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The Large Earthquakes of Iran and their Geological Frame

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ABSTRACT

During the last decade, earthquakes in Iran seem to have increased in number and intensity. Most, however, could not have been predicted from a knowledge of the geological frame. A summary of the geology and tectonics of Iran is given and the main recent earthquakes (Torud 1955, central Alborz 1957, Hamadan 1957, Laar 1961, Buin 1962, Dasht i Biaz 1968) discussed in the light of their regional setting. Particular attention is paid to the seismicity and surface effects associated with the catastrophic Dasht i Biaz earthquake. It occurred in the centre of the northern Lut block, the only true stable block in Iran. In contrast the 670 km long Dornueh fault, forming the northern boundary of the Lut block and displacing recent alluvial fans, is not the locus of earthquake activity. Movement along this fault is supposed to be of creeping type, whereas energy in the block itself may have built up, to be suddenly released.

During the last years much research has been done on the physics and the geology of earthquake processes. Underground nuclear explosions as controlled seismic energy sources, research on the mechanics of faulting on such examples as the San Andreas fault system (ALLEN, 1968) and the setting up of large seismometer arrays with computing facilities have greatly improved our knowledge of the still problematic earthquakes. The influence of water as an important lubricating agent in at least shallow earthquakes such as has been demonstrated in the Denver area (EVANS, 1966) and recently at the Verzasca dam site (SÜSSTRUNK, 1968) have led to optimistic proposals as to earthquake prevention. In spite of all these steps forward in the study of earthquakes, their prediction, the ultimate goal of costly efforts, is far from being achieved. This disappointing fact is most clearly reflected in the latest and largest earthquakes that ravaged various regions of Iran and caused a high toll of human lives. The last, the earthquake in the Dasht i Biaz/Ferdows region of eastern Iran, was, as far as the victims are concerned, one of the most devastating in recent history.

Iran, together with Turkey, is probably one of the most earthquake prone countries in the world. This is understandable, considering the intricate structural pattern and the young, partly recent tectonics, which are so characteristic for the Alpine belt countries in the Middle East. The complicated geologic picture of Iran is slowly emerging after intense geological work by the Geological Survey and the interested Oil Companies (National Iranian Oil Co., 1959). On a regional scale, its structural framework is known today, but much detailed work is needed in order to complete this picture. Aerial photocontrol was and is still an immense help, particularly as far as the younger structural features are concerned, but great care has to be taken in order to avoid too hasty conclusions (WELLMANN, 1966). In the last years Iran has set up a network of seismic stations, spread over the whole country, which greatly assists in locating the earthquake centres and in following the aftershocks, but a considerable amount of work has still to be done on those lines. The effort of the Institute of Geophysics of Teheran University, where much of the earthquake information of the last years is being compiled and published (Institute of Geophysics, Reports 1964 to 1966), is to be especially welcomed.

Iran, with its most varied and subrecent to recent structural features, seems at a first glance an ideal country, where the relation of earthquake occurrences and the structural outlines could be studied and understood. The last large seismic events, which in a curious way seem to have increased in frequency as well as in intensity during the last 10 to 15 years, show on the other hand how difficult it is to relate the seismicity to the known structural features. We have here, if compared to the main earthquake belts of Turkey, a marked difference. Various authors have shown there (KETIN and ROESLI, 1953, PAVONI, 1961) that a belt of major faults and abnormal tectonic contacts is characterized by seismic unrest, producing earthquakes which wander from the east to the west within a time interval of about 20 years. They indicate a consistant horizontal shift of 1–4 m in clockwise direction. It should be noted, however, that the evidence for strike-slip movements of hundreds of kilometers having taken place along these lines of disturbance is not very strong. Personal observations and new geological results indicate a complete lack of comparison of the two sides of the main Anatolian faultbelt and rather suggest north/south compression with much disappearance of material and no major horizontal slips. The presence of the Coloured Mélange with exotic blocks along the fault line (at Gerede) further corroborate this suggestion (GANSSER, 1959).

The structural history and the tectonic frame of Iran have been published recently in an excellent paper by STÖCKLIN (1968). A general structural outline is also presented by the general geological map of Iran with information up to 1957, still up to date as far as structures are concerned, though in some places a stratigraphical revision is needed (National Iranian Oil Co., 1959).

In order to better understand the distribution of earthquake centres a short outline of the tectonic frame of Iran is given (Fig. 1). From south to north, the following main units are readily distinguishable: The Arabian platform underlain by the crystalline Precambrian base of the Arabien shield and covered by little disturbed sequences of Paleozoic to Tertiary rocks. Gentle structures often show a north/south aligned trend. Some are old basement trends and influence the subsequent sedimentation (for instance the Oman high limiting the Infracambrian saline deposits to the east).

With a rather sharp structural but curiously enough less marked lithological change begin the Zagros ranges. Their southern limit coincides with the first marked anticlinal structure, reflecting already the typical north-west/south-east trend. North-eastward, the folding intensity increases, until the south-west directed Zagros thrust forms an abrupt boundary against the complicated masses of Central Iran. Disharmonic surface tectonics due to the middle Tertiary evaporites contrast with the pre-

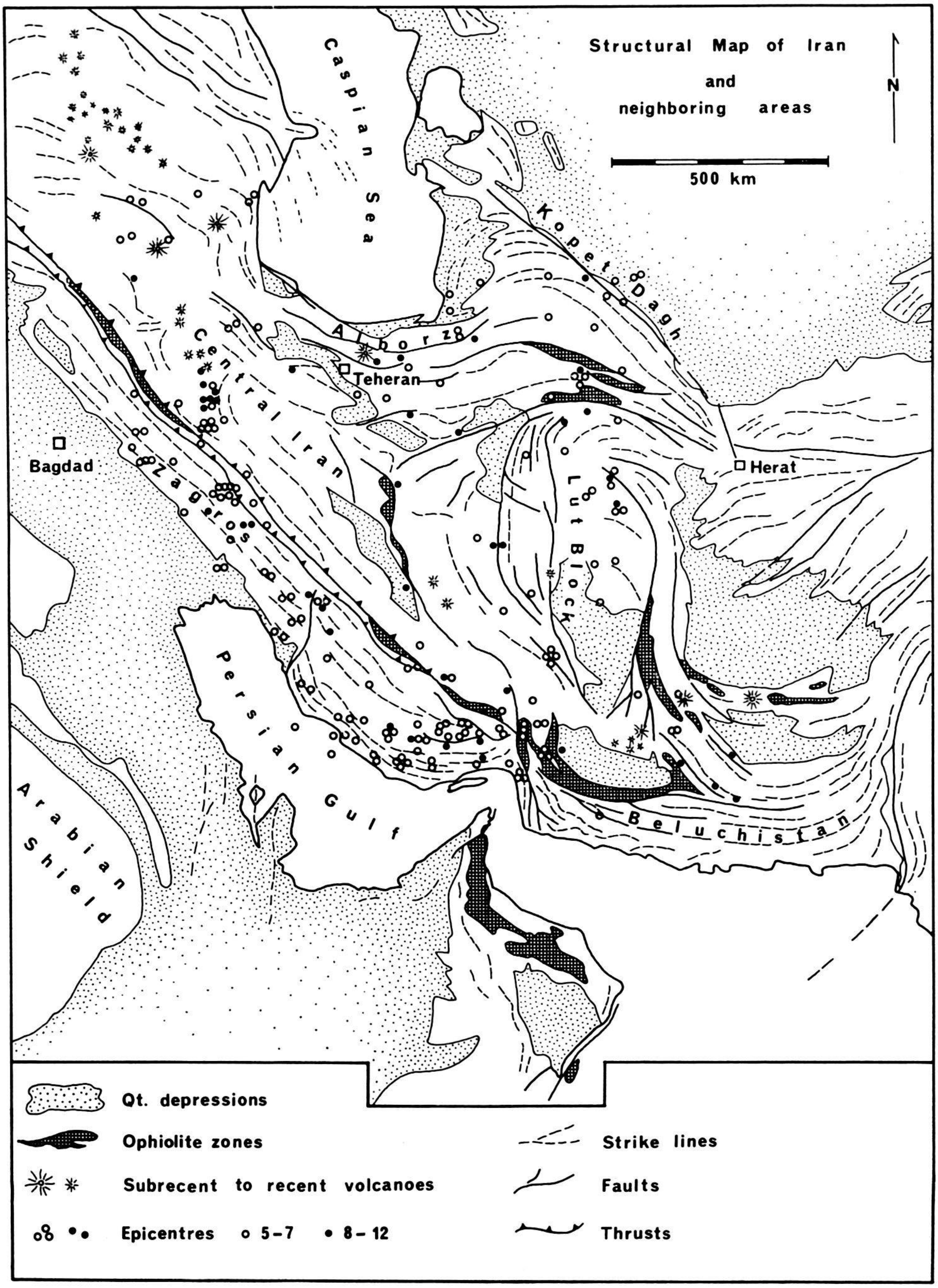

Fig. 1. Structures compiled from STÖCKLIN 1968, NIOC map 1959 and other sources. Epicentres from reports Institute of Geophysics, Teheran University.

sumed decollement of the base along the Infracambrian salt horizon. On the other hand, the thick sedimentary section from Cambrian to the Upper Tertiary is conformable, stressing the fact that no orogenic movement interrupted this marine sedimentary sequence. The Alpine type orogeny affected the Zagros in Plio-Pleistocene times, with many indications of recent tectonics. This latter fact is important in explaining the seismic unrest of this range (Laar earthquakes).

