

**The seismicity of Iran.**  
**The Firuzabad (Nehavend) earthquake of 16 August 1958**

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**SUMMARY.** — The Firuzabad (Iran) earthquake of the 16th August 1958 had a smaller magnitude ( $M = 6.6$ ) than did the last major earthquake in the same area which occurred on the 13th December 1957, and had a 7.1 magnitude. The Firuzabad earthquake killed 132 and injured about 200 people in 170 villages. It affected an area of 1,100 square kilometres within which 2,500 housing units were destroyed or damaged beyond repair. The earthquake had its macroseismic epicentre somewhat southeast of the 1957 earthquake and the shock was felt over an area of 80,000 square kilometres.

The damage pattern from the Firuzabad earthquake did not resemble that of the 1957 shock, in that the Firuzabad earthquake affected a smaller region but was the more intense of the two. In contrast, the 1957 earthquake had a somewhat more moderate surface intensity over a much wider area.

The Firuzabad earthquake was associated with a fault-zone at least 20 kilometres long. This earthquake and the seismic events of the previous year as well as the aftershocks of the 21st of September 1958, show quite clearly a progressive expansion of seismic activity along a northwest-southwest axis in the Zagros mountains.

**RIASSUNTO.** — Il terremoto di Firuzabad (Iran) del 16 Agosto 1958 ebbe una magnitudo inferiore (6.6) di quella del 13 Dicembre 1957 (7.1), la più forte avvenuta in ordine di tempo nella stessa zona; in 170 villaggi, 132 furono i morti e 200 ca. i feriti; l'area colpita fu di 1100 km<sup>2</sup>, mentre le abitazioni distrutte o irrimediabilmente danneggiate furono 2500. L'epicentro macrosismico fu leggermente a SE di quello del terremoto del 1957 e la scossa fu sentita in un'area di 80.000 km<sup>2</sup>. I danni provocati dai due terremoti non sono paragonabili. Il terremoto di Firuzabad, infatti, pur avendo colpito una regione più piccola, ebbe una intensità maggiore di quella re-

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lativa al terremoto del 1957, anche se quest'ultimo ha interessato un'area molto più vasta. Il terremoto di Firuzabad fu associato ad una zona di faglia di almeno 20 km; questo terremoto, gli avvenimenti sismici dell'anno precedente e le repliche del 21 Settembre 1958, dimostrano con molta chiarezza un progressivo espandersi dell'attività sismica lungo un asse in direzione NW-SE nella catena montagnosa di Zagros.

## INTRODUCTION

This paper is a continuation of the report (1) on the Farsinaj earthquake of December 1957. It describes the effects of the Firuzabad earthquake which occurred six months later somewhat southeast of the 1957 earthquake, on the 16th of August 1958.

The Firuzabad earthquake was a comparatively large magnitude shock that affected an area of more than 1,100 square kilometres, killing 132 people. The shock was felt within an area of 80,000 square kilometres and it was associated with faulting.

Until now, the effects of these two large and closely spaced earthquakes in the Zagros were impossible to disentangle. Much of the information about these earthquakes was collected by the authors during a field trip in the spring of 1973. Additional information about the Firuzabad earthquake was extracted from the local and national press and from statistics on damage compiled by welfare organisations. No other significant information has been found. Three months after the earthquake a Japanese mission visited the Firuzabad area, but apart from a very rough intensity map, the mission published no report (3). A brief account about the earthquake was published by Montandon (4); but this was based on second-hand European press reports.

### 1. - FORESHOCK ACTIVITY

Aftershocks of the Farsinaj earthquake of the 13th of December 1957 continued intermittently for almost two months and they did not die out before the middle of February 1958 (1). Six months later, after a short period of relative quiescence, on the 14th of August, a very strong earthquake of magnitude 5.7 marked the beginning of a new series of shocks that led to the Firuzabad earthquake and to its strong aftershock of the 10th of September. The foreshock of the 14th

Table 1 - FORESHOCK - AFTERSHOCK SEQUENCE OF THE FIRUZABAD EARTHQUAKE

No	Date	Origin Time			Epicentre		Depth km	M	Local Time h m	Macroseismic Effects
		h	m	s	°N	°E				
01	1958 Aug. 14	11	27	05	*34.27	-47.78	39	5.7	14	Strong shock causing panic in the region between Asadabad, Nehavend and Tuisarkan.
02		15	26	27	*34.46	-47.92	57	5.5	19 30	Violent shock, caused slight damage to villages between Tuisarkan, Asadabad and Nehavend.
03	15	04	23	14	*34.11	-48.24	87	4.5	-	—
04	16	17	09	19	*34.29	-48.01	58	4.7	20 40	Long series of shocks causing panic in Asadabad, Hamadan and Kangavar. Minor damage in Kangavar valley.
1		19	13	44	*34.36	-47.86	0	6.6	22 40	MAIN SHOCK.
2		20	03		-		-	-	24	Strongly felt in Kangavar.
3		20	05		-		-	-	25	Felt throughout the region.
4		21	15	18	34	-48 ½	n	5.1	-	(Probably the same as at 25 hours).
5		22	14		-		-	-	26	Long duration at Tuisarkan and Malayer
6	17	00	05		-		-	-	03 30	Felt at Kangavar.
7		02	01		-		-	-	05 40	Felt at Kangavar and nearby villages.

