Distribution: limited

FR/RP/CONSULTANTS

---

turkey

The Mudurnu Valley (West Anatolia) Earthquake

of 22 July 1967

by N.N. Ambraseys
A. Zátopek
M. Taşdemiroğlu
A. Aytun

Serial No.622/BMS.RD/AVS
Paris, June 1968

unesco

SUMMARY

A severe earthquake in the west-central part of the Anatolian fault zone occurred on 22 July 1967, causing loss of life and widespread damage. A reconnaissance mission to the area immediately after the earthquake was sent by Unesco at the request of the Turkish Government. This paper gives a summary of the findings of the mission. The earthquake was associated with 80 kilometres of fresh faulting, part of which occurred in a zone ruptured ten years earlier. The sense of movement along the fault-break is right lateral with the north side downthrown. Maximum relative displacements of 190 centimetres lateral and 120 centimetres vertical were measured. Damage caused by shaking in the immediate vicinity of the fault-break was equal to or smaller than that caused at some distance from the fault. Proximity to the fault-break was found to be an unjustified criterion for higher intensities. The instrumental epicentre of the main shock had been located near the east end of the fault-break. The bulk of the aftershocks is concentrated at the other end of the break, in the extreme west.

Serial No. 622

PREFACE

The earthquake of the Mudurnu Valley of 22 July 1967 is but the most recent shock of a series that since 1939 has devastated Anatolia. This earthquake occurred at the west-central part of the Anatolian fault zone, not far from where an earlier shock occurred in 1957. The 1967 earthquake had a magnitude of 7.1 and it was associated with fresh faulting over a length of 80 kilometres overlapping the fault zone which was associated with the 1957 earthquake. It killed 86 and wounded 332 people, destroying over 5,000 houses.

At the request of the Turkish Government, Unesco sent to the earthquake region a reconnaissance mission of two persons (N.N. Ambraseys and A. Zátopek), The Ministry of Housing and Reconstruction detached two members of its staff (M. Taşdemiroglu and A. Aytun) to work with this mission. The main objectives of this mission were to make a preliminary study of the seismological and engineering aspects of the earthquake and to examine, in consultation with the Turkish authorities, what further action should be taken on a long-term basis to improve knowledge of the seismic conditions of the country and of the means of protection against earthquakes.

This report gives a summary of the results of a preliminary study of the effects of the Mudurnu Valley Earthquake on man-made structures and on the ground itself. The first part of this report gives the setting of the Mudurnu epicentral region within the Anatolian fault zone. The main features of the zone are briefly described and an outline of the seismotectonics of the Mudurnu Valley is presented. The second part of the report deals with the Mudurnu Valley earthquake itself, with its geological effects and damage to man-made structures in the fault zone, and with results of quantitative measurements.

Serial No. 622

TABLE OF CONTENTS

Serial No. 622

The Anatolian fault zone

Between 1909 and 1967, thirty earthquakes of magnitude equal to or greater than 6 occurred in the Anatolian fault zone which is shown in Figure 1. Of these earthquakes, at least nine are known to have been associated with faulting; each new rupture, in most cases, overlapping or beginning where faulting had ended in the previous earthquake. The total length of the ruptured zone is more than 1,000 kilometres, extending from the coast of Asia Minor to Lake Van. Two segments of the zone, 150 and 100 kilometres long, near Bursa and Tercan respectively, remain unfractured. Perhaps faulting here was accommodated within a wide zone and has escaped notice. Figure 1 shows the trend and sequence of the successive faulting after 1938.

The question of whether similar ruptures have occurred in the zone prior to 1938, is difficult to answer; but it would seem very singular if they have not occurred. Historical data do show that the seismicity of the fault zone in early times was as high as today, and there is some evidence to show that faulting might have occurred as early as in the 6th Century A.D., (see Table 2). Figure 1 shows the probable location of these early fault breaks which almost coincide with the fault zone and also suggest a probable branch of the zone towards Kastamonu.

In constructing Figure 1, each large earthquake in the fault zone was studied separately, making use of all published and of some unpublished data(1). When faulting was involved, the fault-trace was redrawn from published data on a scale 1:100,000 and then reduced to the scale of Figure 1. In the course of our work we became aware of the scantiness and incompleteness of the information that can be found on the Anatolian fault-breaks. Incomplete mapping of the fault-trace and the lack of geographic control is indeed serious. The length and location of the fault-trace for the various instances of faulting is not always certain. Different authors give different lengths, sometimes varying by as much as 40 per cent. The actual limits of faulting for each case are difficult to establish as overlapping with the preceding fault zone and the lack of detailed mapping obscure the ends of the ruptures. Relative movements have been reported at very few points, mostly where the trace crosses a village or a main road. The following list shows the small number of observations for which relative displacements were established for the various cases of faulting:

1939 26 Dec. 350 km of faulting, measurement points: 3
1942 20 Dec. 70 " " " : 2
1943 26 Nov. 270 " " " : 4
1944 1 Feb. 190 " " " : 2
1951 13 Aug. 40 " " " : 0
1953 18 Mar. 58 " " " : 5
1957 26 May 40 " " " : 1

Usually, the sense of movement is given at a larger number of places, but their exact location on the trace is rarely indicated precisely. Different authors, morever, give values for the observed relative displacements which differ for the same locality by as much as 50 per cent. For the case of faulting associated

---

(1) The authors are indebted to Professors H. Pamir and N. Öçal for most valuable information concerning unpublished data on fault-breaks prior to 1958.

with the 1943 earthquake Blumenthal (1945b), for instance, says that strike-slip movements could not be discerned with certainty; Pamir (1948) indicates that there were some strike-slip movements but quotes no values, while Ketin (1957) gives a displacement of 100 centimetres without specifying its exact location on the trace.

Nevertheless, the observed sense of major fault movements in the Anatolian fault zone is consistently right lateral. Individual horizontal displacements quoted by various authors differ, but on the average their magnitude decreases from east to west, becoming practically zero in the central "hump" of the zone between the 36th and 34th meridians, and increasing again west of the 34th meridian. Vertical displacements vary rather erratically, but on the average they seem to decrease from east to west, showing mostly a throw facing north.

Table 1 gives a summary of the main features of the larger earthquakes and of the fault-breaks which are associated with them. The sequence of these shocks is shown in Figure 1 by the numbers attached to their epicentres which correspond to the entries in Table 1.

It is beyond the scope of this field report to describe the faulting associated with the Anatolian zone and its seismotectonic implications. It is not, however, out of place to mention here briefly some general features of the tectonics of Anatolia and to discuss some of the characteristics of the fault-breaks of the zone.

Orogenically, Anatolia developed in different geological periods and it may be conveniently divided into at least four tectonic units (Ketin 1964, 1966). Starting from the north, the orogenic evolution proceeded gradually south with the raising in early Mesozoic of the Pontid unit. This is the only unit that shows signs of pre-Alpine orogenic movements, Caledonian as well as Hercynian, and exhibits the oldest rocks in Anatolia which are Cambrian and pre-Cambrian (Tokay 1952, Abdusselamoglu 1959, Ketin 1959). In the late Mesozoic, the Anatolids began to rise, followed by the Taurids in late Oligocene. The fourth unit, the Border Folds which form the foredeep of the Alpine geosyncline to the south, developed during the Pliocene.

The Anatolian fault zone lies partly in the Pontids and partly in the Anatolids, and only at its extreme east end does it seem to cross into the Taurids. Unquestionably, Tromp's statement that the Anatolian fault zone is the boundary between the Pontids and the Anatolids, is untenable (Tromp 1947). There seems to be no connexion between the Anatolian fault zone as a whole and the folded structures of the Alpine period. Centres of young volcanism, thermal springs, Alpine folds and ancient massifs are found compressed in the zone. It appears that the Anatolian fault zone is a belt a few kilometres wide, of shear weaknesses restrained in places, rather than a single fracture. The age of the zone can only be inferred; in places, faults disappear under Cretaceous flysch showing pre-Alpine age, while in other places the faults may have been present in Palaeozoic time. Physiographic features of Quaternary faulting abound.

Ground ruptures associated with earthquakes after 1938 are discontinuous. The largest and most uninterrupted of them seldom exceeds 5 kilometres in length and they rarely coincide with mapped geological faults, folded structures or with the relief (see for instance Ketin-Roesli 1953). They usually form a rather complex pattern which is confined within the zone, a kilometre or two wide. In places the new trace, after following a mapped fault for a while, changes from one side of the zone to the other. In many cases new ruptures consist of a series of short segments which step sideways erratically and which are interconnected with small graben and horst features. Many of these features have been published in small scale maps and consequently irregularities have been smoothed out. Tensional and compressional features vary in frequency and magnitude along the fault zone and have never been clearly shown on maps.

It is questionable whether a single mechanism should apply to the whole length of the fault zone. The west half of it may be connected with the intense differential uplifting of the Pontids during late Cretaceous. There is some evidence that in the Malm and the Cretaceous, the north part of the Pontids was involved in a slow sagging and that it was upheaved in early Paleocene. The southern part of the Pontids, however, kept on sagging up to the end of the Paleocene after which it was uplifted intensively (Kirillova 1960). This suggests that along the central part of the zone, along the "hump", large vertical displacements should be expected. It is of interest to note here that it is along this part of the zone that recent fault movements, mentioned earlier, showed only vertical or at the most, negligible horizontal displacements. On either side of the "hump", minor thrust and normal faults within the zone show up topographically in the form of depressions (ova), sag-ponds and young scarps. The general impression gained from the study of the available field reports on the Anatolian fault zone is that a considerable amount of tension (normal faulting) must be involved in the mechanism of deformation within the zone.

Outline of the seismotectonics of the Mudurnu Valley

The insert in Figure 1 shows the location of the epicentral region of the Mudurnu earthquake with respect to the Anatolian fault zone. This region occupies the west-central part of the zone and lies on the westward extension of the area affected by the earthquake of 26 May 1957. The faulting associated with the Mudurnu earthquake overlaps part of the 1957 rupture zone and extends for another 50 kilometres to the west.

The epicentral region of the 1967 earthquake comprises the valley of Adapazari-Sakarya and the Almacik mountains to the north; to the south it comprises the Karadag mountain, the Susuz Plateau and the Komur range up to the Seymon mountain, with the Mudurnu, Elmacic and Balaca valleys in the middle. The highest point of the Almacik mountain which borders the rupture zone on the north for three-quarters of its length, is about 1,500 metres above the Mudurnu valley. To the south, the valley is hemmed in by a series of irregular peaks of the Susuz plateau rising to 1,400 metres. The Karadag mountain is more subdued than its eastern neighbours, rising to just over 1,000 metres over the valleys to the north (Figure 2).

