

**Naghan (Chahar Mahal Bakhtiari-High Zagros, Iran) Earthquake  
of 6 april 1977. A preliminary field report and a seismotectonic  
discussion**

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**ABSTRACT**

The Naghan earthquake of magnitude 6 (Ms) occurred on 6 April 1977 in the mountainous area of Chahar Mahal Bakhtiari in the High Zagros, south of Shahr-e-Kord. It killed 348 people, injured about 200, and caused destruction over an area of 150 Km<sup>2</sup>. The shock damaged beyond repair 2,100 houses and killed 0.7% of livestock in the area; eight schools collapsed and 37 were damaged. The maximum intensity of the main shock did not exceed VIII (MM).

The earthquake was associated neither with any fresh surface faulting, nor with reactivation of the existing faults and salt domes at surface. Heavy rain fell before and during the earthquake and the destruction was more extensive where the saturated clay content of the alluvium was higher; it was also more extensive in water-logged areas or the areas with a shallower water table. Landslides occurred on steep slopes and destroyed or damaged some villages built on slopes. Several aftershocks caused additional damage to the already destroyed or damaged villages.

The Naghan earthquake was another instance of the « *subsedimentary Zagros-Type Earthquake* » in the High Zagros part of the Zagros Active

Folded Belt, indicating that the re-adjustment of the unexposed metamorphosed Precambrian Basement at depth caused no tectonic deformation (surface faulting) at the top of the sedimentary cover. This was due to the presence of the Upper Precambrian Hormoz layers (Salt deposits) acting as a slippage zone along the decollement surface of the Zagros at depth.

#### RIASSUNTO.

Il terremoto di Nagham del 6 aprile 1977, con  $M=6$ , ha interessato l'area montagnosa Chahar Nahal Bakhtiari, nell'alto Zagros, a sud di Shahr-e-Kord. Le vittime furono 348, i feriti circa 200 e le distruzioni coprono un'area di 150 km<sup>2</sup>. La scossa causò danni irreparabili a 2100 case e la morte del 7% degli abitanti della zona; 8 scuole crollarono e 37 subirono danni. L'intensità massima della scossa principale fu pari all'VIII grado della scala MM.

Il terremoto non è stato associato né ad una faglia giovane né ad una riattivazione di faglie esistenti né domi salini superficiali. Una pioggia violenta cadde prima e durante il terremoto; la distruzione fu maggiore dove più alto era il contenuto di argille alluvionali sature e si stese anche di più nelle zone imbevute d'acqua o in quelle con falda acquifera più superficiali. Si ebbero frane su pendii scoscesi, che distrussero o danneggiarono alcuni villaggi costruiti sui pendii. Parecchie repliche provocarono ulteriori danni ai villaggi già distrutti o danneggiati.

Il terremoto di Nagham fu un altro esempio tipo-subsedimentario del « terremoto di Zagros », nell'alto Zagros, parte della catena attiva a pieghe di Zagros, che indica che il raggiustamento del Basamento metamorfico Precambriano sepolto non ha causato alcuna deformazione tettonica (fagliamento di superficie) alla sommità della copertura sedimentaria. Ciò fu dovuto alla presenza di strati della formazione dell'Hormoz del Precambriano Superiore (depositi salini) che agiscono come una zona di scivolamento lungo la superficie di scollamento alla base dello Zagros.

#### INTRODUCTION.

A strong earthquake of magnitude 6.5 hit the northern Zagros range (the High Zagros or thrust zone), heart of the Bakhtiari tribal area (Chahar Mahal Bakhtiari province), 100 kilometers southwest of Esfahan (Fig. 1). The earthquake occurred at 18.0735 (local time Wednesday 17.1.2536), 13.36.35.5 GMT on

6 April 1977, causing damage to houses and orchards in the area. The region, which serves as a summer resort for Bakhtiari, was very sparsely populated at this time of the year. This was the first remembered destructive shock which shook this part

