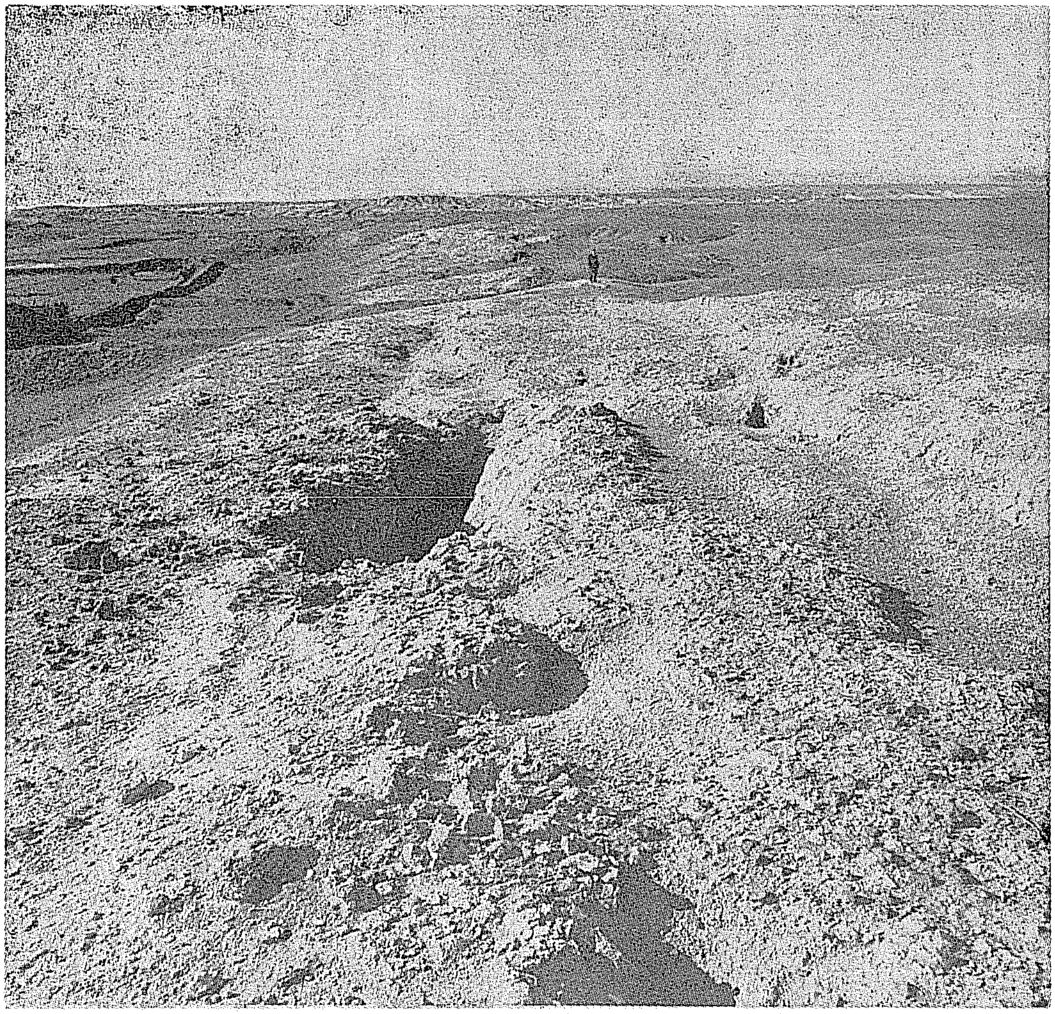


Fig. 33. 1953 ground disturbance in Soltan Ebrahimi, 1km south of Torud (photograph by Tchalenko, in 1971). See also Fig. 30 for the location of the area.

APPENDIX

Examples of opening and closing of earthquake fault fractures at surface in Iran

1 - Tabriz destructive earthquake of 5 February 1641, Azarbaidjan, NW Iran:

...."They say that a shepherd was driving his sheep in front of him one day, when in a certain place, during an aftershock the crust of the earth split and formed an abyss, by which the shepherd and part of his flock were engulfed alive, none of them reappearing". (Arakel Vartabed Tavrizetsi 1874, 1896; Berberian and Arshadi, 1976).

2 - Khalkhal destructive earthquake of 2 January 1896, Azarbaidjan, NW Iran:

...."During a destructive aftershock of 2 January 1896 earthquake, which occurred on 13 January 1896 in Khalkhal region, many people were killed and buildings were destroyed. The ground ruptured and took two people in up to the neck while they were walking from one village to another, then the rupture closed and killed both. After two days a man passing the area noticed two heads sticking out of the ground. The bodies were then dug up and buried in another place. A dry mountain was ruptured and water started to flow out".

(Iran Newspaper, No. 874, Saturday 8 February 1896, Tehran)

3 - Baghan-Germab earthquake fault of 1 May 1929, Koppeh Dagh, NE Iran:

..."Evidence was found here of a quasi-instantaneous opening and closing of the earthquake fault fracture at surface. The transactions of the Kheyrabad Meteorological Station (quoted in Gorshkov, 1941) mention that a fracture appeared along a path, and that the ground opened and then closed again in such a manner that in one place the ears of a donkey were found sticking out of the ground;the donkey was dug up, but the man leading it could not be found. In July 1972, R. Aryan and I were able to clarify this story by talking to Haji Mohammad Qulieh Rezai in Kakeli who had been involved in the same rescue attempt. The young man who had been killed was apparently walking at some distance from the donkey. He was struck by a falling rock, and it was the donkey alone which fell into the crack, which then closed up on it.There is every reason to believe that the substance of this account is factual; if so, it may be added to the two other known cases of living beings fallen into, and crushed by, an earthquake ground fracture, i.e. at San Franciscoi n 1906, and at Fukui (Japan) in 1948 (Richter 1958)". (Tchalenko, 1975).

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