The geology of the eastern part of the epicentral area has been treated by Abdusselamoglu (1959) who has also published a small scale geologic map of the area. Unpublished geologic maps of a scale 1:200,000 and 1:100,000 are available for this region at the Maden Tetkik ve Arama Enstitusu in Ankara. A number of authors have discussed the general geology and tectonics of the region and these authors are listed by Ketin (1964, 1966b) and Erentoz (1966).

The available literature and personal observations of the writers lead to the following generalizations concerning the geologic environment of the Mudurnu earthquake. The Mudurnu epicentral area constitutes a structural block of the Pontids made up of crystalline metamorphics, mostly diorites, micaschists, gneiss and amphibolites (Figure 3). The crystalline series form the basement of the region which has been dissected on either side of the fault zone by two subparallel faults which lie outside the area of Figure 3. For about half of its length these series border the fault zone on the north and for the other half they border it on the south; they outcrop in the fault zone as well.

Silurian-Devonian argillaceous schists and limestones are the oldest fossiliferous formations in the region. They occur on the eastern part of the fault zone, lying discordantly on the crystalline series. They do not occur elsewhere in the immediate vicinity of the zone, but further away they are overlain discordantly by Upper Cretaceous flysch. This, together with the fact that the associated Jurassics are transgressive on the metamorphics suggest that the Devonian rocks have been affected by Hercynian movements.

The Permo-Carboniferous rocks, mostly limestones, are not found in their stratigraphic place. They occur in blocks of various sizes and they have not been mapped. An "exotic" block, of dark-coloured limestone, occurs within the fault zone, south of Caykoy.

The Jurassic rocks, mostly a volcanic tuff series, lie unconformably on the crystalline series. They abound on the east part of the fault zone where they cap the flanks of the Mudurnu hills. They are separated from younger rocks to the north by a long fault that can be traced from Harmanseki to south-west of Yenikoy. Elsewhere the Jurassic consists of flysch facies which turn gradually into Lower Cretaceous limestones.

Lower Cretaceous limestones cover a large part of the region. Within the immediate vicinity of the fault zone they occur on the south side of the Mudurnu valley as well as within the zone itself. Here, they are found dissected by young faults, and limestone breccia occurs east of Yarbasi. These limestones are smoothly stratified and turn gradually into Upper Cretaceous flysch. These facies consist of marls, sandstones, conglomerates and sometimes of limestone, lying in places unconformably on Devonian rocks. They occur also in the fault zone, and south of Igneciler, at Seymen, they are found overlain by the crystalline series (Abdusselamoglu 1959).

Eocene flysch is found mostly on the west part of the zone lying unconformably on Upper Cretaceous flysch. Near Mansular, Eocene rocks border the fault trace for some distance but they show no signs of recent movement.

The Pliocene rocks consist of marls, weakly cemented sandstones and hard clays. They occur on the southern border of the Adapazari valley and they cover large parts of the Karadag mountain. Also they are found, though discontinuously within the fault zone, from Gunay to Yarbasi, forming the floor of small grabens. Pliocene marls have been exposed by the 1967 fault movements near Caykoy. At this point they appear stratified subhorizontally dipping to the north, lying discordantly on older facies.

The alluvium consists mostly of gravel and silty sands. The fault zone is not covered with alluvium along its whole length nor is the alluvium, where found, of great depth. The bedrock, mostly volcanic and crystalline rocks, occurs at or near the surface. Between Derekoy and Mansular and on the north side of the zone, the alluvium is in direct contact with the metamorphics. Outside the zone, in the Adapazari valley, a depression about 50 to 80 metres above sea level, the alluvium consists of Pliocene and Quaternary sediments of great thickness. A borehole at Carksuyu, near Adapazari, failed to reach bedrock at 103 metres.

Slope debris, derived mostly from Lower Cretaceous limestones, covers the central part of the zone. In places it is partly cemented and forms on steep slopes.

Acid and basic eruptions occurred in the Plaeozoic, Mesozoic and Tertiary times. Intrusives (granites, syenites, diorites, pyroxenes and particularly serpentines) outcrop on either side of the fault zone as well as within it. Extrusives do not show a great variety. Andesites are younger than Upper Cretaceous and older than Eocene and they outcrop within the fault zone, where they have been cut by recent fault movements.

The rupture zone associated with the Mudurnu earthquake starts from the Seymen region and follows the valleys of the Elmacik and Balaca rivers (Figure 3). It then continues along the Mudurnu valley, in a curving trend, to the west-north-west. South of Akyazi the trace leaves the Mudurnu valley and continues west, through the Karadag mountain, reaching the Balaban defile in a series of discontinuous breaks. It is probable that the trace bifurcates and that a north-west trending branch cuts across the Sapanca Lake. We were unable to establish this latter branch beyond doubt.

From an altitude of over 800 metres near Seymen, the fault zone descends to 170 metres in the west part of the Mudurnu valley and to only 35 metres near Sapanca.

For about three quarters of its length, from Seymen to south of Akyazi, the trace follows a recognized rupture zone with distinctive features of very recent faulting, typical of the Anatolian fault zone, i.e. narrow valleys with comparatively steep-sided spurs which,however,do not overlap, scarps, young terrace walls, sag-ponds and grabens, with the river flowing close by the north wall of the valleys (Figures 4 and 5). South of Akyazi, the 1967 fault-break crosses the Mudurnu river for the ninth time and continues west in the Karadag mountain where no known faults are plotted on existing geologic maps.

The Sapanca Lake, the valleys of Adapazari-Duzce and smaller valleys in the fault zone are in fact grabens filled with Tertiary deposits. To these grabens one should add the Izmit Bay further west, from where the Devonian sea of Istanbul extended through the Adapazari region to the Mudurnu valley.

From Figure 3 we notice that to the north the fault zone is bounded by crystalline series and Devonian formations which from a block that has been affected by Caledonian and Hercynian orogenic movements. To the south, much younger rocks border the zone, the oldest of them being of Jurassic age. Here Jurassic and Cretaceous rocks are flexured with a strike parallel to the zone, the Jurassic rocks lying unconformably on the crystalline basement, but with no indication that pre-Alpine movements have affected these formations. The fact, however, that the Tertiaries are discordant on Mesozoic rocks suggests that these formations were involved in the Laramide orogeny. Between these two "blocks" the fault zone appears as a gigantic shear zone varying in width from a few tens of metres to 3 kilometres, containing rocks of all sizes and ages, except Devonian. Figure 6 shows the position of the most continuous fault-breaks of 1967 with respect to the fault zone. This figure supplements Figure 3, giving the location of the villages mentioned in the text and of the points where the fault trace cuts through rock. From this figure it is obvious that the 1967 trace, although related to the fault zone, hardly coincides with, and even less follows, mapped geological faults. The pattern of faulting in the zone appears to be generally related to comparatively small scale joints, shear zones, planes of weakness and points of kinematic restrain within the fault zone, rather than to mapped faults. It passes through metamorphic rocks at points 66Mi and 65 M, cuts through Lower and Upper Cretaceous rocks at 49K, 102K, 22JK, 33k, 47k, through massive granites at 54g, andesites at 54a and 01a, and serpentines at 33S and near Guney. None of these points belongs to faults that could have been mapped on the ground surface before the earthquake.

Seismicity of West-Central Anatolia

The history of earlier earthquakes in this region is imperfectly known. For the last 2,000 years the main route from Istanbul to the East lying west of the Almacikdagi, passed through the Balaban defile south to Geyve, following the course of the Sakarya river, thus leaving the Mudurnu region to the east. The Mudurnu valley itself is a cul-de-sac and has always been sparsely settled. The largest and most populous centres of culture in the region, i.e. Iznik, Bursa, Izmit and particularly Istanbul furnish most of the data about early earthquakes in the region and the seismicity of the whole region appears to be concentrated around these cities. During the last 1,900 years there have been 250 earthquakes reported as having occurred around Istanbul, 50 earthquakes around Bursa, 25 in Izmit and 12 at Iznik. These events are not all real, nor do they refer to the actual localities where the earthquakes had in fact occurred. An unmodified use of the existing seismic data would lead to the absurd conclusion that the most seismic area in Anatolia is Istanbul.

Tables 2 and 3 give a list of all recorded shocks prior to 1800 within the region comprising 40°to 41° North and 29° to 32° East but excluding the Istanbul area (Figure 7). During this early period, only large and widely-felt earthquakes were recorded in histroy; smaller events were occasionally recorded, mostly in Istanbul. In other places, these shocks were either never recorded or if they were, the records are now lost. For the period prior to 1450, Table 2 is quite complete. It contains about 40 per cent fewer entries than other catalogues for the same region (Hoff 1841, Perrey 1843-1871, Mallet 1850, Fuchs 1856, Schmidt 1879, O'Reilly 1885, Weismantel 1891, Sieberg 1932, Pinar 1952, Ocal 1961, Ergin 1967) but the entries missing from Table 2 are events which were merely non-existent. The seismologists, who have often had to use literary sources of that period at second or third hand, have not been able to study early accounts critically, with the result that on many occasions the same event, being described differently by various sources, appears in their catalogues as two or even more earthquakes. In compiling data prior to 1450, N.N. Ambraseys resorted to the original sources of information and he avoided using any modern works; he believes that new entries for this period will depend entirely on the discovery of new historical authorities.

For the period 1450 to 1850 the data show large chronolcgical gaps (Table 3). This is perhaps mainly due to the fact that most of the recorded history of the region was read from European and Arabic sources, while useful information in early Turkish sources has so far not been detected. On the other hand, the larger number of events recorded after 1850 is due to the larger number of European documents, press reports and studies that can be found in the literature. Figure 7 shows the location of most places mentioned in these Tables and of the epicentres (micro- and macroseismic) determined for events after 1900.

The seismic history of the region is neither complete nor homogeneous. There is a serious lack of macroseismic information and also an appreciable number of obvious gaps. Conflicting information and non-uniform determinations of intensities, for the later events, make the study of the seismicity of west-central Anatolia very difficult. The author has come to the conclusion that the intensity of past earthquakes in the region has been grossly over-estimated and that any statistical treatment of the available data would lead to erroneous conclusions.

Figure 7 shows the location of epicentres based on the data given in Table 4. From this figure it appears that the epicentres of the largest shocks follow the Anatolian fault zone, but the accuracy of their location is in most cases so low that no detailed study of their relation with local tectonics is warranted. It seems, however, that the relatively quiescent western part of the zone in Figure 7 has been active 100 years ago and that the zone Esme-Izmit-Karamursel-Yalova has been active over 1,000 years ago.