No	Date	Origin Time			Epicentre		Depth km	M	Local Time		Macroseismic Effects
		h	m	s	°N	°E			h	m	
8	1958 Aug. 17	03	47	45	*34.35	-47.91	50	-	07	20	Strongly felt in Kangavar region with minor damage. In Hamadan it caused great panic and in Asadabad slight damage to old houses. Followed by many shocks.
9		03	51	08	*34.50	-48.17	92	-	-	-	(Same as above?)
10		04	57		-		-	-	08	40	Light shocks felt throughout the region.
11		06	46	54	*34.17	-47.34	143	-	10	50	Slight shocks lasting for 20 seconds in Kangavar area.
12		08	56		-		-	-	12	40	Felt in Asadabad.
13		11	16		34	-48	-	-	-	-	—
14		18	45		-		-	-	-	-	Slight shocks felt in various parts of the region.
15	19	15	54	58	*34.19	-48.18	86	-	19	30	Strongly felt at Kangavar where it caused panic; several villages between Kangavar and Firuzabad Bozorg were ruined with casualties; felt at Hamadan and Asadabad.
16	20	-	-	-	-	-	-	-	07	-	Series of sharp shocks in Nahavend and Kangavar.
17	24	08	02	41	*34.37	-48.08	79	-	12	-	Strongly felt at Hamadan and Tuisarkan.
18	25	04	04	45	34	-48½	n	-	08	-	Felt at Malayer and Nehavend.

No	Date	Origin Time			Epicentre		Depth km	M	Local Time h m	Macroseismic Effects
		h	m	s	°N	°E				
19	1958 Aug. 27	-	-	-	-	-	-	12	Shocks in Malayer and Nehavend throughout the day.	
20	28	-	-	-	-	-	-	10	Several shocks felt in Tuisarkan and Nehavend.	
21	Sep. 3	01	34	21	*34.64	-47.89	86	5	05	Violent shocks followed by many weaker tremors felt at Malayer, Nehavend and Hamadan.
22	10	03	49	43	*34.33	-48.01	73	4.5	07 30	Felt in Nehavend and in the villages to the west of the town; followed by many shocks which continued for a few hours.
23		-	-	-	-	-	-	-	09	Strong shock at Nehavend.
24		-	-	-	-	-	-	-	14 50	More shocks at Tuisarkan.
25	11	03	56		-	-	-	-	08	Strongly felt at Bisitun and Sahnch.
26	21	-	-	-	-	-	-	-	13	Very strong earthquake in the Dinawar district, particularly at Karkasar; felt in Kermanshah.
27		16	18	30	*34.52	-47.42	71	5.2	20	Destructive shock in the Dinawar district ruined 7 villages including Karkasar, Gharaghaj, Chuban, and Gamsah killing 16 and injuring 57 people. The shock was felt in Kermanshah and Kangavar.
28	26	07	22		-	-	-	-	11	Series of shocks felt in Malayer.

(\*) Relocated epicentres based on Nowroozi (1971).

of August shook a large area between Asadabad, Nehavend and Tuiserkan. It is not known whether it caused any damage; it did cause, however, widespread panic. Four hours later, another shock of magnitude 5.5 added to the alarm and allegedly caused some damage to a number of villages in the Kangavar valley, Table 1. These two foreshocks were felt over a large area and they were followed by a long series of minor earthquakes, one of which showed a magnitude of 4.7. Tremors continued and two hours before the main shock a strong earthquake of magnitude 4.5, late in the evening of the 16th of August, caused great panic among the inhabitants of Asadabad, Hamadan and of the villages of Kangavar. A number of them were slightly damaged and many summer visitors in Hamadan decided to leave the city the following day.

## 2. - THE FIRUZABAD EARTHQUAKE OF THE 16TH OF AUGUST, 1958

Two hours later, at 10<sup>h</sup>43<sup>m</sup> on Saturday night of the 16th of August 1958, central Zagros in Iran was shaken by a violent earthquake which was felt over an area of about 80,000 square kilometres, Figure 1. The earthquake affected 1,100 square kilometres in the districts of Khezal, Solgi and Sofla along the Gamasiab river and caused heavy damage and casualties in the Firuzabad region.

The Firuzabad earthquake ( $M = 6.6$ ) was the second destructive earthquake in six months in this part of the Zagros, preceded by the Farsinaj earthquake of the 13th of December 1957 ( $M = 7.1$ ) and by many small foreshocks, four being strong enough to be felt throughout the area and recorded at distant stations.

Figure 2 shows the epicentral area of the Firuzabad earthquake; it lies about 1,600 metres above sea-level and comprises the Gamasiab valley and the slopes of Larehkuk including the Kangavar valley. The main shocks destroyed or damaged beyond repair about 2,500 housing units, mainly of adobe construction and killed 132 people injuring 200. In 170 villages the earthquake killed about 3,000 animals and made 10,000 people homeless. The comparatively small loss of life was mainly due to the fact that because of the summer heat most people were sleeping on flat roofs while others, alarmed by the foreshock at 8<sup>h</sup>40<sup>m</sup> p.m. moved out into court-yards and gardens. If the shock had occurred in winter-time, the death toll would have been greatly increased. On the other hand, damage in the northwest part of the