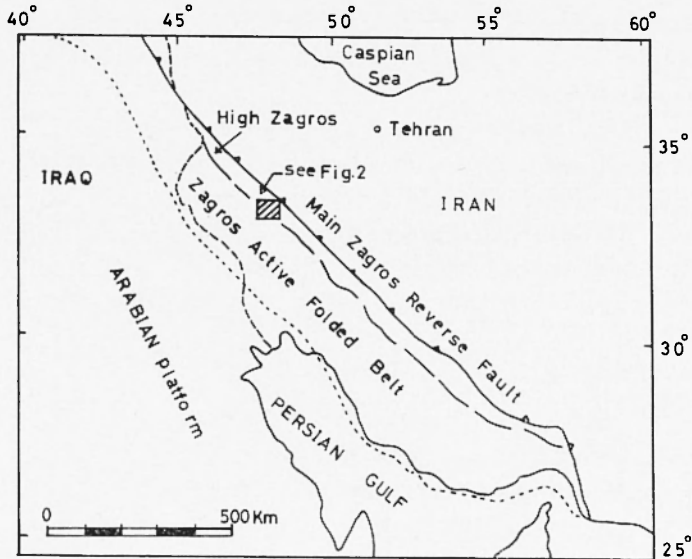


FIG. 1 - Position of the Naghan (Chahar Mahl Bakhtiari High Zagros, Iran) earthquake of 6 April 1977.

of the country, except a minor shock which took place in 1975 southeast of the epicentral region (Fig. 2).

The Zagros Active Folded Belt, together with the northeast dipping "Main Zagros Reverse Fault" (the former Zagros Thrust Line; Berberian 1976 a, b) which bounds it in the north, extends some 1,500 Km from the Taurus mountains in southern Turkey, through the whole of southern Iran, to a north-trending transcurrent (Minab Fault) near the Strait of Hormoz at the mouth of the Persian Gulf. The width of the Belt is from 200 to 350 Km. Immediately southwest of the Main Zagros Reverse Fault there is a "Thrust Zone" (or Imbricate Zone) containing strongly tectonized series with radiolarites and ophiolites as well as some limestone units.

The Imbricate Zone includes the highest mountains of the Zagros (the High Zagros) and the deepest exposures.

Further to the southwest begins the Simply Folded Zagros s.s.t., formed of practically continuous sedimentary series from Cambrian to Pliocene. The Thrust Zone is a complex zone of structures (rather than a simple structure) and several reverse faults of different ages, namely Senonian and Pliocene, are present within it.

The main shock of Naghan occurred at 13.36.35.5 GMT without any premonitory foreshock. The shock killed 348 people and injured about 200. Destruction occurred over an area of 150 Km<sup>2</sup>. It damaged beyond repair 2,100 houses.

The preliminary computation by the U.S. Geological Survey, National Earthquake Service, gives the following data:

Date : 6 April 1977  
Time : 13.36.35.5 GMT  
Epicentre : 31.92N, 50.64E  
Magnitude : 6.0 (Ms)  
Focal Depth: Restricted to 33 Km

The instrumental location places the epicentre of the main shock 9 Km SSW of the macroseismic epicentre. The macroseismic epicentre (taken as the centre of the area of maximum destruction) is located at 31.85N, 50.76E. Several aftershocks of magnitude 4-5 followed the destructive shock and worsened the condition of the already damaged houses.

A preliminary examination of the area was made by a team of the Tectonic and Seismotectonic Research section of the Geological Survey of Iran, which concentrated on observation of the effects of the earthquake in built-up areas and the surrounding country. Attention was particularly devoted to evidence of faulting or reactivation of faults and secondary effects such as cracks and openings in ground, lurching, tension cracks, temporary springs, and any other disturbances. Aerial photographs at a scale of 1:20,000 and 1:55,000, together with the Landsat (A and B) imageries and geological maps (B.P.,

1963; IOOC, 1969) were used for locating the features observed and traces of recent and late Alpine Faults.

The intensity of the earthquake effect was estimated using the Modified Mercalli Intensity Scale. Conversation with inhabitants, their descriptions of the events, statistics, and information from the various authorities were used as guides.