The earliest known major earthquake in the vicinity of the epicentral area of the Mudurnu earthquake of 1967 occurred in May 192 A.D. It affected the region between Izmit and Mudurnu, particularly the Sakarya valley. In 536, an earthquake in Pompeiopolis, in Mysia, caused great damage. The ground opened up, cutting through the town and destroying half of it together with the country around it. The location of Pompeiopolis is difficult to determine. There was one Pompeiopolis in Mysia, west of modern Bursa which has not been identified, and another in Moisia Prima situated about 35 kilometres north of modern Nis in Jugoslavia (Stein 1949). Another Pompeiopolis has been identified 40 kilometres north-east of Kastamonu near modern Taskopru but this would be in Paphlagonia rather than Mysia.

In the night of 2 September, 967 an earthquake devastated the region between Bolu and Cerkes, particularly Claudiopolis in Paphlagonia which can be identified as the modern Eskihisar, 5 kilometres east of Bolu, and the region of Honorias which comprised the country between Gerede and Cerkes.

On 3 May 1035, the army province of Voukellarioi was destroyed by an earthquake together with five villages in the Meriandini region. At Voukellarioi the ground opened up and many people were killed. This settlement has been identified as the region occupied by modern Hamamli and Bayindir on the river Gerede, 40 kilometres east-north-east of the town of Gerede (Ramsay 1890, Tomaschek 1891).

On 18 July, 1668 another earthquake which was followed by many strong aftershocks devastated the same region. Bolu was again damaged as well as Gerede and Kastamonu. Many other localities are reported as destroyed, but their location is very difficult to identify today. Some of them belong to the region of Konya where presumably there was another earthquake during the same period. Bolu was damaged again on 24 November, 1863.

On 19 April, 1878 an earthquake caused heavy damage in the region of modern Adapazari extending as far west as Izmit, killing many people and destroying completely the villages of Sapanca and Esme.

The earthquake of 10 July, 1894 is usually referred to as the "great earthquake of Istanbul". Numerous accounts of this earthquake have been found (Nature 1894, p.273, 581; Davison 1896; Moureaux 1895; Duck 1904; Eginitis 1894a, Press reports). The best known of these reports is by Eginitis (1894b) who visited the coasts of the damaged area. In his report, Eginitis indicates that the damage was equally severe in all places along the coast from Istanbul to Adapazari. He fails, however, to describe the damage east of Pendik, a region which apparently he never visited. Should he have done so he could not have omitted to mention the damage at Geyve, Esme, Sapanca and in Adapazari. At Adapazari for instance, at the time a small town of only 4,000 houses, 836 collapsed killing 60 people and over 3,000 houses were damaged. In Geyve the damage was equally heavy while other villages in the Sakarya valley were partly destroyed (Dybowski 1894; Press reports 1894). From the evidence available now it seems that the 1894 earthquake originated in the depression connected with the Adapazari-Sapanca-Izmit fault zone rather than with the Marmara depression. The reason for which Eginitis failed to observe this fact is alluded to by Dybowski (1894). Without going into details, it may be concluded that the 1894 earthquake originated not far from the epicentral area of the Mudurnu earthquake of 1967 (Sieberg 1932).

During the year 1897 numerous earthquakes occurred between Yenisehir, Osmaneli and Bilecik causing some damage. In October 1902 more shocks were felt in Bolu causing slight damage. During 1935 a number of shocks were felt in Adapazari.

The Cerkes-Gerede-Bolu earthquake of 1 February, 1944, killed about 5,000 people and destroyed over 50,000 houses. It extended along the Anatolian fault zone, within a narrow belt about 190 kilometres long, (Tasman 1944, Pamir 1948, Ketin 1948). This earthquake was associated with a fault-break which began near Bayramoren and terminated near Lake Abant west-southwest of Bolu.

On 20 June, 1943, following foreshocks during the previous night, a severe earthquake shook the Adapazari-Sapanca-Izmit depression. The epicentre of this earthquake was near Adapazari where most of the buildings were wholly or partly wrecked. Arifiye, Geyve, and Hendek were damaged. In Istanbul a few walls collapsed causing general panic. It is believed that over 300 people lost their lives in the Adapazari-Arifiye region. Throughout the year, numerous damaging aftershocks were felt in Arifiye and in Karapurcek.

On 10 February, 1944, a strong earthquake caused some damage in the region between Bolu and Duzce. Soon after, on 15 February, a second shock in Duzce killed 80 people and destroyed 3,000 houses. On 11 March, a strong aftershock killed 700 people near Gerede and destroyed over 5,000 houses. Another strong aftershock on 5 April, at the extreme western end of the 1944 fault-break, caused the deaths of 30 people and the damage of over 900 houses in the region between Akyokus and Mudurnu. Strong aftershocks persisted throughout 1944 and 1945, causing additional damage to the westernmost part of the epicentral region of the 1944 earthquake.

During the following ten years, numerous shocks were felt, mostly in the region of Adapazari, Geyve and Izmit; a shock on 21 November, 1952 caused some material damage at Arifiye.

Thirteen years after the earthquake of 1944 and ten years before the Mudurnu earthquake of 1967, on 26 May, 1957, a strong shock of magnitude 7.1 occurred on the westward extension of the 1944 fault-break. The epicentral area of this earthquake lies in the Anatolian fault zone, in a narrow belt that trends almost westward on the extension of the rupture zone associated with the Cerkes-Gerede-Bolu earthquake of 1 February 1944. The 1957 earthquake was also associated with extensive faulting which presumably began where faulting had ended in 1944. The rupture passes north of Lake Abant and extends in the Mudurnu valley terminating somewhere near Dokurcun, adding thus to the Anatolian zone about 40 kilometres of fresh faulting.

The mechanism of the main shock of the earthquake of 1957 was studied by Öçal (1961b), Sobouti (1963), Constantinescu (1965), Canitez (1967), Sirokova (1967), and their solutions are consistent with the observed right lateral strike-slip movement of the main shock. At the Observatory of Kandilli, the polarity of the first motion was consistent with the observed sense of fault movement, i.e. negative, and the (S-P) time interval calculated from the location of the epicentre is about 22 seconds. Records from Kandilli show that there were at least several hundred shocks in the first twenty-four hours, two of which at 08h54m and 09h36m had a magnitude of 5.6 and 6.0 respectively. In the following four months, over 2,000 aftershocks were recorded at Kandilli together with two additional large aftershocks, on 27 May at 11h01m and on 21 September at 20h16m which showed magnitudes of 6.3 and 5.7 respectively.

In contrast with the initial dilatation of the main shock observed at Kandilli, the four larger aftershocks and 65 per cent of the total number of the aftershocks for which polarity could be established, showed compression. Since Kandilli is 30° N of the fault strike, this calls for a considerable change in the aftershock mechanism. There is no field evidence that the right lateral strikeslip movements of the main shock were followed by a reverse movement during the aftershocks, but the study of the mechanism of the larger aftershocks does show to some extent a change in the mechanism (Canitez 1967).

Following the main shock, the readjustment of strain progressed slowly westwards. A sequence study of over 1,000 aftershocks carried out by the writers shows that (S-P) time intervals from Kandilli did not fluctuate between extreme values but rather decreased gradually with time, suggesting a slow migration of the source westwards into the Mudurnu area. Figure 8 shows the frequency distribution of the Kandilli (S-P) time intervals at six different stages of the aftershock sequence. It can be seen that the largest number of aftershocks originated west of the epicentre and that they migrated westwards, at the same time spreading over a length of over 100 kilometres along the fault zone, overlapping by more than 50 per cent the zone that was ruptured ten years later, in 1967.

Shortly after the earthquake, a team from the Seismological Observatory of Kandilli, led by Dr. Öçal, visited the epicentral area, and later a report was published (Öçal 1959). This is the only field record of the Abant earthquake that we could find. A quotation in English of the parts in the report dealing with ground deformations is given in the Appendix.

With the exception of one point on the fault-break, just north of Lake Abant mentioned by Ocal which was located by Abdusselamoglu (1959), the rest of the 1957 rupture has not been mapped. Figure 9, which is reproduced here by courtesy of Dr. Oçal, shows the trend of the fault-break as depicted by the Kandilli mission of 1957. It shows, in very general terms, one discontinuous trace which, after crossing the Seymendere drainage divide, follows the north slope of the Balaca River, passing north of Tekfurlar, Karacomak, Madenpasalar, Old Arpaseki, and reappearing north of Caylar in the Mudurnu valley. From the text that accompanies this figure, translated in the Appendix, it is not at all clear whether the course of this trace has been established on the ground or whether it has been inferred from the distribution of severe damage in this part of the epicentral area. One more trace is alluded to in the text as passing through Igneciler, Sclfular, Yegendere and Ortakoy, north of and parallel with the trace shown in Figure 9. This trace is not shown in Figure 9, but during our field trip we established a few points of the 1957 rupture that suggest the existence of a northern fault-break. These points, however, are far between and indicate a rather complicated rupture pattern.

Thus, the information so far collected indicates that the 1957 earthquake has been associated with faulting which extended from somewhere east-north-east of Lake Abant to near Dokorcun, a distance of about 40 kilometres, and that the movements on this rupture were right-lateral of at least 160 centimetres. As for the exact location of this rupture, little or nothing can be established with certainty.

Exact information on the extent of damage caused by the Abant earthquake is lacking. The earthquake killed 52 and wounded 100 persons, destroying or damaging beyond repair about 5,000 houses. The villages of Caylar, Dutlar, Haydarlar, Madenler, Arpaseki, Madenpasalar and Karacomak were heavily damaged, particularly the three latter localities where all timber frame houses collapsed. These villages are situated within the rupture zone of 1967; they had been rebuilt since the Abant earthquake. In the vicinity of Lake Abant the damage was also severe. About 3 kilometres from the Lake, to the north, trees were toppled and timber frame houses lost their tiles. The two-storey brick infilled timber Abant hotel situated a kilometre from the fault-break collapsed after swaying 7 to 8 times at right angles to the fault. A near-by timber frame annex of the hotel, sheathed with timber, suffered absolutely no damage apart from window panes that were broken. The shock lasted only a few seconds and it ended as abruptly as it had started. Weeds and water-plants floated up in the Lake forming large islands, and the discharge of spring water changed for some time. A large slide east of Guney, on the Seymendere river, blocked the valley and created a small lake.

Aftershocks continued for some time, most of them being felt in the Adapazari valley. The area between Hendek and Adapazari was shaken on 23 November 1958, and again on 27 March and 9 June 1961.