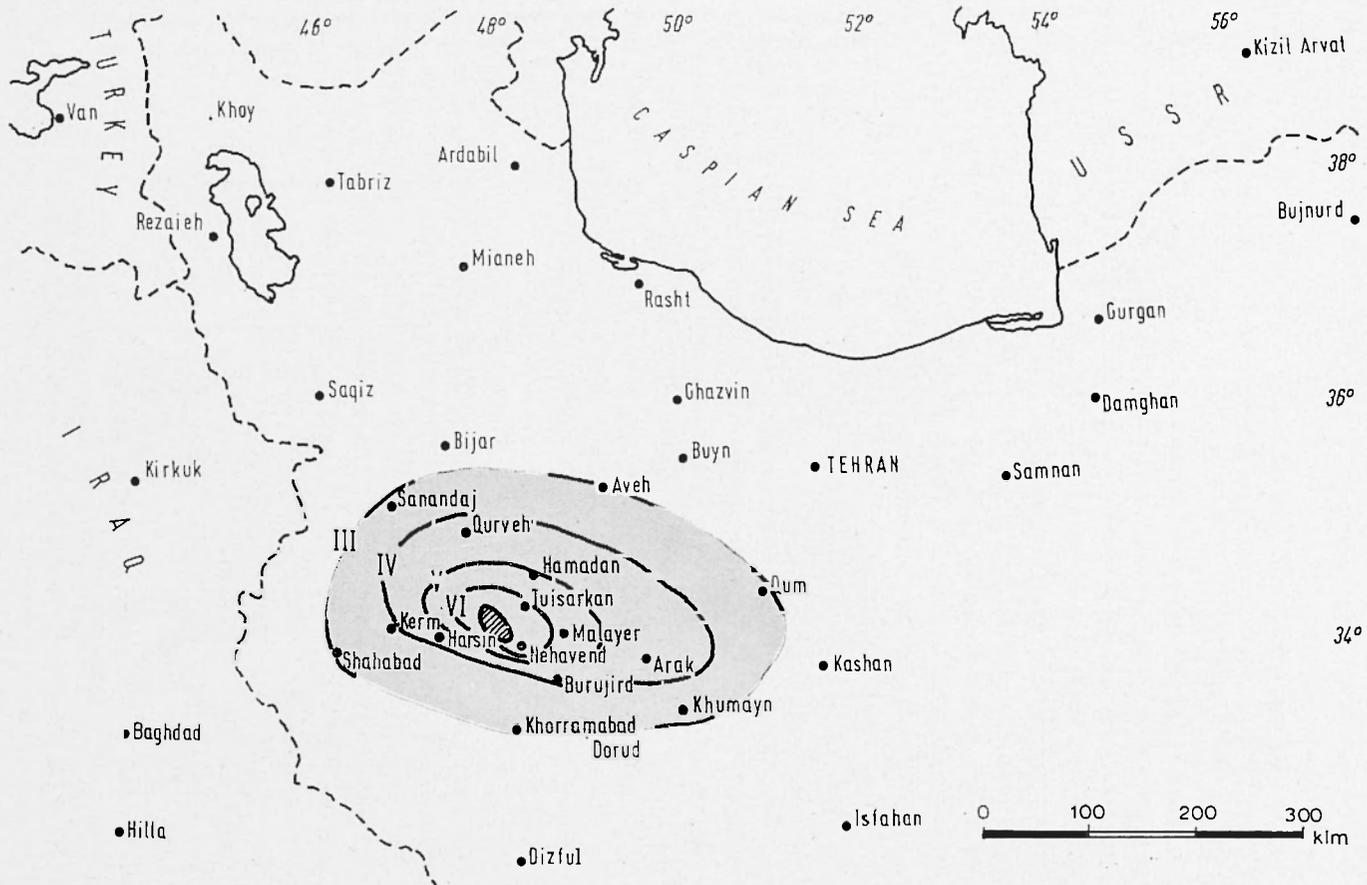


Fig. 1 - Modified Mercalli (MM) Intensity distribution of 16th August, 1958 earthquake. Isoseismal III approximate.