The Zagros thrust, actually a complicated steep north-west/south-eastwards trending zone of imbrication, was already an important tectonic divide during the Mesozoic. Along the thrust we find the thickest development of the Zagros sediments together with a Flysch-like facies in the youngest Mesozoic and older Tertiary. These, as well as ophiolites with pelagic sediments, partly mixed as Coloured Mélange in the Upper Cretaceous, indicate a marked unrest not otherwise present in the Zagros range. A considerable amount of crustal shortening must be assumed along this major tectonic trend. It is interesting to note that except for the section between Kermanshah and Hamadan, major earthquakes are missing along this structural line.

The Zagros thrust zone marks the southern limit of the very complicated area of Central Iran, which shows a triangular shape with the Alborz range forming the northern boundary and the Tabas ranges west of the Lut block the eastern edge. This 'median mass' of older authors (BOECKH et al., 1929) shows a quite distinct geological history, strikingly different from the Zagros range. This fact further underlines the importance of the Zagros thrust zone as a major tectonic feature (fracture de fond). Recent investigations have shown that much more Precambrian basement outcrops in Central Iran than previously suspected. Some of the Paleozoic rocks are not unlike the basal Zagros, outcropping in the zone of imbrication along the Zagros thrust. Rapid facies changes and local unconformities mostly begin with the Mesozoic. A strong orogeny with low grade metamorphism occurred between the Jurassic and the Middle Cretaceous. Pre-Aptian granites intruded into already metamorphosed and intensely folded Jurassic. In the Upper Cretaceous we find shallow water reef-type deposits beside narrow but important belts of pelagic deep-sea sediments with basic and ultrabasic rocks, often mixed as Coloured Mélange. Along these trends we must assume important deep seated movements. These rock assemblages are exposed in the north-east and at the north-westernmost tip of Central Iran as well as in the central zone. In the central part the region of Nain has recently been investigated (DAVOUDZADEH, 1969). Basic and ultrabasic intrusions range from Uppermost Cretaceous to Paleocene and a wild array of faults and steep thrusts in a north-north-west/south-south-east and west-north-west/east-south-east pattern is related to these abnormal formations. A south-eastwards continuation of the Nain area can be followed through the Gavkuni depression until the Zagros fault belt. Narrow patches of Coloured Mélange follow this trend, which has been rejuvenated cutting the alluvial deposits filling this depression. Northwards the Nain trend turns into a west-north-west direction and follows the Paleogene volcanics of the Kashan range with their granodioritic intrusive cores. Marked disturbances but no Coloured Mélange are known in this region. The detailed mapping showed that no direct connection exists with the ultrabasic rocks to the north-east of Khorassan, though one of the youngest and greatest fault systems in north-east Iran, the Doruneh fault zone (see later), trends towards Nain and borders the Khorassan Coloured Mélange area on the south.

A strong volcanism was characteristic of the Paleogene followed by a quieter marine invasion with reef development in local basins (Qum basin) and thick evaporitic to clastic sediments in the Neogene. Stable and mobile areas within Central Iran are limited by complicated interfering fault zones, paralleling the structural frame with its south-east/north-west direction (Zagros thrust zone), east/west direction (Alborz mountains) and north/south trend (Tabas ranges and Lut block). Old fault zones become reactivated, and many important trends are repeated in recent movements, which cut sharply through alluvial deposits. These facts are most significant for the earthquake history of Iran.

North of Central Iran follow the Alborz mountains. This morphologically well outlined range is geologically a continuation of Central Iran, at least its southern part, but with a decreasing intensity of folding. The southern margin is formed by steep south directed thrusts, which partly override Pleistocene deposits. Faulting and steep thrusting is found in the central part, but northwards the structures hade towards the north, and the tectonics decrease towards the Caspian basin. Precambrian cores do outcrop (Alamkuh) and again Precambrian crystalline rocks fringe the eastern and western foothills of the range (Gorgan schists, Guilan gneisses). Marine Paleozoic sediments are well developed but marked unconformities begin only with the Lias. Cretaceous volcanism occurs in the northern Alborz, but Coloured Mélange associations are unknown. Also the Paleogene volcanism does not cross the range which began to form a divide from Upper Cretaceous onwards.

Surprising is the subrecent but localized volcanism in form of the huge Damavand volcano and the newly discovered small outliers east of it (ALLENBACH, 1966). This volcanism seems related to the morphogenetic uplift of the Alborz range with its erosion products, such as the large alluvial fans of the Teheran region (RIEBEN, 1955) which are locally tilted and faulted. Damavand is situated where the west-north-west strike of the range changes rather abruptly into a east-north-east direction. The structural interference was clearly outlined by ALLENBACH (1966) and STEIGER (1966). As we will see, the large earthquake of Central Alborz of 1957 was located in this region.

The eastern branch of the Alborz merges with the Kopeth Dagh range. The relation between the two ranges is not yet clearly understood. A striking feature of the latter, however, is its different sedimentary and structural history, which shows great resemblance with the Zagros fold belt (STÖCKLIN, 1968). No volcanism is known in the Kopeth Dagh.

Of special interest is the eastern part of Iran. We noted already how the north/south striking Tabas ranges form the eastern boundary of Central Iran. They are covered by beautiful maps published recently by the Geological Survey of Iran (STÖCKLIN et al., 1965; RUTTNER et al., 1968). One of the most complete Lower Paleozoic sections of the Middle East is preserved in domal uplifts and north/south striking horsts. Very conspicuous north/south directed fault zones border these blocks. They, too, show a long history of movement with recent rejuvenation. They delimit sections of widely differing sedimentary thicknesses [for instance 6000 m of Mesozoic on the Tabas block against 2000 m on the adjoining Shotori block (STÖCKLIN, 1968)].

East of the Tabas ranges follows the only true consolidated block of Iran, the Lut block, all that is left of the once widely propagated median mass of Iran. Nearly twice the size of Switzerland, the Lut block shows a north/south aligned oval form. Most of it is covered by huge sand dunes, wind-eroded loess and flat-lying Paleogene volcanics. It is so far the geologically least known part of Iran. Recently, Mesozoic and Paleozoic rocks were discovered, also flat and little disturbed (STÖCKLIN, 1968). This remarkable block is bordered by conspicuous fault zones on all sides. On the western side we note the well outlined Naiband fault with subrecent volcanics and hot springs. The northern limit is marked by the Doruneh fault zone, a rejuvenated major structural feature, running west-south-west into the great salt desert (Kavir) and displacing recent alluvial fans. On the eastern side a most complicated fault and steep thrust system limits the block against the very mobile eastern Iranian ranges, which strike north/south and follow the Afghane and Pakistan border. They are conspicuous by zones of Coloured Mélange and up to 5000 m of intensely folded marine Flysch-type Eocene formations unknown in the Lut block. In the Zahedan area the Eocene is intruded by granites and shows an incipient metamorphism. Some branches of this still little known fault system cut obliquely into the north-eastern part of the Lut block and may have some relation to one of the largest recent earthquakes of Iran.

Towards the south, the western and eastern delimiting fault zones of the Lut block merge into the subrecent to recent volcanic zone of Bazman, the most striking and largest young volcanic area of Iran with perfectly preserved small cones and lava flows. It is underlain by Paleozoic rocks intruded by younger granites. Southwards follows the Jaz Murian depression probably still underlain by block-like older sediments and most likely the southernmost extension of an already less rigid Lut block. Only south of this deep depression appear the Beluchistan ranges, striking east/west and reflecting again a most mobile belt with Coloured Mélange and large, chromite bearing ultrabasics. Eastwards these ranges merge with the already mentioned mobile belts of eastern Iran. Westwards they abut against the 'Oman high', reflected in a young fault zone east of Minab, which also cuts and displaces the Zagros thrust. The facies change on both sides of the 'Oman high' is most impressive: normal conformable Zagros sediments to the west, pierced by Infracambrian salt domes against Cretaceous Coloured Mélange and Flysch type Paleogene deposits and huge sections of argillacious Neogene to the east pierced by impressive mud volcanoes, which are missing entirely in the Zagros ranges. This division is one of the most striking geological changes in the Middle East. Earthquakes are particularly frequent where the eastern Zagros (Laar, Bandar Abas) approach this zone from the west. They are rare to the east of the Oman high.