The Mudurnu Valley earthquake of 22 July 1967

The Mudurnu Valley earthquake of 22 July 1967 occurred at about 18h57m local time (16h56m52s GMT). The epicentre of the shock was computed by a number of seismological centres with the following results:

BCIS	40°.72N	-	30°.81E
CGS	40°.7	-	30°.8
ITU	40°.6	-	31°.0

The magnitude of the shock calculated b a number of stations varied between 6 3/4 and 7 3/4, with an average from ten stations of $M = 7.1$, and $6.8 < M_L < 7.3$, $5.5 < M_{PV} < 7.7$, with $M_{LH} = 7.0$ and $M_{LV} = 5.9$. Right-lateral surface displacement reaching 190 centimetres occurred over a 80-kilometre section of the Anatolian fault zone.

The shock was felt over an area of about 450,000 square kilometres, and preliminary focal depth determinations indicate a very shallow focus, less than 10 kilometres deep. In Istanbul, at the seismological stations of Kandilli and ITU, the onset of the main shock was a sharp dilation, followed by numerous aftershocks the majority of which showed clear compression.

The earthquake killed 86 and wounded 332 people, destroying or damaging beyond repair about 5,200 houses. No major engineering structures were damaged and the total property loss was comparatively small.

Aftershocks

At the time of writing this report (end of December 1967), it is premature to attempt a study of the aftershock characteristics because the data are incomplete. We do, however, have some preliminary material which allows some general observations to be made concerning the pattern of the aftershock sequence.

Table 5 gives available data for aftershock epicentres located by various seismological centres. These locations are approximate and give only an idea of the migration of aftershock activity which is shown in Figure 10. From this figure we notice that, as in the Abant earthquake, here also there is a definite migration of aftershock activity to the west, the main shock lying near one end of the aftershock area.

The Mudurnu earthquake had no large aftershocks. The largest of them occurred on 30 July at 01h31m and showed a magnitude of about 5.5; two more shocks showed M = 5, the rest being of smaller magnitude.

The initial motion of the main shock at Kandilli and at the Seismological Station of the Technical University of Istanbul (ITU) was dilatational, while that of the main aftershocks was compressional. About 300 aftershocks recorded at ITU, between 23 July and 11 August, show a clear initial motion. Of these, 56 per cent showed also initial compression and the same percentage was obtained from records at Kandilli.

Figure 8 shows the frequency distribution of about 600 (S-P) time intervals from ITU at six different stages of the aftershock sequence. For the sake of comparison, this is plotted on the (S-P) axis of the Abant earthquake. From this figure we notice that not only the fracture zones of 1957 and 1967 overlap considerably, the one being an extension of the other but also, as should be expected, their aftershock areas overlap. Also, we notice that the largest number of the 1967 aftershocks, at any stage of the aftershock sequence, occurred about 20 kilometres west of the location that corresponds to the maximum activity of 1957. This distance between peaks remains almost constant as the aftershock activity of the two earthquakes moves to the west.

The frequency distribution of the aftershocks for the first 21 days after the earthquake is shown in Figure 11. It appears that the largest number of aftershocks occurred at a distance of about 125 ± 5 kilometres from Istanbul. This can be seen from Figure 10, on which the frequency of the aftershocks shown in Figure 8 has been superimposed. It appears that the largest number of aftershocks occurred on the west part of the fault zone, in the Karadag mountain and in the Balaban defile where the fault-break is incomplete. There were very few shocks in the Mudurnu valley and fewer near the instrumental epicentre whose location, however, is not known very accurately.

Both the largest number of aftershocks and the strongest occurred on the western part of the zone. The main aftershock of 30 July was felt particularly at Arifiye and in the Adapazari valley. According to unofficial information, about 1,000 houses, already damaged by the main shock collapsed. Numerous strong aftershocks were felt throughout the period 22 July to 20 September, mostly in the western part of the area. Two shocks, on 18 September at 19h49m and at 23h39m, caused additional damage at Dogancay and Baglarbasi (seven kilometres north of Geyve in the Balaban defile) where a number of houses damaged by the main shock collapsed; these shocks caused panic in Akyazi and Geyve.

A fitting of the time sequence of aftershocks gave the following results:

$$n = n_o e^{-at}$$

with $n_o = 110$ and $a = 0.15$

n being the number of shocks that occurred the t-th day after the main shock.

Geological effects and damage in the fault zone

One of the objectives of the mission was to locate the position of the surface ruptures as well as the extent of faulting and to establish the magnitude and pattern of the ground deformations that were associated with the earthquake. On 11 August, the authors began their study. Displacements were measured in a large number of places by direct measurements on cracks, offset fences, footpaths, ruts, ponding ridges, on split bushes and roots and on distorted man-made structures. In some cases vertical movements were influenced by landsliding and slipping and it was difficult to separate the two effects. Also measurements upon roots were found in certain instances to be deceptive. The trace was mapped by compass traverses with vertical control of about 10 metres. Orientations were checked magnetically, and altitudes by aneroid barometers. Throughout the field trip mapping was carried out on a 1:25,000 scale. Along the immediate vicinity of the fault zone the geology was also plotted, but with less accuracy, and the performance of all man-made structures within the zone was examined and noted.

The field investigation continued with intermissions for seven weeks, but as it was near the end of the trip that the actual extent of faulting was realized, certain parts of the fault zone had to be covered more quickly than the rest.

The topography of the area is precisely mapped and the authors had the opportunity to consult from time to time 1:25,000 scale maps. The geology of the region is far less accurately known. The Geological Map of Turkey (1964) is on a 1:500,000 scale and too general for the purpose required. Unpublished geological maps on a 1:100,000 scale, prepared by the Mineral Resources Institute (M.T.A.), to which the authors had access, were useful but had no altitude or triangulation control for plotting regional geology. The eastern part of the fault zone dealt with by Abdusselamoglu (1959), is perhaps better known and a regional map given by that author on a scale of 1:200,000 was found very useful.

In what follows we give a description of the fault zone together with the effects of the earthquake on man-made structures in the immediate vicinity of the fault. The area covered is shown in Figure 12; place-names and reference points are given in Figures 13.1, 13.2, 13.3, 13.4, 13.5. Vertical and horizontal displacements have been rounded off to the nearest 5 centimetres. Bearings are given in degrees, measured clockwise from north and they refer to the general trend of a long single crack or to the axis of cracks arranged en·echelon not shorter than 200 metres; they are given to the nearest 5 degrees. Duration of shaking refers to the duration of severe ground movements that we timed upon observers who reconstructed for us their response during the earthquake.

In Figure 13, numbers refer to specific localities on the fault, extended hundreds of meters on either side of the location of the number on the trace. The reader may find these numbers helpful as references; they are not arranged chronologically, and although attention was first paid to the central part of the fault zone, its description begins at its extreme west and continues in an easterly direction.

The average rate of mapping of the fault zone was about 5 kilometres per day, although quite a few days were spent mapping parts of the trace which did not exceed 1 kilometre in length. The average accuracy of the horizontal location of the trace should not be less than 100 metres. Subsequent visits by Aytun and Taşdemiroglu improved the accuracy of the location of the trace. However, the lack of maps and the difficulty of the terrain may account for a somewhat lower accuracy in locating the trace at its extreme western part.

The description of the fault zone follows in a summary form. It is presented in some detail in order to put on record facts that may facilitate further work on this part of the Anatolian fault zone. The authors will be glad to supply those interested with any of the material collected during the mission, i.e. notes, sketches, photographs, which is not presented here.

The westermost ground ruptures observed in the area lie on the shores of the Sapanca Lake, about 15 kilometres south-west of Adapazari. While it has not been possible to establish their tectonic origin beyond doubt they are of interest because they are the most westerly features found aligned with the projection of the main fault-break further east. At point 108, near Esme on the north shore of the lake, a long crack bearing 135° was noted, showing just perceptible lateral displacement and a throw of 15 centimetres to the north-east. On the downthrown side numerous cracks could be followed on alluvium for about 200 metres inland, and the main crack can be followed at the bottom of the lake for a few tens of metres to the south-east. Near here a strip of the coast has sunk and trees 5 metres high are now submerged.

On the south-east projection of these cracks, on the south side of the lake, a wide zone of ground ruptures trending 150° can be followed for 400 metres inland, at point 88. They show right lateral displacements of nearly 20 centimetres and a throw to the north-east of 40 centimetres. Near the shore, lurch cracks and mud volcanoes run along the downthrown side of the zone, and fine silt and sand ejected from cracks in the ground covers a large area. Another crack, running parallel with and to the north-east of the rupture zone was found at the bottom of the lake near the shore and it can be followed for some distance offshore (Figure 14). Between this crack and the rupture zone, the shore has settled considerably and the shore line retreated in places by 30 metres. Here, a reinforced concrete structure, the remains of which are shown in the foreground of Figure 14 has settled considerably and was destroyed due to large differential settlements of its foundation which exceeded 100 centimetres. Further west, a modern five-storey reinforced concrete hotel (Figure 15) also settled and tilted slightly towards the lake. This structure opened up along a construction joint and the two parts of the building were separated by a gap 30 to 50 centimetres wide (Figure 16). The structure is reported to have been built on a thick reinforced concrete mat and, apart from the construction joint, suffered absolutely no damage. A number of small structures within the rupture zone settled by as much as 50 centimetres and mud squirted up through cracks, flooding the area around them (Figure 17.) According to local information, mud was ejected from many cracks, particularly south-west of the hotel, reaching heights of 2 metres or more, and spurting continued for a few minutes. Fences and other linear features crossing the fracture zone showed displacements of up to 50 centimetres, sometimes tensional, indicating that the whole zone by the lake side was involved in a slide towards the lake.

Along this part of the shore, damage to structures was solely due to excessive differential settlements; the actual shaking itself caused little damage and a few hundred metres further inland, on firm ground, not more than 7% of the total number of houses of any settlement were damaged beyond repair.

To date, (December 1967) it has not been possible to establish what effect the earthquake had on the lake itself. There is some indication that the lake tilted slightly to the north-east but corroboration will have to await the results of the survey of the lake-shore currently under way. From interviews with inhabitants of the villages around the lake it appears that there was no perceptible seiche; a strong current, however, noticed about 5 minutes after the earthquake, carried a boat away from the north coast towards the centre of the lake.