#### REGIONAL SEISMOTECTONIC SETTING.

##### *Regional Structure.*

As previously stated, the region under consideration is situated in the High Zagros (Thrust Zone) of the Zagros Active Folded Belt. The geological history of this Belt is comparatively simple, as a relatively quiet sedimentation continued from Upper Precambrian (Infracambrian) to Pliocene. The Paleozoic sediments overlie a shield-like basement of Precambrian age. Regional disconformities occur at the top of the Aptian, the Cenomanian-Turonian, the Cretaceous, and the Eocene (Stocklin 1968, James and Wynd 1965, Berberian 1976 b).

Evaporites have been prominently involved in Zagros tectonism. Jurassic and Miocene evaporitic sequences in the Zagros Active Folded Belt are zones above which disharmonic folding is reported, and similar movements have been postulated at the Hormoz Salt belts of Upper Precambrian age, near the base of the Paleozoic platform rocks, or on top of the metamorphosed Precambrian Basement (the metamorphosed Precambrian Basement does not crop out in Zagros). This important evaporite layer separates the sedimentary column from the basement. In addition, many large Hormoz Salt diapirs, some now active, reach the surface in the Zagros Active Folded Belt (Dunnington 1968, Stocklin 1968 a, b, Falcon 1974, Berberian 1976 b).

The Zagros sediments covering the margin of the Arabian plate were folded mainly during the Main Zagros Orogeny (Walachian diastrophism) at the end of Pliocene-Pleistocene times,

when up to fourteen parallel anticlines and synclines were developed. These structures generally have a northeast-southeast direction, but in the extreme southeast (Fars-Hormozgan provinces) the trend of the fold axes gradually swings towards the east. The spectacular NW-SE striking folds (long, broad structures that are asymmetric or overturned towards the southwest, where they gradually die out) are cut by thrust and high-angle reverse faults that are parallel to the folds but dip both northeast and southwest. These faults appear to be structurally related to the folds, and like them to be the results of plio-Pleistocene and Quaternary compression.

These deformations also generated along the northern side of the mountain range a major tectonic discontinuity, the Main Zagros Reverse Fault, which separates the Zagros domain, in the southwest, from the Central Iranian domain.

According to Falcon (1974), the general picture of the Alpine Orogeny in the Zagros Belt is of a series of waves of depressions and uplifts advancing from the northeast towards the southwest. It is thought that the thrust Zone-Central Iran boundary was close to the northeast margin of the Arabian basement shield at least from the initiation of the Alpine movements.

From the crustal point of view the Simply Folded Belt contains simple folds caused by the rucking up above the décollement of the Phanerozoic column during one orogenic phase. The Thrust Zone is more complex because it has been rucked up twice: the first phase of folding and faulting affected the Thrust Zone in the Cenomanian Turonian to Middle Eocene interval, dominantly in Upper Cretaceous times. The Middle Eocene strata are of flysch facies, while pre-Middle Miocene movements are relatively insignificant in the Simply Folded Belt. In the latter zone only a single phase of folding of Mio-Pliocene age has affected the rocks.

*Regional Seismicity.*

The very high twentieth century seismicity of the Zagros Active Folded Belt, is characterized by a large number of shocks in the magnitude 5 or 6 range, and a very small number with magnitude equal to or greater than 7. The precision of depth calculation of the Zagros is very poor, and without special studies little can be said on the subject, except that most earthquakes occur in the crust, and that they do not appear to exceed 100 km. Series of earthquakes resembling swarm also seem to be characteristic of the Zagros (Berberian 1976 a, b).

The total thickness of the sediments above the metamorphosed Precambrian basement cannot be more than 10 to 15 (or a possible maximum of 18) kilometers. Thus the earthquakes occurring within this depth range may be related to deformation of the sediments and or movements of the salt layers and their diapirism (?).

However, many earthquakes occur at greater depths, and salt diapirism would not necessarily be associated with thrust faulting, whereas the focal mechanism of most earthquakes are thrust faults. It would therefore appear that most of the earthquakes are subsedimentary and probably related to the basement or upper mantle (Haghipour et al., 1972) and that reactivation of some basement faults during readjustment of the basement causes subsedimentary earthquakes within the Zagros Active Folded Belt.

*Previous Destructive Earthquakes of the Naghan Region.*

In 1976, July 27 an earthquake of magnitude 5 was strongly felt at Shalamzar. The instrumental epicentre was located at 31.60N, 50.36E and the estimated focal depth was 77 km.