This complicated structural frame of Iran, repeatedly rejuvenated up to recent times, finds its expression in the frequent and often very large earthquakes (Fig. 1). One would expect that with our present knowledge of the Iranian geology, which has greatly improved in the last decade, the location of the many earthquakes could be understood or at least fitted into the geological frame. This, however, is hardly the case, and we must admit that epicentres and structural frame only agree in the broadest sense and that, as far as we can judge, the time to make forecasts is far from present.

Within the last 15 years one can note a general increase in the seismic activity and it seems that earthquakes of a larger intensity and magnitude occurred more frequently. Five areas must be mentioned, where seismic unrest has led to devastating results: in 1955 Turud, in 1957 south-west Hamadan and Central Alborz, 1960 and 1961 Laar (eastern Zagros), 1962 Buin, west of Teheran, and 1968 Dasht i Biaz in north-eastern Iran. These earthquakes alone caused about 28,000 dead. Except for the Laar and south-western Hamadan region, the writer was able to visit these earthquake areas shortly after the events.

In the following we will try to relate the surface indications to the geological frame as far as it is known today. The greatest handicap is the still scanty geophysical information. Only in the last few years have various seismic stations started operations in Iran (Geophysical Institute, Report 1966). Information on hypocentres are most scanty and the exact location of the epicentre is sometimes questionable. Little is known about the most important aftershocks, which frequently vary their location relative to the main event. Many areas are uninhabitated and no damage control exists in order to evaluate the intensity of the shocks. If, in spite of these short-comings, we try to evaluate some of the major seismic events we do this to show how difficult the interpretation still is and how unpredictably many of the larger shocks occurred.

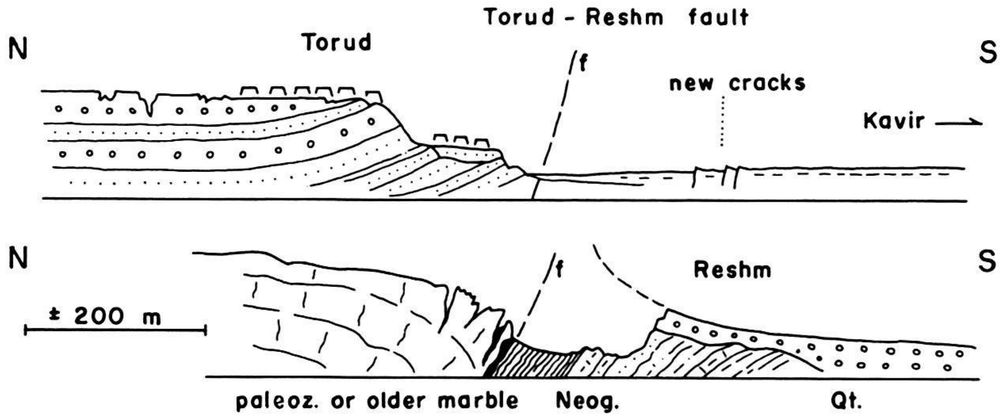

Fig. 2. The fault of Torud and Reshm (GANSSER).

In 1955 the region of Torud, an old desert village situated at the north-eastern border of the great salt desert 320 km east of Teheran was devastated by a strong earthquake. The village was situated on a major fault zone, separating a most complicated basement complex with relictic north-south structures from the deep Neogene Kawir basin studded by numerous salt domes. The Torud fault zone is an easterly branch of the main disturbance bordering the southern Alborz range. Eastwards it continues into the southern Sabzavar region with its extensive ultrabasics and Coloured Mélange formations, one of the major mobile belts of north-east Iran. West of Torud, towards the small village of Reshm, the fault is well exposed and separates old (Paleozoic or older) marbles from north dipping Neogene beds which are covered by thick Quaternary terraces. Along the fault the marbles are fractured and the fractures cemented by travertine. They most probably reflect the effects of older earthquakes. The Reshm area was completely devastated by an earthquake about 150 years ago. The old village of Torud was unfortunately built on the faulted edge of a quaternary terrace which was uptilted against the fault (Fig. 2). The fault scarp is bordered in the south by an alluvial plain leading towards the great salt desert. In this plain just south of the scarp the earthquake fractured the soil with upwelling of liquid mud. Along these east/west running fractures down-faulting to the north was visible, but no horizontal displacement could be observed. The cracks were probably related to a marked lurching effect of the thick saltwaterlogged alluvial ground.

There is little doubt that the shock of the Torud event was caused by movements along this faults zone. From what is known, movements along this disturbance are not of the creeping type, and the energy release must have been sudden after a longer strain accumulation. This fault zone is certainly an area where further shocks could be expected. The Torud-Reshm fault area seems one of the few regions in Iran, where the seismicity can be directly related to the geological frame.

On the 2nd July 1957 the region of the Central Alborz, just east of the Damavand volcano, was devastated by an earthquake. The writer felt this quake in the northern suburbs of Teheran, in the foothills of the Alborz, with an intensity of about 5. The movement seemed horizontal and more or less north/south directed. Considerable damage to mountain villages with about 500 fatalities and the formation of landslides were the results. On the basis of visible destruction, isoseismic contours were constructed, partly based on information provided by the staff of Alexander Gibbs Company (Fig. 3). This Alborz earthquake seems not to have been related to the Damavand volcano, for instance, no changes in its fumarolic and hot spring activity were noted. On the other hand, the region coincides with the sudden change of the western Alborz into an eastern Alborz trend with an interference of the structures. No fault zone of major importance was related to this event, and no local fracture trends were discovered. The general outline of the isoseismals indicates a feature paralleling the eastern Alborz trend. One would have rather expected a seismic activity along the southern edge of the Alborz mountains or along its north-eastern border towards the Gorgan plain, where frequent earthquakes were noted in earlier periods.

Very unexpected was the large earthquake which on the 13th December 1957 destroyed numerous villages in the mountainous region south-west of Hamadan and killed 1200 persons. The area lies on Mesozoic metamorphic phyllites with pre-Aptian granite intrusions, belonging to a major belt running parallel on the northern side of the Zagros thrust zone. The epicentre is located about 50 km from the northern border of the Zagros thrust. At a first glance, an influence of the Zagros fault zone could be expected, since it dips steeply to the north-east and could reach the hypocentric depth of the Hamadan seismic event. However, the epicentres of previous earthquakes as well as one later seismal are known in this area, and they show no alignment parallel to the Zagros thrust, as would be expected if this feature was responsible for the event. They are rather aligned in a south-west/north-east direction, at right angle to the trend of the Zagros thrust. It is furthermore surprising that between Hamadan/Kermanshah and along the area east of Shiraz, no earthquakes have been recorded along the Zagros fault zone (Fig. 1).

The surprising large seismic activity in the Zagros range proper is concentrated in and around the city of Laar in the eastern Zagros (Afshar, 1960). One of the largest events damaged 75% of Laar city on the 24th April 1961 and cost 400 lives. It was repeated on the 11th July of that year with a similar intensity. The epicentres of these large seismals as well as the numerous smaller ones form clusters which show a rough north-west alignment. Another belt exists from Laar to the east and ends at the north-south fault zone reflecting the 'Oman High' just east of Bandar Abbas. The epicentres south of Shiraz and north-west of Laar again are roughly north/south aligned and the seismals in the western Zagros, north of Abadan (Dezful), cluster similarly in a north/south direction. None of the very numerous Zagros epicentres conform to the surface structures or run parallel to the Zagros fault zone (Fig. 1). They seem to reflect a rejuvenation of the old north/south alignment of the Arabian foreland, documented by the Quatar alignment and the Oman trend in particular. The Laar cluster of epicentres furthermore falls into the rather abrupt change from south-east striking to north-east striking structures. Large Infracambrian salt-domes are particularly numerous in this area.