Further inland from point 38, the rupture zone dies out and no attempt was made to investigate the area south-east of the lake. Between Sapanca and Dogancay there is no clear evidence of recent faulting. Landsliding and rock-falls were noticed in places, particularly from the steep slopes of the Balaban defile, through which runs the Istanbul-Ankara railway line. At point 90, south of Dogancay, the line was damaged by a rupture zone which crosses the track, trending 110°. The track is on flat ground. On a transverse section through the line the ground was reported to have been downthrown by 40 centimetres to the north and the ballast by 10 centimetres in the same direction. There was no evidence of lateral movement. The rupture zone could not be traced east of point 90. West of point 90 the zone can be followed up to Nuricsmaniye; the trace is discontinuous, cutting through a thin mantle of soil overlying heavily fractured gneiss, with no evidence of lateral or vertical movement, and it dies out at point 91.

In the Balaban defile, from Arifiye in the north to Alifuatpaca in the south, the effects of the shaking were exceptionally severe. The railway stations of Dogancay and Bogazkoy (Ilimbey) were heavily damaged and large rock and landslides occurred at Orencik and Findiksuyu.

East of the Balaban defile the ground rises from 130 metres to over 500 metres with steep slopes thickly wooded with sycamore and oak. Between Kislacaykoy and Degirmenders a number of north-south traverses run at a kilometre spacing did not disclose any evidence of faulting until point 94. Here, as well as further north, to the east of Degirmenders a number of ruptures, running for hundreds of meters were found. At Kanlicay, a rupture about 2 kilometres long crosses two streams showing right lateral displacements of about 70 centimetres with a throw to the north of 30 centimetres. The bedrock at 93, 94 and 95 as well further east consists of sandstones and shales which have been weathered to a considerable depth and the trace is irregular, consisting in most places of a zone of en echelon scarplets in weathered bedrock rather than a single fracture.

West of Mecidiye, discontinuous ground ruptures may be traced for about 1,800 metres to the west, from point 105 to 73. They show in general small displacements, 5 to 10 centimetres, with the north side downthrown, but it is difficult to discern the sense of horizontal movement. Near the village the ruptures form a wide zone, in places mixed with tension cracks caused mostly by sliding. The damage at Mecidiye is rather small: it amounts to plaster cracking and damaged chimneys, becoming less in the higher parts of the village. Near the crossing of the zone of ruptures by a rivulet, south-west of point 73, several cracks can be seen departing at right angles from the zone, running along the strike of the slope, some of them showing compression features, but mostly connected with landsliding of small masses and with creep of a surface layer of soil and sod which had slipped down slope. A search west of this point failed to produce any evidence that there was a trace of any sort, going north-westerly. Similarly there was no evidence that this zone of ground ruptures continues south-easterly to connect with those found farther east.

East of Mecidiye another series of short zones of ground ruptures can be traced between Ahmediye to the south and point 106 to the north. They consist of individual long cracks, some of them open, trending almost north-south with the east side downthrown by 5 to 40 centimetres. Starting from Ahmediye, a long crack may be traced near point 74, on flat ground and to the west some pressure features can be seen. At Ahmediye, the damage was negligible, amounting to some cracking of chimneys and plaster. Some houses on sloping ground were distorted mainly due to differential sliding on their foundations. No reliable measurements of the ground displacements on this crack could be taken.

North of Ahmediye, the terrain is very difficult, in some places becoming almost inaccessible, and a careful but not exhaustive search for a continuation of the crack found north-east of the village gave no results. To the west, a long crack could be seen near point 3 from a distance. North of the village, near point 72, individual cracks about 200 to 300 metres long in a criss-cross arrangement repeat themselves for about 1,600 metres to the north. The first four cracks cross linear features and a small stream, with 15 to 40 centimetres of displacement, up to the west,(i.e. to the down-slope) and they provide a measurement of right-lateral displacement of 5 to 30 centimetres. They are mixed with slides and some of the tension fractures seem to be due to landsliding. The fifth crack near point 106 can be seen from a distance but was not visited.

Further to the east, no more ground ruptures were found until point 107, about one kilometre west of Bickidere. From this point the fault-trace can be followed to the east, almost continuously, for more than 50 kilometres. At point 107 a wide zone of small cracks, arranged en echelon, runs up the west slope of a small hill and down the east side, showing irregular displacements. Before crossing the stream that flows through Karaagaclik, the zone turns into a single crack with strong tension and compression features and with scarplets facing mainly to the north. An isolated old timber frame house, with walls filled with mud-bricks, straddled the crack and was destroyed. The cracks are discontinuous and they are mixed with landslide tension fractures until they reach the stream, where they fade out. On the east bank of the stream the crack can be followed through cultivated ground but with no indication of any appreciable offset, up to the point where it begins to climb a small knoll towards the southern outskirts of Bickidere. For a short length the cracks turn into moletracks, with slabs of soil humped up in places and at point 71 the pattern becomes more regular, showing right-lateral strike-slip displacements from 5 to 25 centimetres and 5 to 10 centimetres down to the north (Figure 18). At Bickidere the trace passes diagonally under a two-storey timber frame house (Figure 19). The ground floor was heavily damaged and it was displaced on its rubble masonry foundations by 20 centimetres to the east (Figure 20). In contrast, the first floor hardly suffered any damage, not even cracking of its exterior plaster. Further east from this house, a barn straddling the fault was distorted but did not collapse. The shaking at Bickidere was so severe that people standing were thrown down, but the damage to man-made structures was comparatively small. The ground motion was predominantly horizontal and it lasted between 13 and 15 seconds. A few tens of metres from the fault, timber frame houses suffered negligible damage amounting to plaster cracks and destroyed chimneys. The maximum observed fault movements just south of Bickidere were 25 centimetres right lateral with about 10 centimetres vertical, the north side downthrown.

East of point 71, the trace continues with the same features, mostly with tension cracks and pressure ridges, crossing a thickly wooded slope. At point 79 the trace turns more to the south and becomes difficult to follow. Displacements remain small, 10 to 30 centimetres both in the horizontal and the vertical sense, and tension features predominate, showing consistently right-hand displacements with scarps facing either to the north or to the south depending on the direction of the slope.

East of point 79 the trace runs through wooded country and is at times difficult to follow. It runs up and down over small ridges passing through topography showing no signs of previous movement, with the exception of a few saddles that the trace chooses to pass through, following rivulets and other erosion features. Approaching the twin settlements of Tasburun, the trace begins to wander between 110° and 150°, cutting across small drainage divides and small streams. About one kilometre west of the village the trace, still in the form of pressure ridges and tension cracks, cuts across fences which it displaces in a right lateral sense by 10 to 40 centimetres. The vertical movements here show consistently that the south side was downthrown by 10 to 15 centimetres. Just before crossing the village, the trace disappears for a few tens of metres and reappears trending more to the south, with increasing vertical displacements and with large tensional characteristics. Numerous linear features offset by the fault between this point and point 70 show right lateral movements between 10 to 40 centimetres and throws, with the north side up, of 10 to 20 centimetres. The trace can be followed quite easily up to 500 metres west of point 70. There, with the south side downthrown, it turns south sharply. Strong tensional features over a zone 2 to 10 metres wide are apparent. The trace continues for a few hundreds of metres and swings back to an east-west direction. At this point the north side is downthrown in a succession of steps that form the south wall of a small graben. The trace here is not single; before turning south it bifurcates, and if the north trace (which forms the north limit of the graben) is followed it would appear as if the south side was downthrown.

After crossing a small stream at point 70 the ruptures continue east, running parallel with and to the south of the Mudurnu river. They form pressure ridges, 5 to 10 metres wide, with conjugate short gaping tension cracks. The sense of lateral movement is consistently right handed but the north side now is downthrown. At one point, a barn straddling the fault was distorted and part of it collapsed (Figure 21). Houses of timber frame construction in the immediate vicinity of the fault-trace were displaced on their foundation by as much as 25 centimetres but suffered little damage. At Tasburun the damage in general was very small. It amounted to plaster cracking and the loss of brick chimneys and tiles. The mosque of the village, of brick masonry construction, was damaged more than other constructions but its minaret, also of brick, was still standing.

East of Tasburun the trace turns into a moletrack, and crosses at right angles a number of rivulets with little discernible displacement. Approaching point 69 the vertical displacements decrease to steps facing either north or south with lateral displacements up to 65 centimetres measured upon displaced furrows and foot paths. Near point 68 the fault-trace turns abruptly to the south and in so doing it bifurcates, forming again a small graben, about 20 metres wide with numerous irregular steps on either side and with strong tensional cracks. The only topographical features indicating that the course of the trace has been determined here by previous movements are the small saddles that the trace crosses on either side of the graben (Figure 22). Local information indicates that some ground deformations at this point had been observed shortly before the earthquake; a boulder at the edge of a slope rolled down and some slumping of the ground was noticed.

East of point 70 and up to about point 68, not many ground features that can be attributed to geologically recent movements were found and no clear cases of previous faulting could be observed. From point 68 eastwards, however, the fault-trace follows saddles and scarps with increasing evidence of past movements. For about 300 metres the trace follows a scarp on the south bank of the Mudurnu river which it soon crosses for the first time at point 86. At this point, slumping and landsliding of the banks conceal the actual displacements and the trace continues eastwards, cutting across alluvium first with small displacements, and then running up a hill towards point 85. Along its course the trace is discontinuous with weak cracks arranged en echelon, some of them open up to 5 centimetres with small displacements. Near point 85 the trace crosses thickly wooded country and shows small but quite clear right lateral displacements of up to 10 centimetres. After crossing a small stream, the trace runs up a steep slope passing under a house, which was destroyed, and continuing to the top of Hill 369. Near where it crosses the stream, the trace shows a reversal in the vertical movements, with the south side downthrown, but this is due to sliding of the slopes facing south. Near the top of Hill 369, open cracks in a thin mantle of soil exposed smaller gaping cracks in crystalline schists dipping 80° to the south. The trace here is composed of many small cracks forming a zone several metres wide with no apparent displacement.

Another trace to the north, about 1,800 metres long was found leading to Yongalik. It follows discontinuously the north slope of Civek Tepe (Hill 369), and joins the main trace practically at the top of the hill. A house straddling this trace near point 67 was deformed (Figure 23). At Yongalik, a few houses situated in the fault zone were heavily damaged, particularly those of brick construction. Elsewhere in the village, brick masonry houses with light timber bracing collapsed, as did the school.

From Hill 369, the trace continues eastwards, cutting in places through exposed crystalline schists with no indication of any appreciable offset. Accross to this part of the fault was difficult, as rockfalls and slides had blocked footpaths and the road leading to Dere Mahalasi. At points 66 and 65, horizontal displacements of 5 to 15 centimetres in a right-lateral sense and throws of 10 to 20 centimetres can be measured upon cracks in a thin cover of soil overlying schists. At point 66 the trace widens and forms a zone of small fractures passing around a knoll of outcropping schists which it has shattered. The total lateral displacement measured across the zone was about 15 centimetres and the total vertical displacement was 20 centimetres, down to the north. The trace crosses a small stream and passes through another outcrop offsetting linear features by 5 centimetres in a right lateral sense and by 10 centimetres in a vertical sense, with the north side downthrown.