The only known semi destructive earthquake in Naghan region is the Sarpir earthquake of 21 September 1975. The instrumental epicentre of this shock, which took place at 14.16.37.8 GMT (17.46.36 local time), is located at 31.599N, 51.037E. The

macroseismic epicentre was located at 31.228N, 51.04E (Fig. 2). The magnitude was 5.2 (Mb), the estimated focal depth 33 km (N) and the maximum intensity VI-VIII (MM). The earthquake destroyed Sarpir village and damaged Dorahan and Deh Bagh. Two people were killed in Sarpir.

#### EARTHQUAKE EFFECTS.

The following description of surface manifestations are represented in Fig. 2.

#### *Faulting.*

Study of the Landsat imageries (A and B) at a scale of 1:1,000,000 and 1:500,000, aerial photographs of the region at a scale of 1:20,000 and 1:55,000, the existing geological maps (B.P. 1963 I00C 1969) and detailed field study shows that there are only four major faults in or near the Naghan epicentral region, namely the Ardal Fault, Shalamzar Fault, Dopolan Fault and Dena Fault.

*Ardal Fault:* This is a NW-SE reverse fault 80 km long, on the southeastern end of which the epicentral region is situated. It deepens towards the northeast. A linear Hormoz salt plug is intruded along its northwestern part. The fault is covered by Quaternary alluvial deposits.

*Shalamzar Fault:* This fault is situated north of the epicentral region. Its length is about 60 km and it deepens towards the northeast.

*Dopolan Fault:* This is another northwest-southeast fault 65 km southwest of the epicentral region. It starts from Dopolan in the NW and joins the Dena fault at its southeastern extremity.

*Dena Fault:* It is a NNW-SSE fault about 30 km southeast of the epicentral region. It seems that the macroseismic epicen-