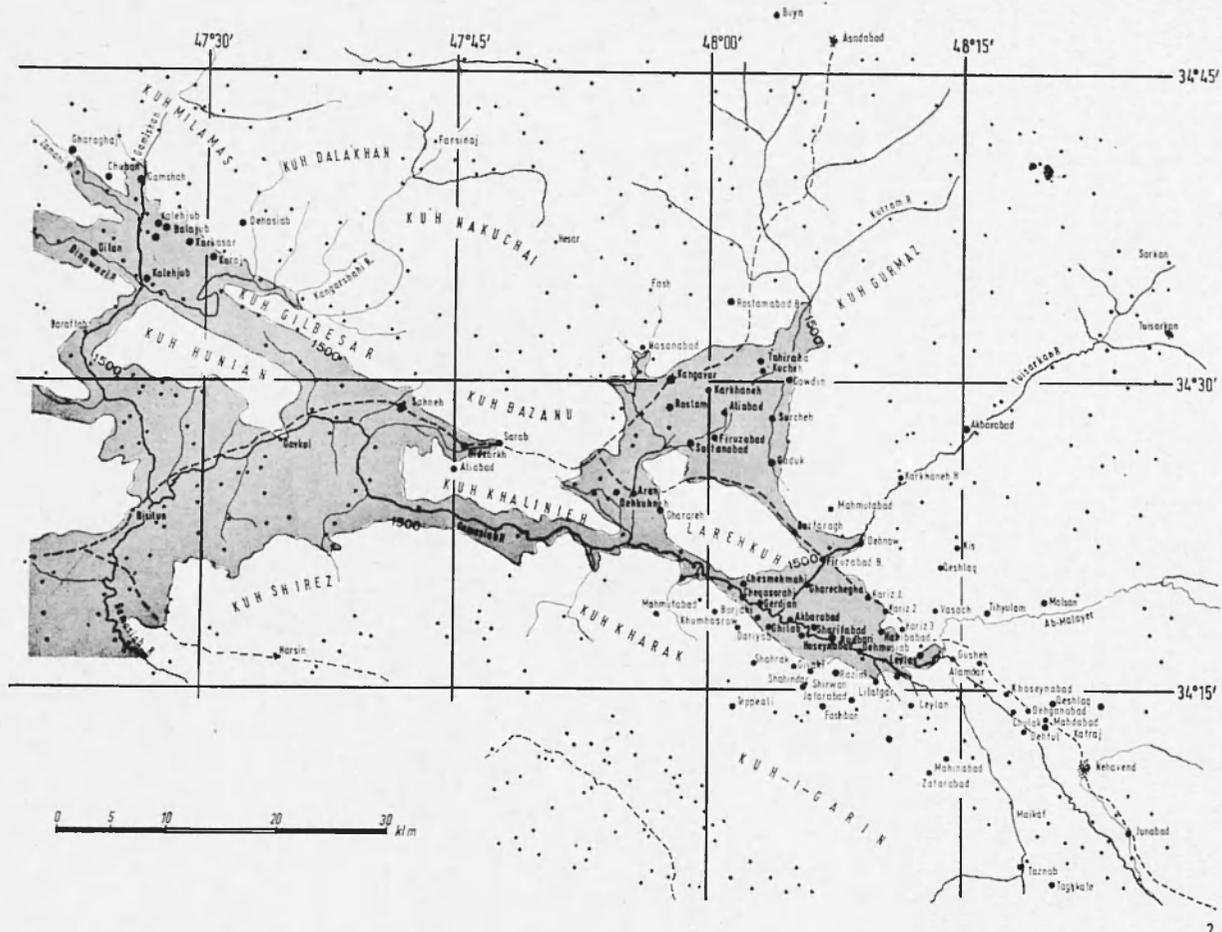


Fig. 2 - Location map of meizoseismal region of Firuzabad earthquakes of 16th August, 1958 and of damaging aftershock of 21st September, 1958 showing all towns villages and settlements in the region. Large dots show localities affected by main shock and aftershocks. Small dots show other localities not affected or uninhabited during the earthquake. Shading shows land below 1500 metres altitude. Dashed line, main road.

meizoseismal region was much heavier than it should have been; there, many villages which had been damaged in 1957 sustained additional and in most cases heavier damage in 1958. This reoccurring earthquake damage was aggravated by some of the latter aftershocks of the Farsinaj sequence.

The most severe damage was sustained by the Lelekan villages, a group of four settlements in the district of Solgi, about 10 kilometres southeast of Firuzabad Bozog (\*). In Leylas-Leylan, Litagar and Jafarabad all houses were completely destroyed and about 200 people were either killed or injured. In Leylas alone, 16 people were killed and more than 50 injured, many of whom died later as a result of the injuries sustained. Here, the shock was so violent that cattle were thrown to the ground and people found it impossible to stand during the earthquake which lasted 5 to 10 seconds. The local inhabitants reported that after the earthquake a long ground fracture appeared in the fields running for many hundreds of metres parallel with the road to Kangavar. In places the fracture caused steps to form with the valley side downthrown by as much as one metre.

Between Leylas and the Gamasiab valley is a maze of irregular terraces and abandoned small settlements allegedly destroyed by the earthquake. To the northwest of Leylas, the village of Dehmusiab was totally destroyed and one person was killed and 9 injured. The shock was so severe that even low garden walls were levelled to the ground. Further on, at Rudbari, much of the destruction seems to have been due to excessive ground deformations and slumping. Villagers attest that shaking was not violent and that they had no difficulty in remaining upright during the earthquake. Not very far away, on either side of the Gamasiab river, Sharifabad and Hoseynabad were totally destroyed and not a single house was left standing. In Sharifabad a large number of animals were killed and more than 16 people were injured. A few kilometres away from the river, on the slopes of Kuh-i-Garin, the villages of Shahrak and Givaki suffered comparatively little damage, particularly the latter where only 29 of its 59 houses collapsed. Also Akbarabad, on the east bank of the Gamasiab on thick alluvium, sustained considerable but not heavy

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(\*) Large scale maps of the region show different locations and spelling for the Lelekan villages; those shown in Figure 2 are from information obtained locally.

damage; here, although all houses were shattered, very few collapsed and no lives were lost. On the west side of the river, Ghilab a large village on conglomerates, was totally destroyed; one person was killed and 12 died later from injuries. Also on conglomerates at some distance from the river, Dariyab was totally destroyed and the 16 houses of the settlement were levelled to the ground. However, here as elsewhere, no one was killed; the inhabitants, forewarned by the foreshock at 8<sup>h</sup>40<sup>m</sup> p.m., had fled their houses. Also at Gerdian, the shock was of destructive intensity and only 2 out of 90 houses were left standing; those that collapsed killed a large number of animals. Damage was less serious at Chequasorahi where 50% of the houses collapsed and the rest were damaged beyond repair. In contrast, not far from here at Cheshmehmahi, not a single house was left standing and many of the villagers were seriously injured and a number of cattle killed. On the other side of the river, at Borjaki which is situated on better ground, all houses were damaged beyond repair and some of them collapsed completely, without casualties. Further away from the river on higher ground, Khumhosrow was badly damaged but few houses were destroyed. It seems, however, that here the shock was very violent; people were thrown to the ground and large stones on sloping ground were dislodged and displaced. To the west of this place, intensity falls off very rapidly and at Mahmutabad Kharaki only a few houses collapsed and no one was injured.

Past Gerdian, and before the Gamasiab turns west, the river flows between Kuh Kharak and Larekuh. Villages in this small valley were not visited but the information available shows that they suffered comparatively little damage.

From the Lelekan villages to the northeast of the river, damage extended throughout the Gamasiab valley to the northeast flanks of Larekuh. Habibabad, near Leylas was totally ruined with some loss of life. At Gusheh all houses were destroyed and adobe walls levelled to the ground. Damage was noticeably less serious at Alamdar, a small settlement, where almost all houses were left standing.

Kariz-3, on the main road Kangavar, was totally destroyed and three persons were killed. Not a house escaped destruction, whether made of adobe, brick or wood. A wide zone of ground fractures passing through the village destroyed some well built adobe storage sheds killing a few animals. A few kilometres further on, Kariz-2 suffered equally heavy damage; 4 people were killed and dozens injured. This place comes in fact next to Lelekan in the extent of damage done by the

earthquake to settlements in the Gamasiab valley. The shock was definitely more severe and the ground was intensely fractured and gaping fissures as much as 10 centimetres wide appeared running through the village. This zone of ground fractures, in places about 200 metres wide, was reported by local inhabitants to run for a few kilometres parallel with and mainly to the southwest of the Kangavar road, extending all the way to Kariz-Jamal (Kariz-1) and beyond. Kariz-1, a small village, was also destroyed but with no loss of life. To the southwest of the Kangavar road the ground slumped and in places formed steps down to the southwest, with gaping fractures extending uninterrupted for 100 to 200 metres towards Firuzabad Bozorg.