Further east from point 65, the hillside is shattered and the trace mixes with features that appear to be the result of land-sliding. North-north-east of Dere, near point 81, the trace gradually turns almost east-west and shows very strong compressional features which were found to be mainly due to a comparatively large horizontal displacement of a meandering trace. Soil plates humped up and pushed over indicated right lateral displacements of 60 to 80 centimetres (Figure 24).

Just before crossing the Mudurnu river for the second time at point 80, the trace straightens and loses its compressional features, becoming wider with cracks arranged en echelon, and showing larger vertical displacements. It crosses the river with some displacements of the bed and pronounced vertical offsets of the banks (Figure 25).

North of Beldibi, the trace cuts accross the flood-plain of the river and shows at point 51 right lateral displacements of 100 centimetres with numerous branches of long en echelon cracks leading north-west and south-east. Between points 51 and 52, the horizontal displacements are at least 100 centimetres; near point 51 the north side is downthrown by 10 to 20 centimetres but at point 52, 120 centimetres of vertical displacement can be measured. East of 52, the trace crosses the river for the third time, uplifting its bed in the form of a long pressure ridge, and turns sharply, trending 140°. For about 500 metres it follows the north-east bank, running across a gravel flood-plain where individual measurements of relative displacements could not be made, and crosses the river again, for the fourth time, at point 61. Between these two last crossings of the river, although no measurements of relative displacement were possible, right lateral movements could be discerned from the pattern of fissuring in fine-grained deposits in gravel depressions; small fissures were found in dry silty sands stepping to the left on either side of the fault zone.

Near point 61, no tension cracks can be seen in the gravel plain of the river but only pressure ridges, some of them having uplifted the river bed by 30 to 50 centimetres, exposing clean gravel and forcing the river to flow around the ends of the ridges. Further east, the fault cuts across a 4 metre high bank, which it shatters over a wide front, and emerges in an open field south of the river in the form of a wide zone of fractures. At first, this zone is wide with numerous tension cracks en echelon, some of them 20 to 30 metres long, stepping to the left with no apparent pressure ridges (Figure 26). Then, after 200 metres, the zone narrows gradually and massive but short pressure ridges begin to form, stepping to the right. Tension cracks trending 140° show throws of 5 to 15 centimetres to the northeast. The cumulative strike slip and throw measured across the fault zone here is about 100 centimetres right lateral, and 50 centimetres vertically down to the north, respectively.

About 300 metres from the point where the fault crosses the river, the fracture zone narrows to a single fracture trending 95°, showing clear right lateral displacements of 120 centimetres and throws of 85 centimetres down to the north (Figure 27). These displacements persist for about 100 metres after which the trace turns gradually, bearing 110°, and forms a small graben, about 30 centimetres deep with strong tensional features bearing 140°.

The trace continues eastwards, cutting across a gravel flood-plane with pressure ridges 30 to 50 centimetres high, and crosses the dry bed of a small tributary of the Mudurnu river east of point 53. From this point it turns gradually, bearing 80°, and runs through a thick wood of young plane-trees with dense undergrowth, where the trace could be checked only at a few points. Roots were offset in a right lateral sense by 120 centimetres and 85 centimetres vertically down to the north. The trace can be followed with difficulty on the eastern side of the tributary, where it appears mainly as a series of pressure ridges and moletracks of uplifted soil slabs and roots. There is no well-defined evidence of shear movement until a right lateral displacement east of point 54 is found. Here the trace demonstrates a 60 centimetre right lateral offset of a flood bank consisting mostly of gravel with a 50 centimetre throw of its toe to the north. Further, east, broken roots have displaced tips which showed that the southern side moved west by 20 to 40 centimetres.

Approaching the river from the south, near Samanpazari, the trace bearing 80° diffuses into a wide fracture zone, in the middle of which outcropping volcanics were found shattered but with no evidence of relative displacements. This zone can be followed up to where it crosses the river for the fifth time, just south of Samanpazari. The shaking of Samanpazari was severe, throwing down people standing or sitting, and causing considerable damage to the local timber frame houses. One of the most severely damaged structures was the mosque of the settlement which is shown in Figure 28. The shock was felt first as a jarring east-west vibration which soon culminated into a sudden movement of the ground from west to east followed b, a series of sharp vertical vibrations. Local information indicates that it was the strong eastward movement that caused the damage. The severe shaking lasted for about 13 seconds.

The fault, after crossing the river, continues to the east and for about 300 metres forms a wide zone of fractures bearing 110°. Between points 6 and 2 the trace bifurcates and forms a small graben 80 metres wide, which at the time of our first visit was flooded, creating a shallow poind about 200 metres long (Figure 29). A transverse tension crack bearing 160° cuts through the middle of the graben and extends to the south for a few tens of metres. The impression gained here is that the graben formed between the old flood banks of the river to the south and an old fault scarp to the north shown by point A in Figure 29. No relative displacements could be measured in the graben which showed a depression in the middle of about 40 to 50 centimetres. At the west end of the graben, however, near point 6, a right lateral displacement of 80 centimetres with the north side downthrown by 90 centimetres can be measured in a corn-field.

East of the graben, near point 2, the fault zone narrows and approaches the old bank of the river from the north, bearing 120°. Along this part of the fault thick vegetation conceals the trace. Pressure ridges and tension cracks can be measured only in clearings such as those shown in Figure 30, where roots have been pulled apart and others humped up and broken. At this place the strike slip movement is about 145 centimetres right lateral; the vertical movement could not be measured as the surface of the ground was uplifted as a slab of soil and roots leaving a gap beneath it of at least 30 centimetres.

Beyond point 2, the trace emerges from the thickly vegetated banks of the river and it can be followed as a single fracture, in places open by 30 centimetres, showing 50 centimetres right lateral movements with 60 centimetres throw, down to the north. It then turns a little to the south, bearing 130°, and after following the flood banks of Mudurnu crosses almost at right angles a fence which it offsets by 150 centimetres in a right lateral sense and by 50 centimetres vertically, again down to the north. This point is situated near the edge of a 3-metre high bank and the fault-trace has caused some slumping of the bank with the result that the vertical displacements here are not solely due to the fault movements (Figure 31).

About 80 metres north of the fence, a newly built two-storey timber frame house straddles one of the cracks leading to the fault. It had its ground floor shattered and its chimney thrown down (Figure 32). An inspection of the first floor, however, showed absolutely no damage, and as shown in Figure 32 not even the plaster of the first storey was cracked. Near-by, a barn partly of stone masonry and partly of timber, also straddling the crack, suffered absolutely no damage. There is some evidence, from interviewing the owner of the house, that not all of the observed distortion of his house occurred during the earthquake but rather after the shock.

Returning to the displaced fence, the fault-trace widens into a narrow zone of numerous fractures, two of which are very long, bearing 70° and 160°. The former passes under the two-storey house just mentioned. The zone of fractures passes around outcropping andesite, part of which was found broken but with no evidence of relative displacements. At this place, the shaking must have been severe, because boulders around the outcrop, embedded in a thin layer of top soil have been rocked out of their nests and vigorously pushed against their west-south-west edges (Figure 33).

At point 02, about 130 metres south of the main road, the fault crosses the dry bed of a small tributary of the Mudurnu river. Displacements not exceeding 30 centimetres have been measured by means of numerous roots pulled apart or broken by buckling (Figure 34). They show right lateral movements with imperceptible vertical displacements.

Before crossing the river, east of point 02, the trace cuts across a corn-field and develops into a zone of cracks about 10 metres wide, composed of five separate pressure ridges and as many tension cracks bearing 15°. The total shortening across two of these ridges was estimated as 80 centimetres, and the vertical uplift of the south side as 50 centimetres, but the actual amount of horizontal movement is not clear. Approaching the banks of the river from the north, pressure ridges die out gradually, tension cracks widen up to about 60 centimetres and the trace mingles with a local slide as it crosses the river (Figure 35). Horizontal displacements here are difficult to measure but there is evidence for vertical movements of 50 centimetres, down to the north. The fault crosses the Mudurnu river for the sixth time without any perceptible change in the elevation across the river.

Between points 03 and 04 the trace cuts through partly wooded and partly cultivated land. For about 500 metres, after it crosses the river, the trace is difficult to follow. It consists of short en echelon cracks showing right lateral movement of a magnitude difficult to assess. It could not be followed for the rest of its length up to point 04.

About 600 metres north of this point, the village of Derbent suffered some damage and one of its twelve houses, an old timber house, collapsed (Figure 36). In contrast, elevated barns, one of which is shown in Figure 37, suffered no damage.

Returning to point 04, the fault after crossing a small stream continues towards Cakiroglu bearing 115°. The trace here is marked by numerous short open cracks and small compression ridges. Roots near the surface were found buckled and broken (Figure 38), indicating an overall shortening from 10 to 30 centimetres. The indication of movement on cracks is predominantly right lateral. The cracks alternate with conjugate compression ridges, but the compression which did not amount to more than 30 centimetres predominates. In one or two places the north side is in general downthrown by 10 to 20 centimetres. A small branch of the fault, about 200 metres long bearing 330° cuts back across the stream, showing no throw but a right lateral movement with displacements, near point 04, not exceeding 10 centimetres.

Approaching Cakiroglu from the west, the fault-trace first runs up the west slop on which the village is situated, showing small but continuous cracking arranged en echelon. Then it follows the 320 metre contour, running parallel and to the south of the road that leads to the village along a small scarp of a terrace facing north. Here the downthrown side coincides with the down slope of the terrace and, locally, mass movements obscure the trace. Just before entering the village, the road, which runs parallel with the fault-trace makes a shart S-turn with a total northward displacement of its axis by 7 metres, (Figure 39). At the two ends of the S-turn, the road is cut across by two branchs of the fault which run almost at right angles to the strike of the slope. Both traces show left lateral offsets varying from 40 to 50 centimetres with the west side up by 10 to 20 centimetres. The west branch trends 165° and extends to the south for 300 metres while the east branch bears 335° and runs down the slope all the way to the bottom of the valley. It is not clear whether the S-turn of the road has been the result of some previous landsliding or due to previous slow movements on these two cross faults.