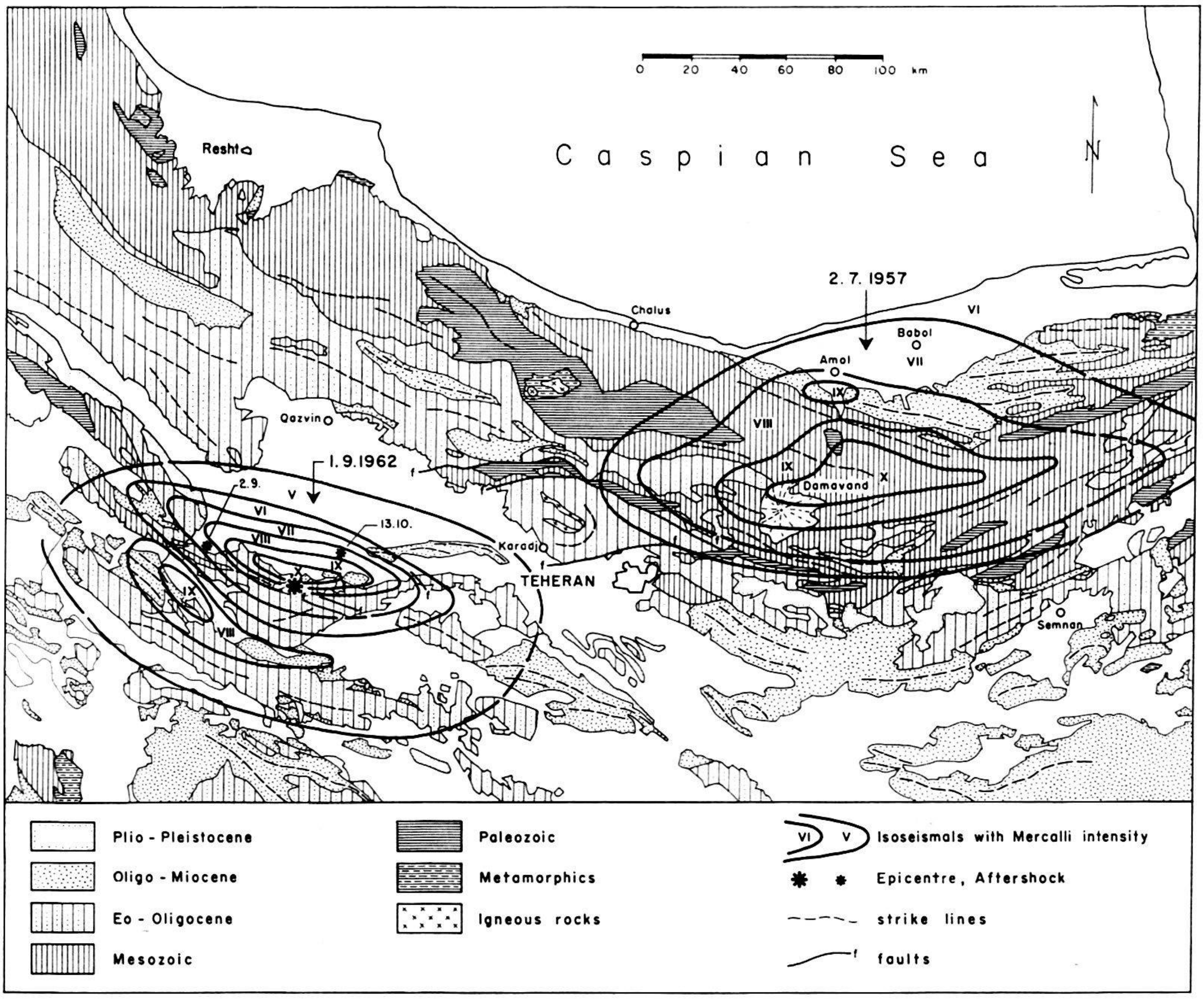

Fig. 3. The earthquakes of Central Alborz (1957) and Buin (1962). Geology compiled from NIOC map 1959 and other sources. Seismic information Institute of Geophysics, Teheran University 1962 and AMBRASEYS 1963.

As a further surprise to the geologist well acquainted with the geology of Iran came the large earthquake of Buin, 150 km west of Teheran. It shook the area on the 1st September 1962, destroyed completely numerous villages and caused up to 12,000 deaths. The Buin earthquake was the first major seismal which could be recorded by various stations in Iran and which was subsequently studied by experts from various institutions (Institute of Geophysics, 1962; AMBRASEYS, 1963).

The epicentre falls just at the edge of the Eocene volcanics which border the large alluvial plain of Qazvin on the south side. The plain is underlain by evaporitic Mio-Pliocene beds outcropping in a diapiric ridge west of Karadj. No major disturbances are known to exist in this area, apart from smaller fractures within the Eocene volcanic belt. These fractures mostly strike from east-south-east to west-north-west parallel to the main trends of the area. Some east/west striking structural features interfere with this strike direction and are already visible in the southern Alborz mountains west of Teheran (for instance boundary fault north-west of Teheran, Ab i Yek uplift with Paleozoic core; SIEBER, in preparation) and the already mentioned diapiric ridge west of Karadj. The interplay of these east/west structural trends with the 'normal' direction may be a possible reason for the occurrence of the Buin earthquake (Fig. 3).

During the main shock a nearly 50 km long fracture zone opened along the northern foothills of the Eocene volcanic belt. This fracture, not continuously exposed, consisted of a composite system of feather-faults which widened when crossing hard alluvial filled riverbeds (Fig. 4). It appeared that the movement which produced this

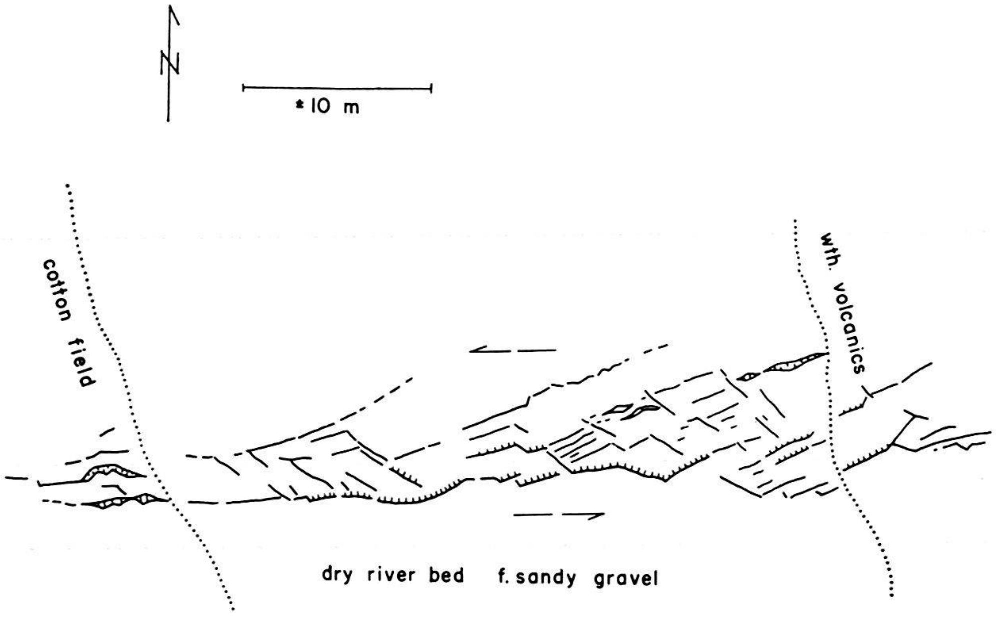

Fig. 4. Fracture zone Buin earthquake 1962 (GANSSER).

fracture system was most complex, with a combination of vertical and horizontal as well as shear effects. In general a counter-clockwise movement was observed, and most frequently the north side was downthrown, which, on the other hand, coincided to some extent with the northern slope of the hills. The fracture zone, which was not straight, varied roughly along its east/west trend by about 20°.

The villages near the epicentre were completely destroyed and the reported loss of lives varies between 10,000 and 12,000. This high death rate and total damage reflects rather the extremely poor construction of most dwellings (mud brick constructions built mostly on soft alluvial ground) than a particularly high intensity (Geophysical Institute, Report No. 32, 1966). The intensity hardly reached grade 10 on the Mercalli scale. A Richter magnitude of about 7,5 was calculated and the focal depth of about 21 km is shallow, a fact characteristic for most of the Iranian earthquakes. The analysis of the seismograms seems to indicate that the energy was not concentrated and released in a direct impulse but rather in several shocks within a few seconds. This explains the complicated picture of the surface effects (fault zone) (AMBRASEYS, 1963). On visiting the damaged area one was struck by the selective destruction in the regions where the devastation was not total. High rectangular walls enclosing cultivated areas were thrown to the north when running west/east but were more or less left standing when north/south aligned. This would suggest some north/south directed movements and only a minor east/west strike slip effect.