Firuzabad Bozorg was badly shaken and almost all its houses were damaged beyond repair and many collapsed killing hundreds of animals and beast of burden. No ground fractures were noticed passing through the village. Villagers, however, still remembered a wide zone of cracks running in a general northwest-southeast direction through fields about 400 metres to the southwest of the village. At its crossing with the Tuisarkan river this zone turned into a landslide area causing some slumping of the river banks. The bridge on the Tuisarkan was damaged by slumping of the river terrace on which its west end rests.

Barfaragh, a large village on the road to Kangavar, had suffered some damage six months earlier from the Farsinaj earthquake, particularly from its aftershocks. At the time of the Firuzabad earthquake the village had been repaired and a few new houses were built. The earthquake totally destroyed Barfaragh killing three persons and injuring at least 9. A year later the village was rebuilt near its old site.

Equally severe was the destruction of Gharechegha on the Tuisarkan river southwest of Firuzabad Bozorg; there, three quarters of the village collapsed entirely and the remaining houses were badly damaged.

To the north and northwest of Larehkuh, in the Kangavar valley, the intensity of the shock was probably smaller than the actual damage would indicate. This part of the epicentral region had suffered considerable damage from the Farsinaj earthquake and from its aftershocks a few months earlier, and most of the houses in villages were still unrepaired or in the process of being repaired but not strengthened. The worst-hit area in the Kangavar valley was that of Dehkuhneh. This village had suffered considerable damage in 1957 and although by the time the Firuzabad earthquake occurred new houses had already been built to replace those rendered uninhabitable by the Farsinaj earthquake, repair work on old houses was still going on. The

village was totally destroyed and 2 people were killed and 23 injured. Local inhabitants report that after the earthquake cracks appeared in the ground, running discontinuously from near the village to Kaladeh (corral). These cracks were sometimes 100 metres in length and 5 to 15 centimetres in width and formed steps, in places as many as five indicating that the valley side to the northeast had dropped by as much as one metre.

At the near-by settlement of Aran, damage was less serious; all houses were damaged beyond repair but few collapsed. Also at Ghareh, quite a few houses survived the shock which, from interviews with the inhabitants appears not to have been very strong. At Firuzabad, a few houses which were repaired after the Farsinaj earthquake collapsed and a number of newly built adobe houses had their walls shaken down killing two people. At Gaduk and Soltanabad all houses were shattered but few collapsed. In Aliabad, the damage was less serious; a number of repaired houses, however, were demolished by the shock killing one person. At Kucheh, Tahirabad and Gowdin, more than 50% of the houses were ruined but none collapsed.

To the southeast of the Keriz villages, Khoseynabad was totally destroyed and more than 50% of its houses collapsed killing a large number of cattle, but no lives were lost. Near here the ground slumped and the river banks in places slid into the Gamasiab. At Chulak much of the damage was due to slumping of the ground and the village, though not seriously damaged, was abandoned. The people from Chulak were rehoused together with other refugees in the new village of Dehganabad. The damage at Dehful, a large village on alluvium, was not serious; not more than 30% of the village houses suffered any damage and only two collapsed. At Mahdabad, the damage was small.

To the southeast of Leylan, the village of Chambakut was totally destroyed but no lives were lost. Also, the settlement of Mahinabad was almost totally ruined and the village was rebuilt on the same site. Fashban, Kafradj and Zafarabad were partly destroyed without casualties.

Villages on the Tuisarkan and Malayer rivers suffered varying degrees of damage. On the Tuisarkan, Dehnow Balaki was totally ruined and both Mahmudabad Bala and Pain were destroyed, without casualties. At Karkhaneh Hajjikehrola damage was exceptionally heavy and many animals were killed. On the Malayer river, Vasach was ruined and a few people were injured. At Tihyulam, the shock was much less severe than at Vasach a few kilometres away. About

one third of the village houses were heavily damaged and during the aftershock period a few collapsed. At Malsan the shock caused very little damage.

The region on Kuh-e-Hadjabad, between the Tuisarkan and Malayer rivers was not visited. This region is sparsely inhabited with no perennial settlements. Information from near-by villages suggests that in this region only Qeshlaq was ruined.

Outside the epicentral area, damage was widespread but not serious. At Karkhaneh a few houses that had sustained some damage from earlier shocks collapsed and many new houses suffered minor damage. The shock caused great panic in Kangavar where in a few houses cracks appeared in the walls. The earthquake was particularly strong in Sarab, Aliabad and Bidsorkh where all the houses built after the Farsinaj earthquake were damaged in various degrees. At Sahneh a few newly built houses were ruined but most of the older ones suffered no damage. At Bisitun the shock was very strongly felt; it caused no damage but it affected the yield of a spring of water that was used for irrigation reducing its flux by 80% to a trickle.

The earthquake was very strong at Asadabad where it caused great panic. It was accompanied by noise and one old house collapsed trapping a boy in its ruins. The duration of shaking in Asadabad was abnormally long and the ground motions were so intense that they caused people to walk unsteadily; however, no damage resulted. Also at Buin and Gavanleh, near Asadabad, a few walls cracked and a roof caved in. In the town of Tuisarkan the earthquake caused no damage; nor at Malayer where, however, ground shaking lasted for a very long time causing trees to shake and waves to appear on ponds. In Nehavend, damage was negligible and nothing collapsed except two free-standing walls which were destroyed by one of the aftershocks. Junabad suffered absolutely no damage; however, a few of the aftershocks were felt there more strongly than the main shock, causing great panic but no damage.

The foreshock at 8<sup>h</sup>40<sup>m</sup> p.m. was felt very strongly at Hamadan and caused great concern particularly among the summer residents in the town. The main shock caused consternation and great panic and a few people, who jumped from roofs and windows of upper floors, were injured. Apparently ground motions lasted for more than one minute and caused waves on ponds.