Although these faults do not show displacements large enough to explain the distortion of the road they do show the right sense of movement. This, together with the fact that there is no perceptible difference in the elevation at the two ends of the S-turn suggests that while these cross-faults do not extend very far they may be of some tectonic importance.

Further east, the main trace cuts across the village where the total strike slip movement measured on cracks is more than 50 centimetres right lateral with the south side sometimes up and sometimes down by 10 to 20 centimetres. In two places the trace follows the upper end of a new landslide at the edge of a terrace with severe cracking of the ground (Figure 40). The damage at Cakiroglu was comparatively slight. Well-built timber frame houses withstood the shock with surprisingly little damage.

The fault-trace continues eastwards bearing 115° and it can be followed for a few hundreds of metres. It crosses obliquely the hill on which is situated Cakiroglu, showing right lateral movements varying from a few centimetres to 60 centimetres but with no indication of vertical movements. Soon the larger displacements disappear and the trace continues in a series of small cracks with no obvious displacement. No attempt was made to follow the trace further east.

A wide zone of tension fissures, bearing 115° was found about 800 metres west of point 08. It follows the contour line of 320 metres showing feeble right lateral displacements. At point 08 the trace turns northward, bearing 75° and develops into a single fracture. Here the trace runs along the strike of a very steep slope following the 310 contour line and for a length of about 250 metres shows the north side downthrown by 30 centimetres with no perceptible horizontal movement. Although there are no marginal fractures, nor does the trace curve down the hill, there is some evidence that the fault triggered movement of landslide masses.

The trace then becomes discontinuous but at point 13 it forms a narrow zone of cracks that can be followed through cultivated fields, bearing again 115°, and showing right lateral displacements. A it emerges from the cornfields, the trace loses its tensional features and it becomes impossible to judge the amount or sense of movement. At this point, a thick root of an old acorn-tree crosses the trace at a small angle. As a result of the strike slip on the fault the root buckled and broke and it was found sticking out of the ground as shown in Figure 41. The shortening of the root is 60 to 80 centimetres and there is no sign of vertical displacement. Near the root a lime-kiln had its stone masonry thrown down but the timber frame was found standing, with the roof. Two timber frame houses near-by suffered some damage; one of them had some of its tiles and the wall facing east thrown down, while the other lost some of its tiles. At this place the first shock was horizontal, of very short duration, from east to the west, followed by severe vertical ground movements. The whole event lasted 13 seconds and it was accompanied and followed, but not preceded, by a rumbling noise. People standing or sitting were thrown to the ground by the first shock. A flock of sheep grazing at the time on the slopes of Beyler was sent rolling down the slopes.

The fault trace passes under the kiln and after crossing a rivulet east of point 13, loses completely its linear features. Near the kiln the fault trace has shown large horizontal displacements.with wide cracks but no measurements could be made because of trampling by cattle and repairs carried out by the owner of the kiln. On the east side of the rivulet the trace turns into a wide zone of moletracks and pressure ridges. Here a thin mantle of soil covers massive boulders of limestone, some of them outcropping 100 metres east of the kiln. Pressure ridges were found composed of boulders and soil, humped up 50 to 100 centimetres (Figure 42). Smaller ridges consisted of a series of soil plates humped up, on which no lateral movements could be measured. Only shortening across the ridges could be assessed, and this was over 100 centimetres. Here, cobbles and boulders of various sizes, embedded into the topsoil were thrown out of their sockets (Figure 43), or jostled and displaced from their seats (Figure 44). This was noticeable near the fault zone both here, and in many other places, particularly where the top soil covering bedrock was thin.

Further east, the fault can be traced with difficulty. It trends 130°, crossing untilled country strewn with boulders, outcropping limestones and in places it is covered with dense shrubs. Discontinuous pressure ridges can be followed up to point 12, where the trace crosses the road leading to the Haydarlar bridge. At a point, the total lateral displacement, measured across the whole width of the fault zone where it cuts bedrock, is only 10 centimetres right lateral with no perciptible vertical displacements.

At point 11 the trace turns, bearing 90° and proceeds, cutting through limestones and thin detritus. It can be followed with some difficulty but it is not possible to determine the sense of the lateral and vertical movements. In places, pressure ridges of soil slabs were found humped up between outcropping limestones which were shattered. Fungus growing on the outcrops was found shaken off leaving white patches on the'rocks. At point 10,just before the crossing of the stream north of Haydarlar by the main trace, a long crack running on a north-facing hill is encountered. From this point eastwards, the trace appears mainly as a sequence of pressure ridges with no well-defined evidence of vertical movement, until near point 09 a right lateral displacement with a throw may be noted. Near this point, the trace consists of three sub-parallel fractures spaced about 40 metres apart. Each of these fractures consists of numerous short cracks arranged en echelon, one of which is shown in Figure 45. The central fracture demonstrates 40 centimetres right lateral offset of a footpath and climbs steeply into a thickly wooded slope (Figure 46). The other two fractures die out in the sides of a gully. Further up the slope, near point 19, the indication is that the trace dies out into a zone of fracturing of considerably less total offset, marked by open cracks with 5 to 10 centimetre gaps and small pressure ridges which indicate feeble right lateral displacements.

The trace re-appears on the eastern slope of the hill, cutting across cultivated land with large horizontal displacements. It then skirts a water-mill and a farm-house and dies out at the foot of the hill. The farm-house and the mill were hot damaged but a wooden water conduit of the mill that crosses the trace at a small angle was found pulled apart by at least 100 centimetres. Near the mill, two cracks leading away from the fault pass on either side of the house and its elevated barn (shown in Figure 47), and they disappear down the slope. These cracks do not show any relative movements and they seem to be connected with a general slumping of the north-east slope of the hill on which the farm is situated.

About 100 metres east of the farm down the hill, the fault crosses at a small angle a foot-path and a side irrigation ditch which are offset in a right lateral sense by 80 centimetres (Figure 48). A thick root running near the ground surface parallel with the ditch was pulled apart. However, its two ends did not match and the 160-centimetre displacement that can be measured on this root is questionable. Further down the hill the trace is obscured by the erosion caused by the water that escapes from the ditch which follows the trace all the way down to the foot of the hill where a small depression was flooded. Along this part of the fault, the trace follows the 300-metre contour, bearing invariably between 105° and 110° and shows small vertical displacements.

On the east edge of the flooded depression, near point 19, a number of short cracks can be traced bearing 260°. One of them shows clearly characteristics of local slumping; it skirts around the depression and crosses back into the other side of the stream. Another crack, open in places, trending 80°, passes under a two-storey timber house, crosses a corn-field and joins the main trace which re-appears east of point 19. The house that straddles the crack lost most of its tiles and was shifted a few centimetres on its concrete foundation, but otherwise was not damaged.

Between points 19 and 20 the trace, following the 280 metre contour of a north facing slope, appears in the form of a series of long open cracks arranged en echelon which step left, with occasional pressure ridges. The trace turns gradually from 80° to 115° as it runs around the nose of a spur and for the next 1,000 metres it cuts across corn-fields (Figure 49) following faithfully the foot of the scarp of an old gravel terrace 2 to 5 metres high. Approaching point 20 the trace develops tensional features and forms a widening zone of fractures which at point 20 develop into a small graben. This graben is about 100 metres long and 5 to 15 metres wide; it was formed by the hanging wall of the terrace on the south and by the fresh wall of the fault on the north. At first sight it appeared as if the north side had moved up, which is contrary to the vertical displacement of almost all the traces to the west where the south side was lifted up. However, a close inspection of the scarp of the gravel terrace revealed vertical movements which were much larger than those of the opposite wall, suggesting that the north side was in fact downthrown by 10 to 120 centimetres. Measurements on displaced ponding ridges and by matching roots across the graben showed 140 centimetres of right lateral movement. But this varied considerably from place to place.

From a point half-way between 20 and 21 the trace changes direction gradually from 115° back to 80° and leaves the gravel terrace to the south. It continues to follow the 280 metre contour and the graben that can be traced up to this point dies out, giving place to an antisymmetrical feature, i.e. to a narrow zone, 10 to 15 metres wide and about 80 metres long, of fractured soil upthrusted, showing an apparent throw on either side. Since the throw to the south (up hill) was in most cases smaller than that to the north, it appears that here also the north side was downthrown by 15 to 80 centimetres. The lateral movement was invariably right lateral with a total displacement across the zone of at least 100 centimetres. At one place, a thick root of a wild pear-tree crossing the north trace obliquely was pulled apart 50 centimetres with no evidence of any appreciable vertical displacement. The south trace dies out at about this point and the fault continues as a single fracture, bearing 80°, cutting across corn-fields with small right lateral movements.

Near point 21 the trace is arrested by a massive limestone outcrop, and it spreads out in numerous small cracks. This outcrop is cut in a north-east-south-west direction by a narrow gorge, 4 to 8 metres wide and 150 metres long through which flows a stream to the north. At the southern end of the gorge, four closely spaced cascades in the stream show an accumulative vertical displacement of about 100 centimetres, down to the north. Each cascade is associated with a tension crack that extends a few tens of metres on either side of the stream. These cracks form a fracture zone which skirts the south edge of the outcrop, trending 135°, on which no lateral movements were noted. A thick root of a plane-tree running parallel with the tension cracks was humped up. The outcrop itself was shattered and huge masses of rock had blocked the gorge (Figure 50). At the north end of the gorge, more cracks can be traced crossing the stream which show small lateral displacements without any indication of vertical movement. The cumulative lateral offset of the stream was estimated at about 80 centimetres in a right lateral sense. Other ruptures between points 21 and 22 were mostly tensional, with the north side down. Boulders near here, both on the outcrop and in the surrounding area have been rocked or thrown out of their seats.

The trace reappears at point 22, about 200 metres south of the place where it was arrested by the limestone outcrop. It resumes its course, trending 80° and following faithfully the 280 metre contour on the hill-slopes facing north, through terraced fields. Up to point 24, the trace follows the scarps of terraces and shows right lateral movements with the north side down. In places the trace is complicated by local landsliding and slumping where the sliding utilized the trace as an upper boundary and in places it has modified it. East of point 24 the trace turns gradually to the south and climbs up the slope showing strong tensional features. Just before crossing a stream, it produces a 130 centimetre right-lateral offset on ponding ridges without any indication of vertical displacement. Between points 24 and 23 the topography of the area suggests that large right-lateral movements must have taken place in the past as streams and smaller drainage features show very recent offsets. Approaching point 23, however, the trace shows diminishing evidence of shear movement and gradually it develops a throw of 30 to 40 centimetres to the north with very small horizontal displacement. At point 23, another rupture trending 240° merges with the main trace. This rupture is continuous, extending perhaps as far as Kuloglu, and has a throw to the south. Thus, the block bounded by this rupture and the main trace seems to have been uplifted relative to the rest by as much as 30 centimetres.