Several hundred aftershocks were recorded by the Iranian stations but only a few by foreign seismographic centres. On the 2nd September one aftershock was recorded with a magnitude of 4.75, 40 km to the west-south-west. On the 13th September a shock of 5.5 magnitude located over 10 km to the north-east of the epicentre occurred and was felt in Qazvin, to the north of the wide plain, in Teheran and curiously enough along the Caspian shore (Institute of Geophysics, 1962). The activity of aftershocks decreased strongly after September 15th and died out about the middle of November 1962.

The region of the Qazvin basin west of Teheran was so far not known to be seismically active. As already mentioned, no major geological disturbance is known in this area except minor faults in the volcanic Eocene and the intersection of various structural trends. The reported complexity of the main shocks as well as the location of various important aftershocks in opposite directions and the fact that one of them was even felt along the Caspian shore suggest some relation of the seismal with the complicated structural frame. The somewhat irregular shape of the east-west aligned surface fracture caused by the seismal, which runs parallel to the diapiric Neogene ridge, may reflect a deeper yet unknown east-west alignment.

The northern part of the peculiar Lut block was struck by a heavy earthquake exactly 6 years after the Buin catastrophe. On the 31st August and the 1st September 1968 the areas of Dasht i Biaz and Ferdows were heavily damaged by one of the strongest earthquakes within the last decade, which, in spite of hitting a scarsely populated area, caused approximately 12–13,000 deaths. This earthquake was geologically particularly interesting since it produced surface evidences from which the complexity of the seismal was well documented. It occurred in an area where only sporadic seismic activity was known in the wider surroundings, and in a geological setting which hardly suggested recent tectonic unrest (Fig. 5). Similar to the Buin seismal the event of Dasht i Biaz was subsequently investigated by teams organized by UNESCO, in cooperation with the Geological Survey of Iran. Only preliminary investigations of these studies were so far available [AMBRASEYS et al., 1968; CRAMPINS et al., 1968, Geological Survey of Iran, Report 1969 (in Persian)].

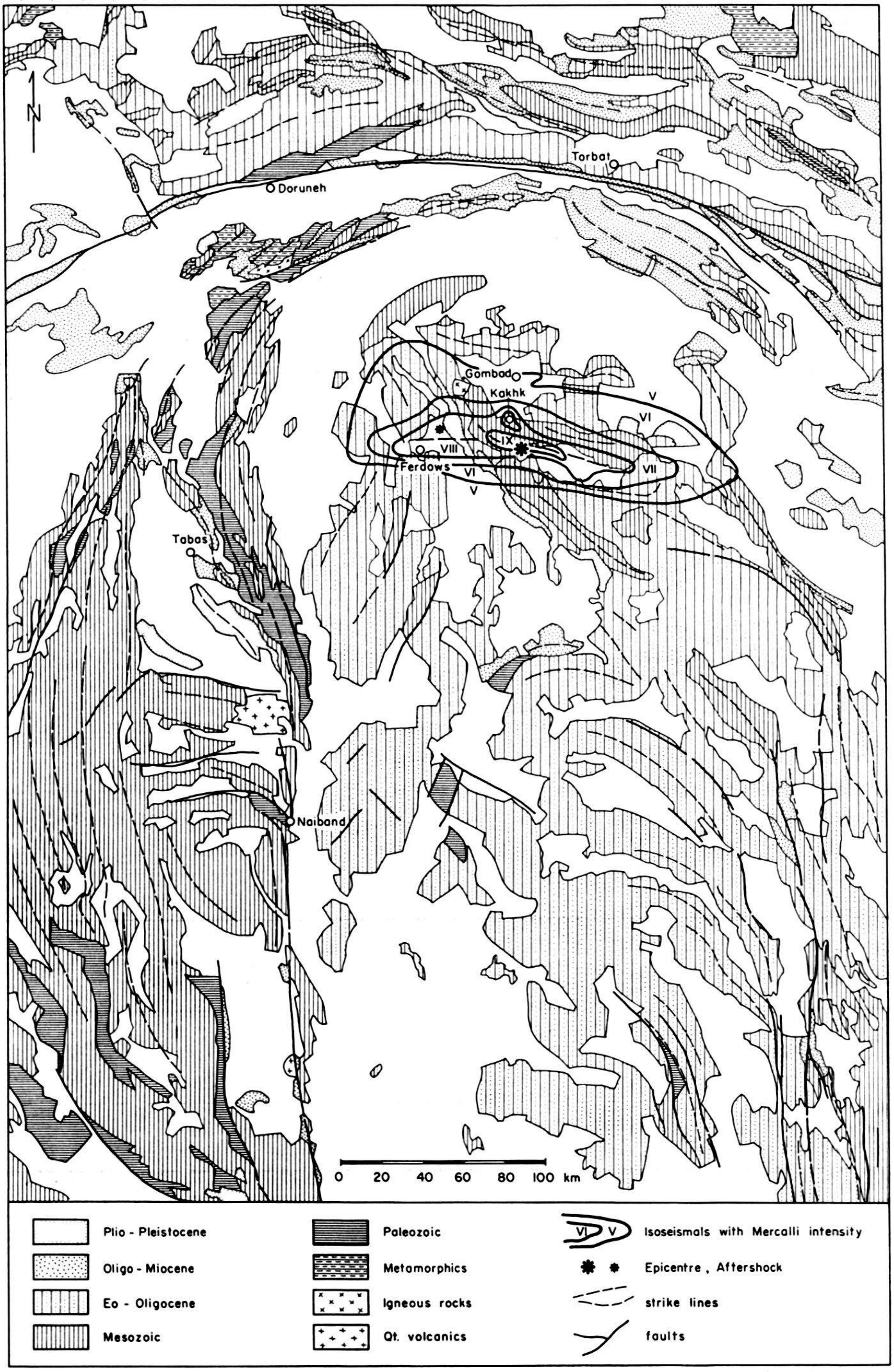

Fig. 5. The northern Lut and Dasht i Biaz earthquake 1968. Geology compiled after Stöcklin 1968, NIOC map 1959 and other sources. Seismic information by Geol. Survey Iran report and Ambraseys 1969.

The Dasht i Biaz region lies 130 km to the south of a large fault zone which limits the Lut block to the north and which is a still active feature. This fault zone which runs from the Afghan border in the east into the great salt desert (Kavir) in the west can be followed for a distance of 670 km. It cuts through alluvial fans and displaces within the salt desert the youngest structures. During our previous investigations in Iran this fault zone was called the Doruneh fault. It was later mentioned by WELLMANN (1966), who considered it to be a sinistral strike slip feature. The Doruneh fault forms also the southern limit of a most complicated geological belt which runs parallel and to the south of the eastern Elburz range. Well known is the ultrabasic zone of Sabzawar with its south-eastern continuation north of Torbat and just north of the eastern Doruneh fault. Besides large bodies of diallage serpentine we note Coloured Mélange mixed with pelagic sediments of Upper Cretaceous age. Towards Doruneh geologists of the Geological Survey recently discovered early Paleozoic rocks, intruded by granites. No Coloured Mélange nor pelagic Cretaceous is known south of the Doruneh fault and within the Lut block. The geological aspect changes