The shock was felt at Qurveh where rafters in houses creaked and windows rattled. At Sanandaj the shock was felt by few people. At

Aveh and Qum it lasted 2 to 3 seconds and it was felt by all. It was also perceptible at Arak where it lasted 5 to 10 seconds. The shock was also felt in a number of villages of the Khumayn-Kashan district; in some of them it caused some panic, and it was perceptible in Burujird and in Shahabad. At Kermanshah, the earthquake lasted only 2 seconds and it was felt by those who were awake at the time. The shock was not felt in Dizful, Dorud, Isfahan, Tehran and Ghazvin.

### 3. - GROUND DEFORMATIONS

The Firuzabad earthquake was associated with what seems to be a discontinuous fault-zone, about 20 kilometres long extending between the villages of Kariz and Barfaragh. Two smaller zones of rather doubtful origin, occurred on the southwest slopes of the Gamasiab valley between Balajub and Razini as well as between Kaladeh and Dehkuhmeh, Figure 3.

The Kariz fault-zone, which for the scale to which Figure 3 has been drawn is shown with a straight line (\*), clearly breaks Quaternary deposits, mainly young terrace materials, and extends, not every where clearly defined, from the bend of the Gamasiab river near Gusheh in the southeast to Barfaragh in the northwest. This zone, to which our attention was drawn by the local people, is a relatively wide belt of closely spaced sub-parallel eroded terraces with the southwest side usually downthrown by a few tens of centimetres. It bears between  $130^{\circ}$  and  $140^{\circ}$ E, and it is particularly conspicuous at Kariz Jamal and Kariz-2. Both villages lie somewhat to the northeast of what seem to be the fracture zone associated with the Firuzabad earthquake, and local people still remember some of the details of surface faulting in this part of the zone. For some of the individual branches of the break within the zone they confirmed throws to the southwest of many tens of centimetres.

This fault zone, clearly extends to the southeast of the Gamasiab river for many tens of kilometres, in places cutting terraces and Recent alluvium. However, we could find no evidence of recent movement along this part of the zone. Northwest of its crossing with the Gamasiab river, in the vicinity of the Leylas (Lilatgar) and Gusheh, many

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(\*) A detailed study of this zone will appear in (2).

small elongated depressions mark a recent fault trace; the road to Kangavar follows a low ridge on the side of the hills for a few kilometres and passes through the Kariz villages. Further to the northwest, sub-parallel ridges follow the road to Firuzabad Bozorg and although several eroded scarps occur on each side of the road, the fault trace is not obvious from the new road. It crosses a number of small drainage systems without any clear indication of lateral motion of the two sides. Near Firuzabad Bozorg the zone widens up and despite the absence of obvious evidence of faulting in some of the most intensely cultivated areas, small elongated depressions mark a lineament bearing  $130^{\circ}\text{E}$ . The villagers of Firuzabad do not remember any large ground displacements occurring after the earthquake; they do recall, however, areas heavily fractured with cracks gaping 5 to 20 centimetres running for 50 to 100 metres discontinuously in a north-south direction. The zone becomes visible again a few kilometres before it reaches Barfaragh; it is heavily eroded in places and not very well preserved. Those who remembered the ground deformations caused by the earthquake in this part of the meizoseismal area do not mention any preferential vertical or horizontal motion of the two sides. They more clearly recall cracks running in strands in a northwest-southeast direction about 400 metres to the southwest of Barfaragh.

Another system of ground ruptures was reported southwest of Razini. Villagers remember ground fractures running from Razini in a southeasterly direction to a point north of Balajub and from there all the way to Mahinabad. In fact a series of linear features such as terrace scarps and narrow closed depressions can be followed from Razini for 4.2 kilometres to the southeast. These features bear  $125^{\circ}\text{E}$  and suggest a predominantly vertical motion with the valley side downthrown. Because of heavy erosion actual displacements are difficult to discern but some of the scarps stand many tens of centimetres high.

Local information suggests that the ground between Razini and Rudbari was also very heavily fractured and that the banks of the Gamasiab river in places slumped.

There is some inconclusive evidence of faulting near Kaladeh. Today, although no single linear feature can be followed for more than a few hundred metres to the northwest of that place, the local physiography does not exclude faulting in 1958 in a general direction  $120^{\circ}\text{E}$ . Further to the northwest, however, in the vicinity of Dehkuhneh, local information about faulting in 1958 is corroborated by a single

strand of linear scarps in alluvium, which although heavily eroded today indicates that the northeast block has been depressed. The amount of vertical motion that allegedly occurred in 1958 was not possible to determine. Local information is confined to statements that the Kharaki-Kuh was "lifted up" and that the ground opened up in the valley and formed steps which could be followed from Du Ab to Kariz.

There is also some evidence that either during the Farsinaj earthquake of 1957 or during the aftershock of the Firuzabad earthquake of the 13th of September 1958, ground deformations, most probably of tectonic origin occurred in the region of Karkasar (<sup>1</sup>). Further field work is needed to substantiate this information.

#### 4. - AFTERSHOCK ACTIVITY

The earthquake was followed by many aftershocks of which at least 30 were of magnitude equal to 4 and smaller than 4.9, and three of magnitude between 5 and 5.5. Of these, 11 were recorded by a sufficiently large number of stations to allow relatively accurate determination of epicentres. Table 1 lists all aftershocks for which sufficient information has been found.

The aftershocks of the 17th of August, at 7<sup>h</sup>20<sup>m</sup> a.m. local time seems to have caused additional damage to villages in the Kangavar valley and it was followed by a long series of minor shocks which alarmed the population. At Kangavar a few houses damaged by the main shock developed new cracks and at Karkhaneh two newly built houses which had survived the main shocks, were ruined.

In the evening of the 19th of August, at 3<sup>h</sup>30<sup>m</sup> local time, another violent aftershock caused the collapse of many ruined houses in the region of Firuzabad Bozorg, particularly at Akbarabad and Asadabad (?), killing a few people. The shock was felt over a large area and in Kangavar it caused great panic.

Aftershocks were being felt throughout the region. On the 3rd of September at dawn, another strong shock followed by many smaller ones, was felt throughout the meizoseismal area. It was particularly strong in the region of Kuche where it caused serious damage.