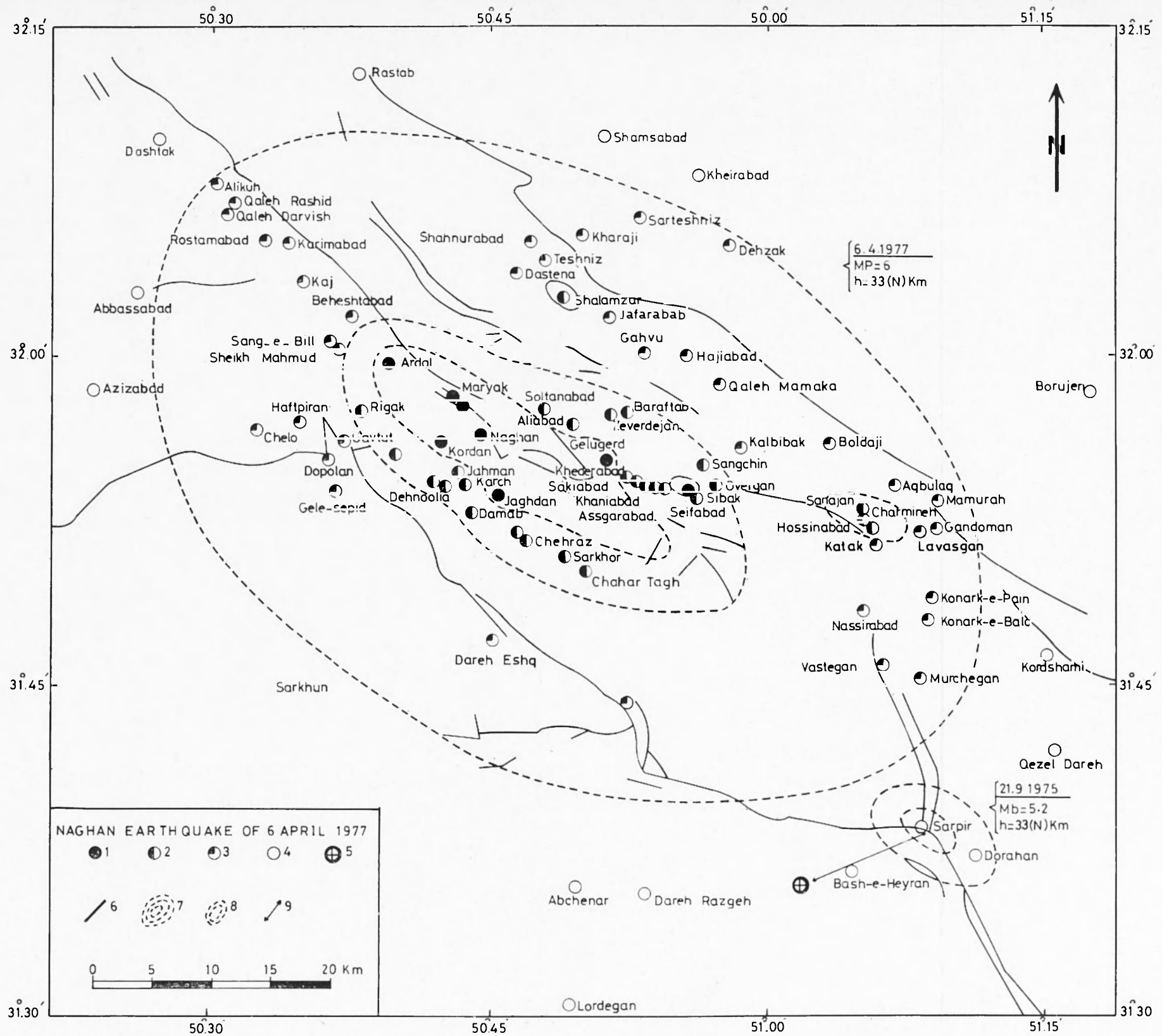


FIG. 2 - Map of the Naghan (Iran) earthquake area showing the main tectonic and damage features. The intensity grades correspond to the Modified Mercalli Scale.

1) Severely damaged, 2) Considerable damage, 3) Light damages, 4) The shock strongly felt, 5) Instrumental epicentre, 6) Fault, 7) Isoseismals, 8) Distance between macro-seismic and microseismic epicentres, 9) Salt domes.

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tre of Sarpir earthquake of 21.9.1975 was located on this fault.

During a very careful investigation, these faults were checked in their entirety, and they were not reactivated at surface during the Naghan earthquake. Neither was the earthquake associated with the formation of new surface faults.

#### *Salt Domes.*

There are two late Precambrian salt domes (Hormoz salt) in the Naghan region intruded along Ardal and Dena faults: the Ardal salt dome in the north western part of the epicentral region, and the Dena salt dome in the southeastern part of the region (in Sarpir).

During the field investigation the contacts of the salt domes with the adjacent rocks have been carefully checked but no fresh movement has been found.

#### *Landslides and Displacement of Stones.*

Several large scale landslides occurred during the Naghan earthquake, including one about 1 km in length north and north-west of Ardal near the Ardal fault. The strike of this linear landslide is about N150° E.

Another landslide destroyed a vineyard and moved towards Sakiabad village, pushing, fissuring and destroying a few houses in the village (Fig. 3). Some landslides on the way to Ardal destroyed parts of the road.

Many stones in Quaternary alluvial deposits were upthrown and displaced during the earthquake (Fig. 4).

#### *Rock falls.*

Numerous rock falls occurred in different mountainous areas. Before and during the earthquake it was raining; consequently the rocks which fell during the earthquake left visible indentations in the damp earth, clearly showing the path of the falling rocks.

*Extensive destruction on saturated clay.*

Due to the heavy rain before and during the earthquake, the clay alluvium of the epicentral region was saturated with water. It has been observed that the destruction was more extensive when the clay content of the alluvium was higher; it was also higher in water-logged areas or areas with a shallow water table. The northern part of Shalamzar village was not damaged but the southern part which has a very shallow water table (1 m), was damaged or partly destroyed.