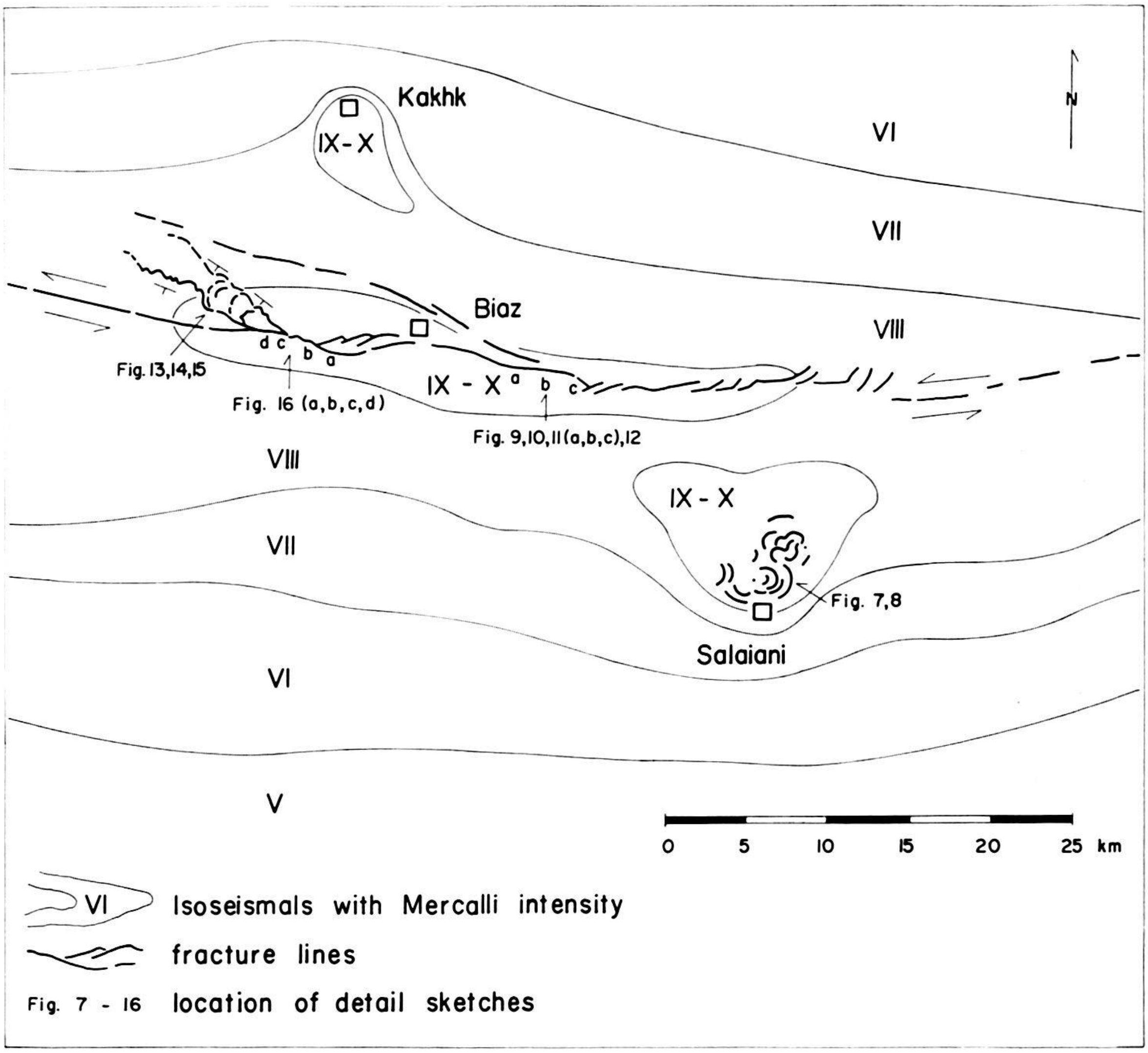

Fig. 6. The Fracture zone Dasht i Biaz earthquake 1968. After Geol. Survey Iran report, AMBRASEYS and GANSSER.

abruptly south of this structural trend. No match is possible between the two areas bordering this fault and no proof exists for large scale horizontal movements. Immediately south of the Doruneh fault a wide belt of Neogene structures fringes the northern Lut block. Into this belt merge and plunge, coming from the south-west, the Paleozoic ranges of Tabas with their cores of Precambrian granites and metamorphics. Only further south do the Cretaceous and volcanic Eocene rocks set in, which cover wide areas of the Lut block. South of Gonabad steeply folded Liassic shales occur which show an incipient metamorphism and which are intruded by granodiorites between Gonabad and Ferdows, relations reminiscent of conditions in Central Iran and rather unlike the normal Lut cover. This somewhat abnormal Mesozoic belt shows a marked east/west alignment. Towards the east it turns to a south-east direction and connects with the aberrant structures, branching out from the north-south striking mobile belt bordering the Lut block to the east. These features interest us in particular, since they form a frame for the Dasht i Biaz area, where the large earthquake occurred (Fig. 5).

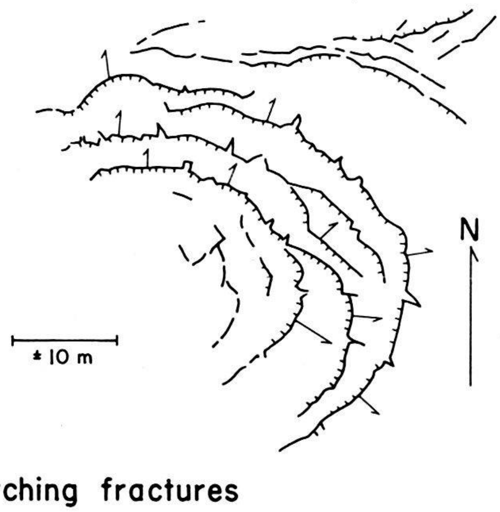

Fig. 7. Detail of lurching fractures at Salaiani (GANSSER).

The first shock on August 31st fractured the surface over a distance of 80 km. This fracture line shows an east/west alignment and parallels the Mesozoic range to the north of the Biaz alluvial basin. On the south-eastern side of this basin the ground was intensely broken near the village of Salaiani. Here the fractures are arched and the ground is tilted away from the centre (Fig. 6, 7, 8). Obviously these fractures do not reflect any deeper seated tectonics but are the effect of considerable lurching of the rather unconsolidated and saltwater logged ground. Small mud springs were active shortly after the event. The Salaiani area is an excellent example of the distinction between surficial effects due to lurching and such features related to deeper fault movement such as the northern fracture zone.

On its western and eastern ends the main fracture line becomes discontinuous. In the alluvial and deeply weathered terrain, the fracture zone shows an echelon pattern with a complicated diagonal fault system, bordered by two main fault lines (Fig. 9). This pattern indicates a clear anticlockwise slip movement (left lateral), which is confirmed where irrigation walls and ditches are sharply displaced up to 4 meters (Fig. 10, 11a, b, c). In most well exposed outcrops, the northern part of the fracture is down-thrown with a maximum amplitude of about 1 meter, although further to the west, the opposite throw is visible (Fig. 12). In a few spots along this fracture zone the ground is cemented by a calice-like lime crust suggesting some previous water extrusions. It seems possible that they indicate an older fracture line caused by some previous disturbances, to which the new feature runs more or less parallel. It is a fact which needs a careful investigation.

Fig. 8. Arched lurching fractures, Salaiani. Dasht i Biaz.

Towards the west the fracture zone enters the Miocene red beds with sandstones and shales, which form the southern foothills of the Mesozoic range to the north. Here the fracture zone splits into branches and upon entering the outcrops, the fracture itself becomes much sharper with no echelon pattern (Fig. 14). Two main branches split off the main trend and run in a west-north-west direction into the hilly country more or less parallel to the strike of the beds. On entering the region in which the Miocene dips constantly south-westwards, the normally vertical fracture turns into the dipslopes and hades between 40 to 50° to the south-west. Along its trace the beds are highly fractured (Fig. 15). No previous disturbances have been noted in this particular area (Fig. 13).

Of special interest is the fault face west of the totally destroyed village of Dasht i Biaz, near the place, where the side branches begin. Here the east/west directed main fracture line displays a vertical smooth cliff of about one meter hight along a south facing slope. The downthrow is clearly to the south, but may be somewhat influenced by the original south slope of the hill. In some places the fault face was perfectly preserved in the red silty shales of the Miocene and the smooth surface showed clearly outlined slickensides representing the fault movement. In spite of the regionally well displayed anti-clockwise strike slip, the striae suggest a most complex movement (Fig. 16a, b, c, d). At a, parallel striations rising somewhat to the west are well displayed. In the next outcrops (to the west) an older steeper westwards dipping feature is cut by the younger westwards rising striae (b). Further to the west, the younger