On the 10th of September, early in the morning, another earthquake at Barfaragh caused some damage with no loss of life. It was felt strongly to the east of the village and it caused some concern in Nehavend.

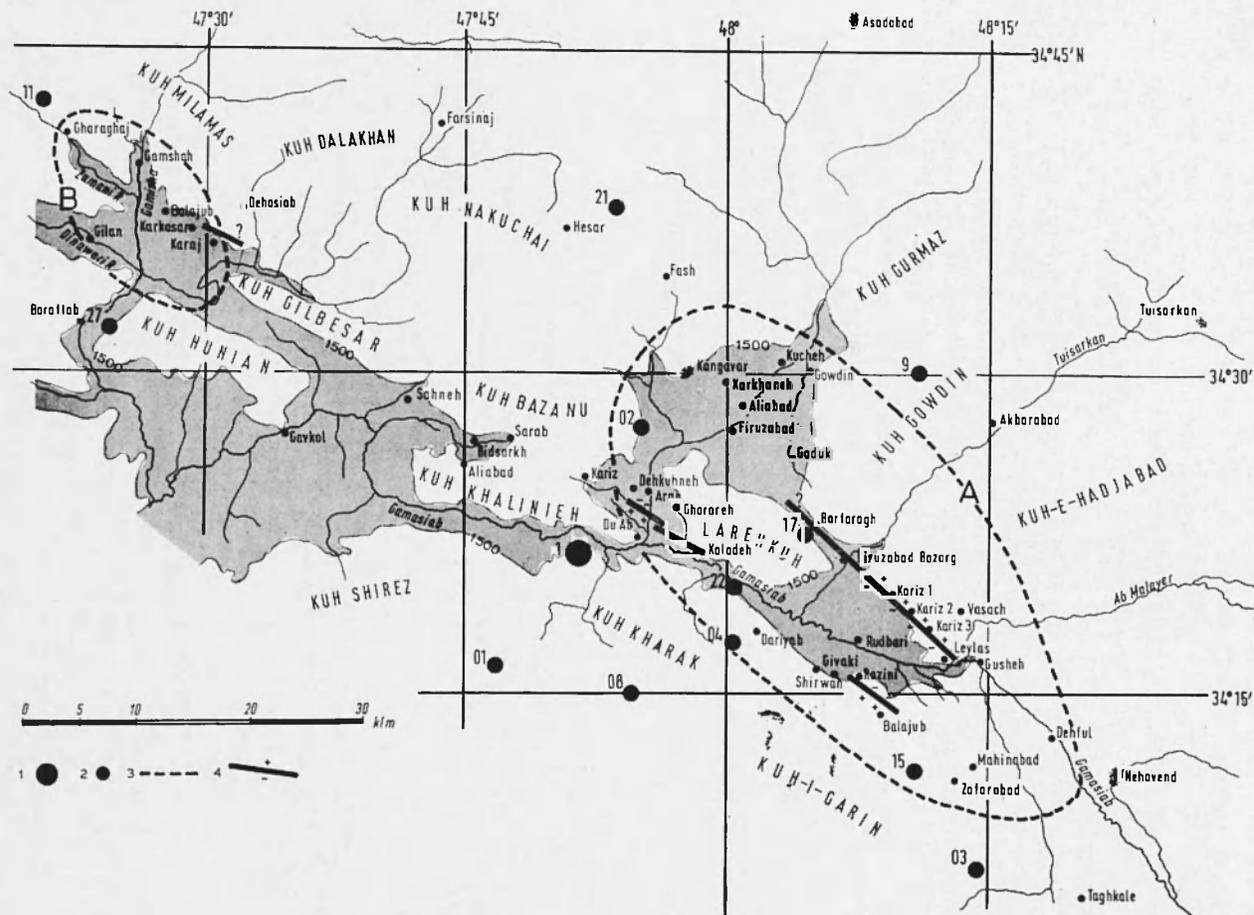


Fig. 3 - Dashed line shows meizoseismal Area: A of main shock, B of aftershock of 21st September 1958. 1 - epicentre of main shock; 2 - epicentres of aftershocks; 3 - damage limits; 4 - fault-zone and of other linear ground deformations. Shading indicates altitude below 1500 metres.

In the days that followed, shocks decreased both in number and intensity. On the 21st of September at noon, however, violent shocks were reported from the region of Dinawar which lies to the northwest of the meizoseismal area of the Farsinaj earthquake of 1957. At Karkasar a few houses cracked and at Karaj one house was ruined and many others suffered some damage. The shock was strongly felt at Kermanshah where it lasted a few seconds.

A few hours later in the evening, a violent shock of magnitude 5.2 ruined seven villages in the region of Dinawar. The villages of Karkasar, Karaj, Balajub, Gamshah, and Kolehjub were ruined and 16 people were killed. The shock was particularly violent at Karkasar and Karaj where 57 people were injured, Figures 2 and 4. Damage extended over an area of at least 100 square kilometres which is shown in Figure 4 (region B2). Some of these villages which apparently had been damaged by the Farsinaj earthquake and by its aftershocks sustained additional and much more serious damage from the aftershock of the 21st of September, 1958. However, details about this case of cumulative damage were impossible to disentangle from interviews with the local people sixteen years after the earthquake.

##### 5. - DISTRIBUTION OF DAMAGE

The Firuzabad earthquake was felt over an area of about 80,000 square kilometres, a felt area exceeded only by the Farsinaj earthquake in the same vicinity which was felt within an area of 180,000 square kilometres.

The intensity map shown in Figure 1 was prepared from a comparatively small number of press reports; no intensity questionnaire cards were in use in Iran at that time. The lower intensity isoseismal in this Figure is, therefore, only approximate.