*Damage to houses and other constructions.*

The buildings in the Naghan region may be divided into the following groups:

a) *Adobe-brick constructions with wooden beam roofs:* These, together with the next group, comprise 90% of the houses in the area. The walls are of adobe-brick and clay mortar, and the roofs of wooden beams covered by clay and straw and tamped earth. New layers are added annually to the roof as a protection against rain and snow percolation. Most of these constructions are now completely destroyed, or are seriously damaged and unsafe as dwellings (Fig. 5). The high ratio of deaths to injuries emphasizes that the traditional adobe houses of the devastated region, with their weak walls and heavy earthen roofs, offer little resistance to strong earthquakes. Total collapse and heavy loss of life were normal in these buildings. The adobe houses were completely destroyed at Jaghdan (Fig. 6), while the stone masonry communal bath, with reinforced concrete ring beams was only slightly fissured (Fig. 7).

b) *Masonry constructions with wooden beam roofs:* The mortar used here is often clay, so these constructions had a resistance similar to adobe-brick houses. The weakness of some of these buildings was further accentuated because each wall



FIG. 3 - Landslides near Sakiabad which cut the vineyard and moved towards the village, damaging houses.

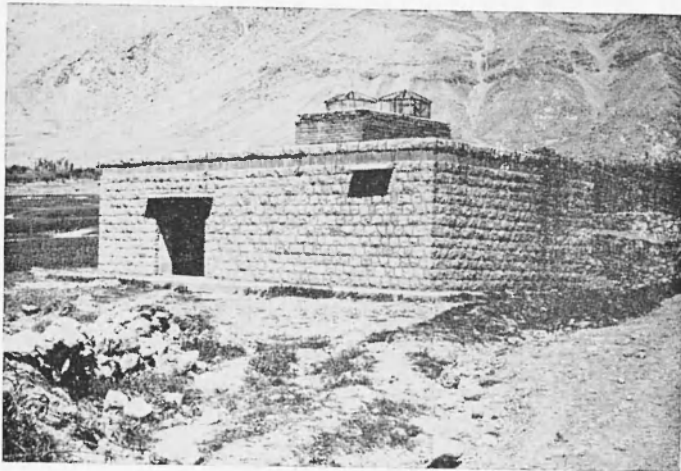


FIG. 4 - Displaced stone near Ardal.



FIG. 5 - Typical adobe-brick houses at Naghan, which completely collapsed.

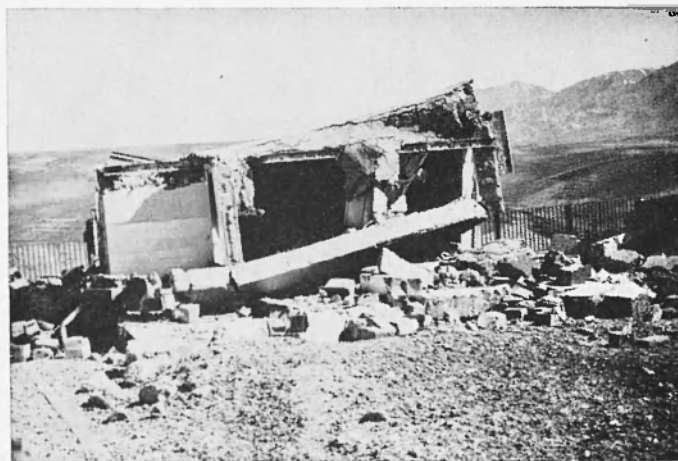


FIG. 6 - Destruction of adobe houses at Jaghdan.

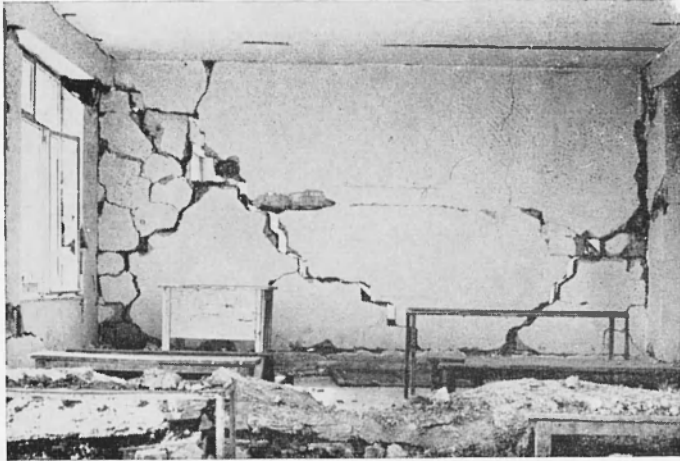


FIG. 7 - Stone masonry bath at Jaghdan with reinforced concrete ring beam only slightly fissured, where all the adobe houses in the village collapsed completely.