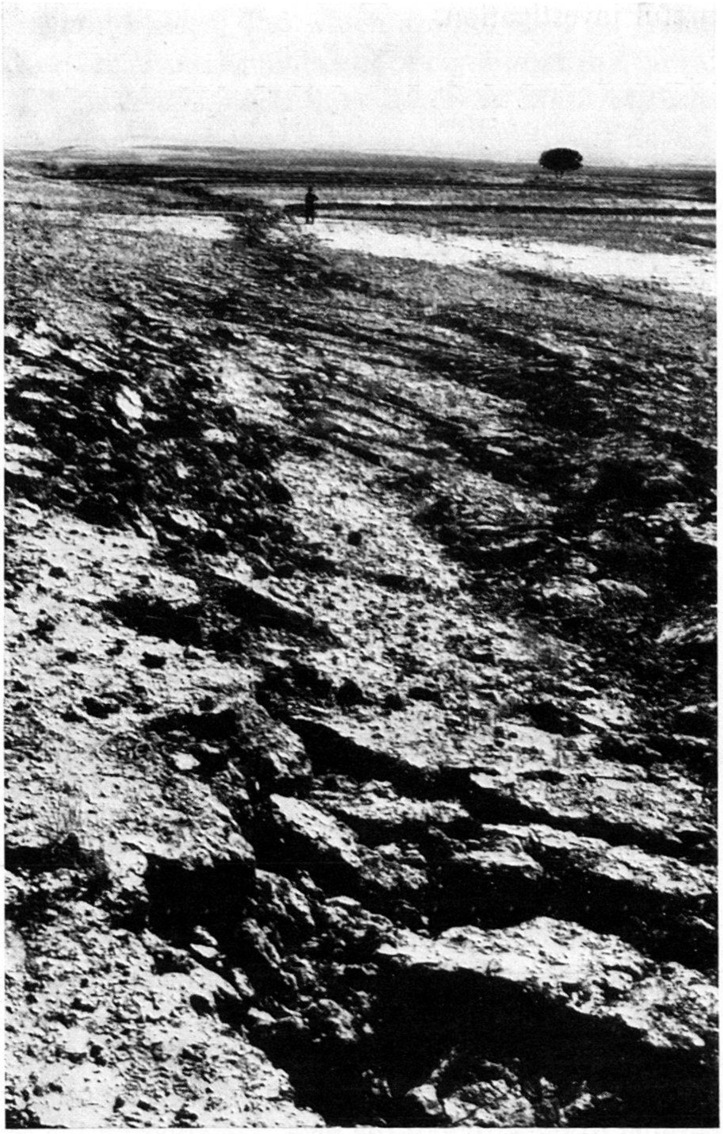

Fig. 9. Diagonal echelon pattern on main fracture zone, looking E. Dasht i Biaz.

striae become considerably steeper (c). Most striking is the most western outcrop, where the striae indicate a clear rotational movement (d). These observations seem to indicate the effects, not of a single shock, but of a rather complicated and composite movement. Various impulses, selective filtering and channelling of the released energy from its source, which from available information was shallow (about 17 km), could have produced this picture. It is unlikely that the strong aftershock of the 1st September located north-east of Ferdows had anything to do with it, since that was not

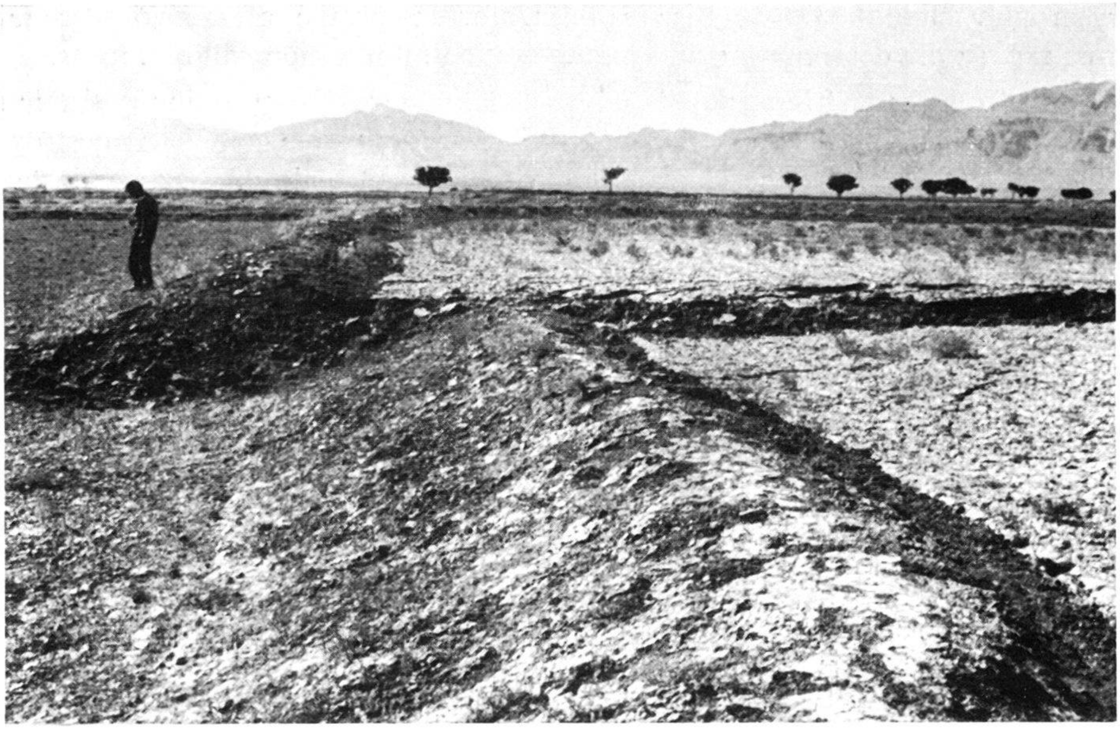

Fig. 10. Anticlockwise displacement on main fracture zone. View to S. Dasht i Biaz.

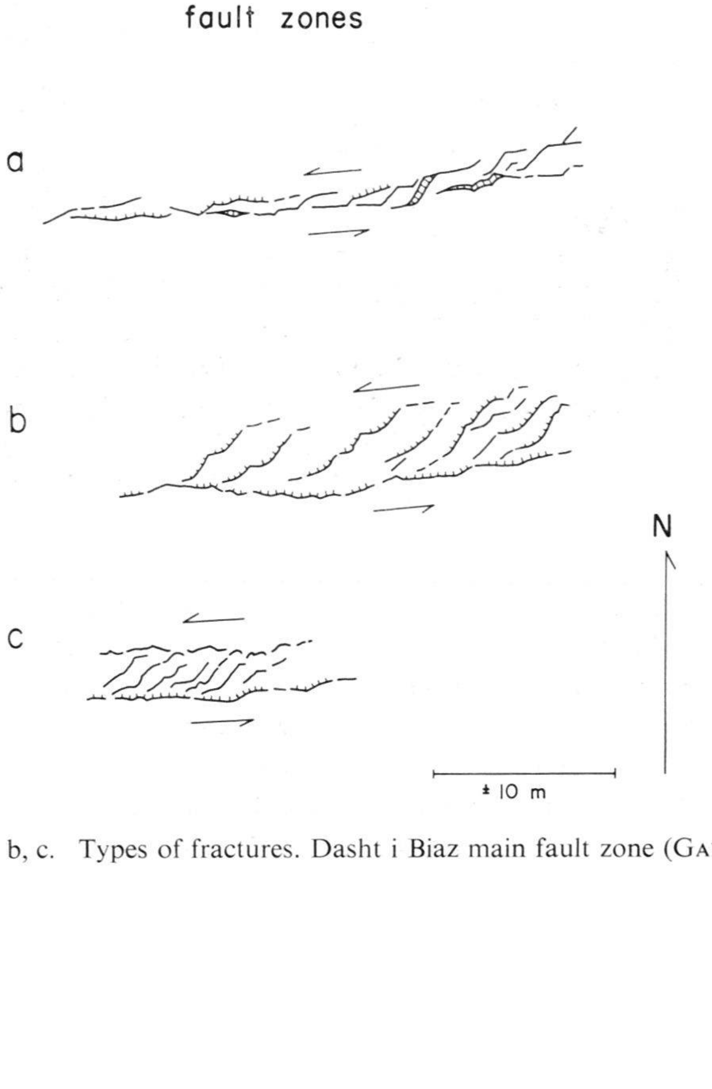

Fig. 11 a, b, c. Types of fractures. Dasht i Biaz main fault zone (GANSSER).

very strongly felt in the Dasht i Biaz region. Unfortunately the soft faces of these fault scarps are rapidly deteriorating and the interesting information will disappear.

Apart from these striking details, the regional picture of destruction is also irregular and variable. Villages situated along the fracture zone were completely destroyed. Similarly destroyed were the villages within the alluvial plain of Biaz (for instance

Fig. 12. Main fracture zone with downthrow to N, looking E. Dasht i Biaz.