The earthquake was characterised by a relatively large intensity VII meizoseismal area (Figure 4 area A). Within this area it is very likely that intensities in small pockets reached IX (MM). However, it was not possible to assess actual intensity grades and their distribution above  $I_0 = VII$ . The reason for this is that in the meizoseismal region only adobe houses were available for observation. These types of houses with their widely different inherent resistance to earthquake shocks, will disintegrate when intensity exceeds VI or VII (MM) leaving no evidence in the ruins for the assessment of higher intensities. Also, in

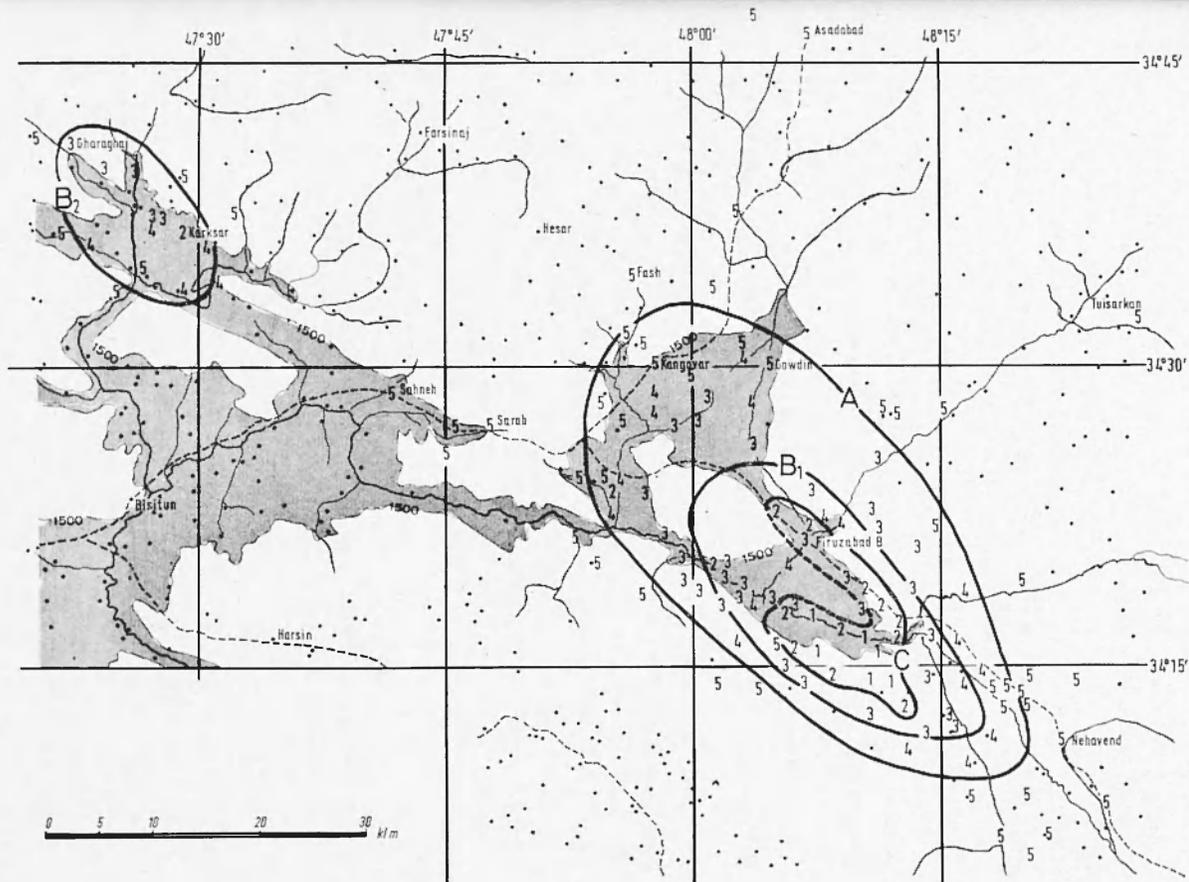


Fig. 4 - Damage map. Numerals show location of affected sites and degree of damage. 1 - 100% of adobe houses destroyed or damaged beyond repair with more than 5% of inhabitants killed. 2 - 100% destruction with less than 5% of the population killed or injured. 3 - 100% of adobe houses damaged beyond repair or destroyed without fatalities. 4 - 50% to 99% of adobe houses destroyed or damaged beyond repair no casualties. 5 - Damage less than 50% without casualties. Area marked **A** more than 50% of adobe houses ruined; **B** all adobe houses destroyed, ruined or abandoned with small loss of life; **C** total destruction with loss of life. **B2** region affected by the aftershock of 21st September 1958. Shading indicates land below 1500 metres above sea level. Thin dashed line, main road

the northwestern part of the meizoseismal area intensities that could be deduced from damage would have been misleading. This part of the affected area had already suffered serious damage from the Farsinaj earthquake and its aftershocks six months earlier and most of the houses had already been weakened. Houses which apparently had been damaged in 1957 sustained additional damage and many of them collapsed in 1958. Also newly built adobe houses and mud huts with their clay walls and roofs still moist, collapsed as far as Sahneh. Therefore, in this part of the meizoseismal area the apparent high intensity cannot be taken at face value.

Within the meizoseismal area damage was most serious along the fault-zone between Leylas and Barfaragh as well as in the Gamasiab valley in the region of Rudbari and Razini. Elsewhere, pockets of severe damage could be associated with local geology with the exception of the area near Dehkuneh where some of this could be associated with damage caused by the 1957 earthquake and with the effect of ground ruptures.

Figure 4 shows the distribution of damage within the meizoseismal area. Within zone C, not only was destruction total with heavy loss of life but ground movements were so violent that people were either unable to stand or they were thrown down, ground deformations occurred in this zone. Within zone B1 all houses were destroyed or damaged beyond repair and the old bridge of Hajji Alimurat was slightly damaged.

In the Gamasiab valley, particularly near the river on soft alluvium, many villages destroyed by the earthquake were left with shattered but standing walls. In contrast, along the road to Kangavar, in the Lelekan villages and further on to the northwest on compact alluvium, not a single wall was left standing.

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