FIG. 8 - Complete destruction of typical adobe - stone houses at Sarmur.



FIG. 9 - Ardal school. A steel concrete frame school with arch type roof. Southern heavy wall collapsed to south and northern part of the building collapsed from the shallow roots of the columns.



FIG. 10 - Diagonal shear cracks in the wall of an Ardal steel concrete frame school.

had been built virtually from two unanchored facings between which was a filling of earth (Fig. 8).

c) *Masonry constructions with doomed roofs*: In the area, there were a few structures of this type with thick walls supporting the arch roof. The usual mortar is gypsum plaster, or a mixture of gypsum and clay.

d) *Modern buildings with brick masonry and steel beam-Jack arch roofs*: A few buildings of this type existed in the area. The school in Ardal was heavily damaged and partly destroyed (Figs. 9 e 10).

#### SEISMOTECTONIC DISCUSSION.

Berberian and Tchalenko (1975) and Berberian (1976 b, c) stated that there is no obvious relation between "*Earthquakes*" and "*Structure*" in the Zagros Active Folded Belt, and that it is not possible to use seismicity to establish smaller seismotectonic units with the information presently available. Neither the mountain/depression division, nor the large scale fault-flexure zones and strongly folded arcs, nor the mapped faults seem to exert any strong earthquake locations in the Zagros.

According to Berberian (1976 b) the apparent lack of agreement between earthquakes and structures may arise from two factors: "*Deficiency of data*" and "*Unknown basement-surface relation*".

The "*seismological data*" is deficient because of the brevity of the observation period (about 70 years) and the inaccuracy of focal depth determination ( $\pm 30$  km). The "*geologico-structural data*" is deficient because the tectonic history of fundamental structures, such as the Kazerun zone, had not yet been established by detailed field work. The major problem, however, is the *unknown relation* between the "*Precambrian metamorphosed basement*" at depth where most earthquakes presumably occur, and the "*top of the sedimentary cover*" whe-

re the geological structures are observed. Between basement and cover, a "highly plastic salt layer (the Hormoz Salt)" acts as a "zone of slippage" on the decollement surface, disconnecting the cover structures from those at depth. Consequently surface structures may not always reflect the underlying basement structures in a simple manner.

Even within the sedimentary cover, other plastic layers, such as the Gachsaran Formation, are responsible for remarkable structural changes: synclines at surface correspond to anticlines 1 km down; faults change from high angle reverse to near horizontal thrust, or die out altogether, etc.

The Naghan earthquake of 6 April 1977 of magnitude 7 is another "Subsedimentary Zagros-Type Earthquake" case in the Zagros Active Folded Belt, showing that the reactivation of some basement faults at depth during the readjustment of the basement caused no tectonic deformation at the top of the sedimentary layers because of the presence of Hormoz plastic deposits. The thickness of the top sedimentary cover in the Naghan region is about six kilometers (Morris 1977). This six kilometers sedimentary cover overlies the Hormoz salt beds and together overlie the metamorphosed Precambrian basement.

As mentioned, the reactivation of the metamorphosed Precambrian basement caused no structural effect on the top of these six kilometers of sedimentary folded and faulted layers. No reactivation along faults or salt domes have been observed, and no fresh surface break was formed. The subsedimentary Zagros-type earthquakes which are characteristic of the Zagros Active Folded Belt, while having no relation to the top of the sedimentary cover, represent an important phenomenon which creates curious problems in the seismic zoning of this part of the country. It seems that the Zagros Active Folded Belt should neither be divided into several seismotectonic zones in the manner of Nowroozi (1976), nor given several expected maximum intensities for future earthquakes in different zones.