Salaiani). The destruction was, however, considerably less severe in villages situated south of the Biaz plain, along the southern foothills. Most unexpected was the nearly total destruction of the village of Kakhk, where 3500 out of the 5000 population was reported killed (Fig. 17). It is situated about 10 km to the north of the fracture zone and on the northern foothills of the Mesozoic range. On the other hand, small villages just to the west and east of Kakhk, along the same foothill trend, were only slightly damaged. The village of Kakhk is an excellent example of how the destruction depended on the type of construction as well as on its location. The part of the village situated

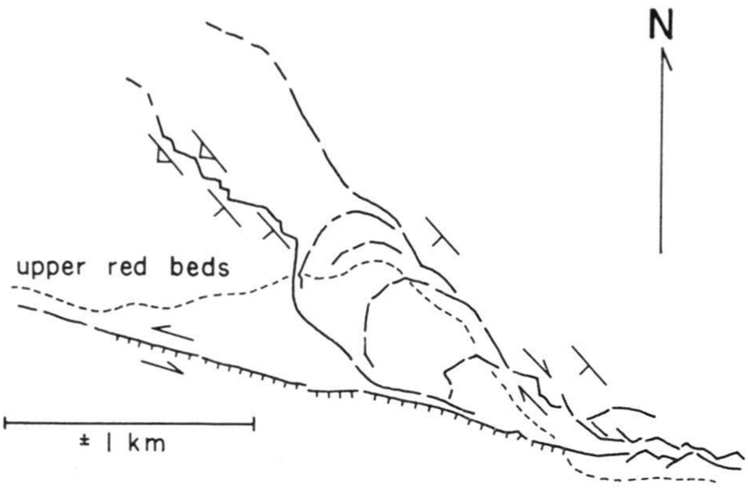

Fig. 13. Branching fractures W of Biaz, entering Miocene formation (GANSSER).

on the alluvial fills of the Kakhk river was completely razed to the ground. The group of houses standing on the Mesozoic outcrops were damaged, but some of the walls were still standing. A little bathhouse, built of good brick and on a solid platform of stone slabs, moved as a whole but was not damaged, except for a few cracks. Most surprising was the beautiful cupola of the large mosque of Kakhk. Most of this building collapsed, but the cupola itself remained intact (Fig. 18).

After the strong earthquake of August 31st followed, on the 1st September, a most severe aftershock. Its epicentre was 40 km to the west of the Biaz centre, about 15 km

Fig. 14. NW branching fracture zone entering Miocene hills (F). Dasht i Biaz.

Fig. 15. Fracture zone in SW dipping Miocene beds, following dip. Dasht i Biaz.

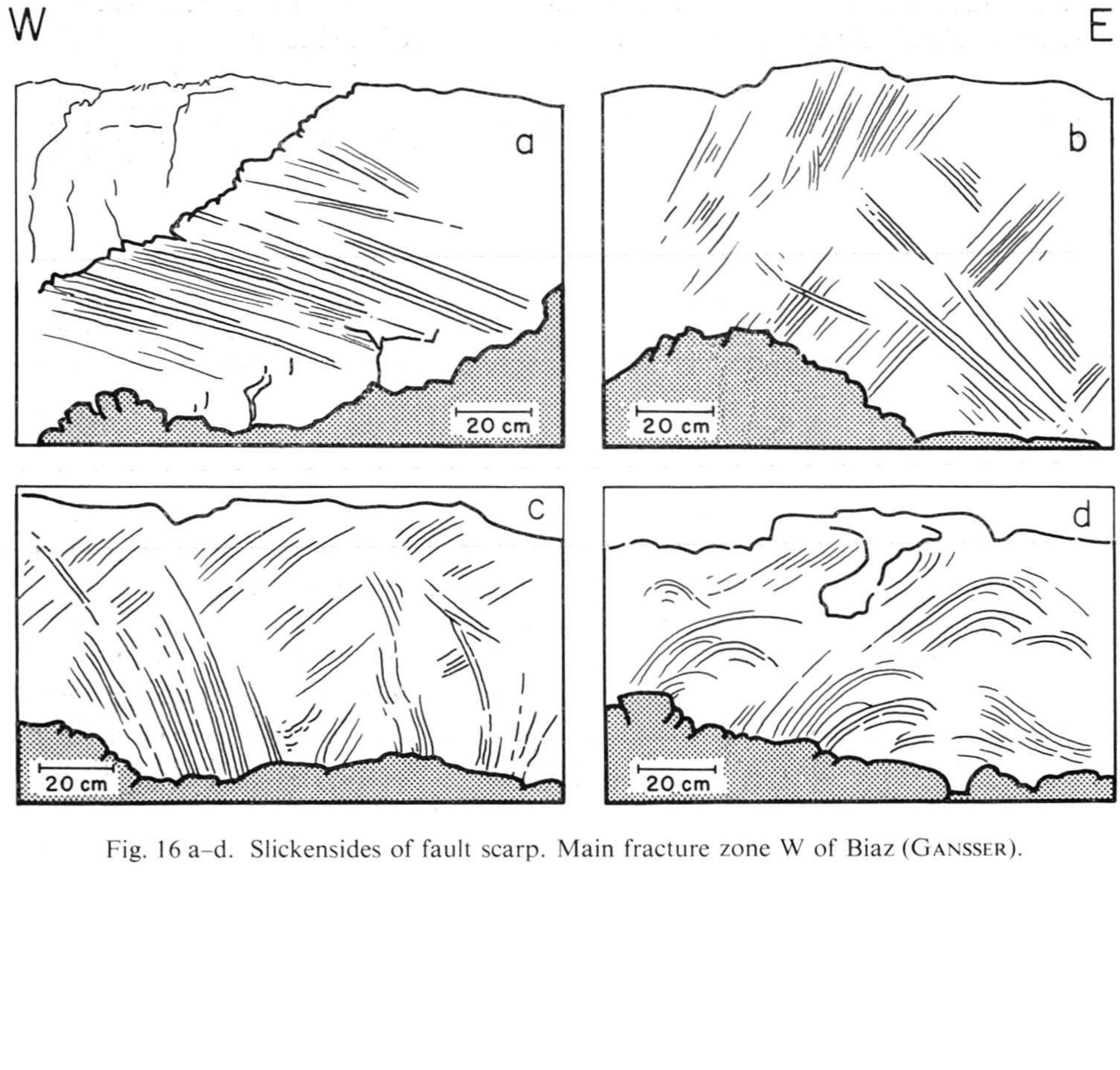

Fig. 16 a–d. Slickensides of fault scarp. Main fracture zone W of Biaz (GANSSER).

north-east of the town of Ferdows. This town with its 12,000 inhabitants, was warned by the Biaz earthquake the day before, which caused only slight damage. During the aftershock the greater part of the town was destroyed, but 'only' about 1000 people were killed. This aftershock was rather weak in the Biaz region. At the west end of Ferdows stands a chimney stack built of good bricks, over 40 m high. It remained practically undamaged, in spite of the soft clay ground with deep excavations surrounding it. The Ferdows aftershock apparently did not produce any fracturing of the ground.

Fig. 17. Total destruction in Kakhk.

A seismograph station, situated on a massive limestone hill 15 km north of Dasht i Biaz began to operate two weeks after the main shock (CRAMPIN et al., 1968). During the first day of its operation 580 local events were recorded, the number gradually decreasing over the next six weeks. The preliminary information of the main shock and the aftershocks was published by AMBRASEYS and TCHALENKO (1968). The main shock was reported with a magnitude of 7.3 and a focal depth of about 13 km. The heavy aftershock of Ferdows had a magnitude of 6.3 and was 15 km deep. Further aftershocks varied between magnitudes of 5.5 to 4.5 and focal depths of 15 to 24 km. The later events were concentrated in the south-eastern part of the general area.

With all the available information it remains most difficult to assess the cause of the Dasht i Biaz–Ferdows earthquake. Similarly to other Iranian events, the focal depth is shallow. The surface fracture and the isoseismals indicate an east/west extended feature. Less well aligned are the locations of the various aftershocks. From the general structural outline of the northern Lut block we note that the Dasht i Biaz region is located in the centre of the northern half and that the earthquake fracture parallels the large Doruneh fault. Inquiries at Doruneh indicated that the Dasht i

Biaz event was felt with an intensity less than V. One would actually expect that strong earthquakes be related to the Doruneh fault, which limits a rigid Lut block from a mobile ophiolitic belt. The Doruneh fault cuts alluvial fans and seems continuously active, most likely of a creeping type without any substantial accumulation of energy which could be suddenly released.

Fig. 18. The undamaged cupola of Kakhk mosque.

The direction of movement along the Doruneh fault has been deduced clockwise by some investigators or anticlockwise by others (sinistral) (e.g. WELLMANN, 1966). For both directions the evidence is not convincing. Particularly unconvincing are arguments based on the present drainage pattern. Along a reactivated fault system the fault itself could form an obstacle to normal drainage, and changes in the drainage pattern could be subsequent to the existant fault barrier. A slightly tilted ground could be responsible for a uniform drainage change, which needs not reflect a horizontal shift.

The structural trends of Dasht i Biaz may be related with the eastern mobile belt east of the Lut block. Branches of this fault zone cutting into the rigid block may be more prone to sudden energy release than major fault zones delimiting two completely separate tectonic units, and which by cutting through alluvial deposits may indicate creeping and thus slow dissipation of energy.

In conclusion, we can only reiterate that the Dasht i Biaz event, similar to Buin, Hamadan and Elburz earthquakes and unlike Torud, was most unexpected and not related to clear surface features and that with all the modern information on earthquakes we are far from the time when it will be possible to predict such an event and to safe lives and property.

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