The Khurgu (North Bandar Abbas, Iran) earthquake of 21 March 1977 (Berberian, Papastamatiou, 1977) of magnitude 7.0, which occurred a few days before Naghan earthquake, was ano-

ther "subsedimentary Zagros-type earthquake" which reinforces the present conclusions. These events showed that earthquakes may occur anywhere in the Zagros Active Folded Belt and since no correlation could be established between the seismicity and the tectonic features with our present knowledge, it should be assumed that an event has the same probability of occurrence anywhere within the Zagros Active Folded Belt. That is to say, the seismic risk level is the same everywhere along the Belt. Hence 20th century epicentre maps maybe dangerously unsuitable for the purpose of subdividing the Belt (and the country) into active and non-active regions. Reliably catalogued historical (pre-1900) earthquakes are so few as to be of little help. It would therefore be wrong to assume a very low risk rate in areas with no known record of a strong shock in the Zagros Active Folded Belt.



Village	Casualties	Injuries	Houses Destroyed	Population (families)
Naghan	202	100	mostly	500
Maryak			4 collapsed, others damaged	72
Dareh-e-Gel-e-Gerd	3	2	1/3 collapsed	52
Kordan	7	4	mostly	10
Dehno Glia			1/3 collapsed	38
Damab	1		1/4 collapsed	66
Sarkhor (Parkhor)			mostly	8
Jaghdan	43		mostly	130
Hajali			mostly	4
Karch	1		4 destroyed, 2 fissured	6
Ardal	64		mostly	430
Dastgerd	11	25	115 collapsed	800 persons
Gelugerd	2		46 collapsed	
Sarmur	3		9 destroyed	
Sangchin	1		half destroyed	18
Jahman			damaged	60
Bajgiran			7 destroyed	130
Seifabad			25 collapsed	
Dehno Sofla			damaged	32
Aliabad			10 collapsed	20
Soltanabad	1	2	1/2 collapsed	21
Zeverdejan-e-Sofla			31 partial collapsed	33
Zeverdejan-e-Olia	1		20 partial collapsed	
Zeverdejan-e-Olia			31 fissured	
Baraftale			1/2 partial collapsed	3
Overgun	1		20 collapsed	
Sakiabad	3		11 collapsed	21
Sibak			20 collapsed	200
Khaniabad	2		37 collapsed	
Khederabad	2		50 collapsed	68
Kalbikak			1 collapsed	
Hajiabad			40 badly fissured	92

Village	Casualties	Injuries	Houses Destroyed	Population (families)
Qalch Mamaka			fissured	120
Asgarabad	1		partial collapse	3
Gahru		1	fissured	650
Jafarabad			fissured	100
Shalamzar			50 partial collapse	640
Gaytut			badly fissured	30
Chehraz			1 collapsed	50
Zolmabad			6 collapsed	65
Chahar Tagh			damaged	45
Dopolan			slightly damaged	65
Gel-e-Sefid			slightly damaged	40
Haftpiran			5 partly collapsed	
Chelo			fissured	
Boldaji			fissured	
Gandoman			1 ceiling collapsed others fissured	
Charmineh			5 collapsed	
Hosseinabad			20 collapsed	
Katak (Olia and Sofla)			2 collapsed	
Senagan			1/2 fissured	
Konarak			fissured	
Beheshtabad			1 collapsed, others fissured	
Kaj			2 walls collapsed, others fissured	
Karimabad			Houses fissured	
Rostamabad			10 partly collapsed, others fissured	
Abbasabad			strongly felt	
Josib			strongly felt	
Cheshmeh Soleiman			strongly felt	
Sarchah			strongly felt	
Hosseinabad			slightly fissured	
Qalch Darvish			slightly fissured	
Qalch Rashid			slightly fissured	

Village	Casualties	Injuries	Houses Destroyed	Population (families)
Alikuh			a few fissured	
Seikh Mahmud			fissured	
Tang-e-Bill			fissured	
Rigak			fissured	
Deh Kohneh			3 partly collapsed, others fissured	
Dastena			fissured	
Teshniz			fissured	
Kharaji			slightly fissured	
Sarteshniz			slightly fissured	
Avasgan			fissured	
Mamureh			slightly fissured	
Aqbulag			fissured	
Konak-e-Pain			a few collapsed	
Konak-e-Bala			2 collapsed, others damaged	
Murchegan			1 wall collapsed, others fissured	
Vastegan			slightly fissured	
Nassirabad			slightly fissured	
Shamsabad			felt the shock	
Borujen			felt the shock	
Shahreza			felt the shock	
Shahr-e-Kord			felt the shock	



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