Between points 23 and 17 the trace is discontinuous with no clear evidence of shear or vertical movement. East of point 17 the trace climbs gently towards Yenikoy, trending almost 90° (Figure 51). Weak pressure ridges and strong en echelon cracks show right lateral movement the exact magnitude of which is difficult to measure but with some evidence of a throw to the south (Figure 52). At point 16 the tension features, assisted by landsliding, become locally violent with cracks open to a depth of 150 centimetres and 40 centimetres wide. Further east the trace offsets a fence over a wide zone in a right lateral sense (Figure 53) and runs up a slope of a hill on top of which is an old cemetery. Here the trace is composed of a series of tension cracks and pressure ridges of soil slabs humped up (Figure 54) and of roots buckled up sticking out of the ground. They form an en echelon fracture system indicative of right-lateral movement but with the south side (i.e. the uphill side) downthrown. Figure 55 shows a sketch of the fracture zone in the cemetery. From this figure it may be noticed that as the fracture zone turns north, it begins to show features indicative of left-lateral offset (Figure 56). These are very local, and judging from the direction of the hillslope they may be due to a comparatively thin layer of soil slipping to the south-east down the slope on the rock beneath it. Individual measurements on cracks and on pressure ridges show right lateral movements of about 80 centimetres and throws of 40 centimetres, down to the south. At one place the total throw is 120 centimetres, but this is local and it was measured on a pressure ridge.

East of the cemetery the trace, after passing just north of Yenikoy, runs up a hill showing comparatively small but distinct right-lateral strike-slip movements (Figure 57). In its course, it offsets a fence by 50 centimetres and displays a throw of 40 centimetres, down to the south (Figure 58).

Returning to point 17, the trace of an old landslide can be followed up the steep slope skirting the village to the south. Along most of the length of the trace, from point 17 to point 14, the ruptures that can be observed are clearly the result of movement or resumption of movement of landslide masses, with the exception of two parts of the trace, one near point 17 and another east of point 14. These parts of the trace cut at an angle the landslide scar and show small vertical displacements.

The shaking must have been severe at Yenikoy because people were thrown down and heavy objects were displaced on their foundations. The most severe shock came from the west and the destructive part of the earthquake lasted 4 to 5 seconds. The damage to the village houses was nevertheless small. Two old houses partly collapsed and a few others were damaged. Figure 59 shows one of the two houses of rubble masonry in-filled walls that collapsed in part. Houses of the type shown in Figure 60 suffered absolutely no damage, and even their tiles remained in place. East of point 15 the trace runs up and down over small ridges and is at times difficult to follow. Here it consists of short cracks not always en echelon and in places they give the impression of a narrow fracture zone which has been subjected to a number of shear reversals, showing features on which no left or lateral movement can be noted. The vertical offset is small and variable, the south side being uplifted in some places, the north in others, occasionally the sense of movement depending upon the hillslope.

West of Sigirlikoy the trace forks and one branch departs from the main zone of fracturing and strikes 115° towards the stream. The other branch continues east passing north of the village. Near this point of bifurcation, left-lateral movements noted on a number of tension cracks seem to be the result of sliding; well developed slides can be seen just north of this point.

The trace then passes to the north of Sigirlikoy offsetting linear features by as much as 40 centimetres. At point 55 a water-pipe in an open trench crosses the trace at an angle and it was sheared and offset horizontally by 30 centimetres. The vertical displacement was not possible to measure as the pipe was also stretched and was no longer in contact with the ground, which was heavily fractured. Judging from the surface features at this point, the vertical displacements must have been about 40 centimetres, down to the south.

The trace continues, mainly as a single crack and cuts through a granitic outcrop which it shatters with no evidence of shear displacements. Here it loses its strike-slip features and turns into a wide zone of small tension cracks superimposed on larger pressure ridges. This is a local feature controlled by the outcrop, on the south-east side of which a combination of open cracks and small pressure ridges indicate the existence of a small branch of the trace leading down the slope. To the south-west of this trace, is a series of ruptures that appear to be the result of landsliding.

The village of Sigirlikoy was heavily damaged. Timber frame houses on stilts collapsed and others built on rubble masonry slid on their foundations, in most cases to the west (Figure 61). North-west of Sigirlikoy another crack can be traced for 500 metres running parallel with and to the north of the main trace. This is a continuous break, open in places with the south side downthrown by 5 to 15 centimetres. It lies at the edge of a berm on a south-facing slope and shows little evidence of lateral movement. Near its ends the crack does not follow the berm but turns to the north and dies out in a ravine.

East of the granitic outcrop, the trace appears again mainly as a single rupture and cuts across a cemetery, showing large displacements. Here the vertical offset varies between 40 and 125 centimetres, down to the south, and the horizontal displacement amounts to as much as 90 centimetres. In the downthrown side there are multiple fractures of conjugate sets of tension cracks and pressure ridges, forming a zone about 20 metres wide, and showing additional horizontal displacements. A fence two metres from the fault scarp, enclosing a grave and straddling two of these fractures, has been distorted in a manner indicative of a right-lateral displacement of about 30 centimetres (Figure 62), point 56. Two old oak-trees within a few metres on either side of the fracture zone were toppled; that on the south side fell to the west and the other to the east.

From point 56 the trace approaches Kavakkoy from the south with diminishing vertical displacements, trending 80°. East of the village a branch trace crosses the main road and, after passing between two massive outcrops of flysch and serpentine, follows an eroded scarplet trending 15° (Figure 63). This trace shows feeble right-lateral movements of about 10 centimetres and a throw to the west of nearly 30 centimetres. It crosses a stream and at point 33 branches off again, the smaller of the two branches, trending 50°, displaying left-lateral displacements over a length of about 150 metres. The throw here is small, about 10 centimetres to the south-east, and the lateral offset variable, from a few centimetres to 50. West of point 33, at point 32, a crack crosses the main road and terminates at the crest of a hill joining another crack about 100 metres long, which had the appearance of a landslide fracture.

Returning to Kavakkoy, a long trace about 500 metres south of the village can be followed, running parallel with a stream bearing almost east-west. Between this trace and the main fault-break to the north the ground is heavily broken; short open cracks and pressure ridges in thin topsoil trend in almost all possible directions and they become consistent with a right-lateral strike slip movement only in the vicinity of the trace.

From Kavakkoy the fault-break crosses cultivated land, bearing almost east-west. It shows right-lateral displacements of 60 centimetres and a throw to the south of 30 to 50 centimetres (Figure 64). Near point 35, the trace begins to climb a very steep slope from an altitude of 300 metres to 500 metres. Just before it starts its climb, the trace steps right and demonstrates left-lateral movements in the form of strong tensional cracks. This reversal of horizontal movement is rather local and is due to a thin cover of top soil sliding on bedrock down the slope. It persists all along the trace, showing displacements of 10 centimetres and throws to the southwest of the same amount. In places the bedrock was exposed by wide tension cracks in weathered material but there was no evidence of the movements observed extending into the underlying flysch. A search east of point 37 failed to produce any evidence that there was a fault trace of any sort to connect with those found further east.

A second trace, starting from near point 35 and bearing 195°, runs up to the top of the same hill, reaching an altitude of 530 metres near point 36. This trace showed small right-lateral movements of a few centimetres and a small throw to the east. Figure 64 shows a panoramic view of the Kavakkoy area, to the north-west from this point.

At point 39, a single crack crosses the main road which at the time of our visit had been repaired. The crack trends 100°, cutting through a thickly wooded slope facing north and it could not be followed very far. The slope is very gentle and there is no indication of landsliding. Short tension cracks, such as those shown in Figure 65, indicate left-lateral strike-slip movements, and broken roots show lateral displacements of 20 to 30 centimetres with negligible vertical movements. The crack was followed eastward, towards point 38 for about 150 metres until, near point 38, the vertical displacements begin to predominate, showing 55 centimetres throw to the south (Figure 66). No attempt was made to follow this crack further east; perhaps it joins the trace that passes through Sabanlar and Akyokuskava to the east.

South of Sabanlar, the trace passes through Akyokuskava and Haftasizkoy. It shows a downthrow, in places 40 to 50 centimetres, to the south with little evidence of lateral movement. In fact, feeble right-and left-handed movements alternate, depending on the direction of the hillslope, but they do not exceed 10 to 20 centimetres. Approaching point 31, the trace turns south, bearing 110° and it dies out as it runs up a slope. The villages of Akyokuskava and Haftasizkoy suffered some damage; almost all timber frame houses on trestles were thrown down (Figure 67). In contrast, houses of similar construction on proper foundations were only slightly damaged (Figure 68).

While the trace does not extend east of point 37, short fractures can be traced for small distances about three quarters of a kilometre from this point, bearing 100° to 110°. Further east, on the projection of this zone of cracks, a trace of tension cracks and pressure ridges can be followed eastward for about 1,600 metres, showing right-lateral movements with the north side downthrown. In a number of localities, particularly near the eastern part of the zone, the trace becomes complicated with numerous branches trending to the south-east. The trace here follows the contours at the base of a series of hills facing north and is about 300 metres out and 120 metres below the face of the mountain that rises just south of Akyokus, at the base of which another trace running east-west can be followed for 2,500 metres. This trace runs at the base of small ridges of terraces attached to the steep mountain slope facing north. West of Akyokus the trace, after crossing a stream with small horizontal and vertical displacements, follows an old landslide scarp which forms part of the terrace ridge that faces the village. At point 25, the trace shows a right-lateral strike slip movement of 120 centimetres and a throw to the north of about 110 centimetres (Figure 69). These movements are clearly the result of faulting and are superimposed on those caused by the resumption of movement of an old landslide which had utilized the fault break as its upper end. According to local information, the faulting associated with the 1957 earthquake had followed exactly the same trace as the 1967 rupture, and at this point had caused a throw of many tens of centimetres. At the time of our visit, the 1957 trace could still be seen, running almost parallel with and to the south of the 1967 rupture showing now a throw of 30 centimetres (Figure 69). In its course, the trace bearing 100° crosses a fence with a 110 centimetre right-lateral displacement (Figure 70), passes under a house, which it stretches, and continues east with the north side in places downthrown by 80 centimetres. The vertical displacements noted on this part of the fault vary erratically from a few centimetres to many tens of centimetres and they must have been controlled by the landsliding of the ground. While the observed displacements here are not purely tectonic, it is an interesting fact that almost the whole length of this part of the fault was ruptured ten years ago, displacing fences such as the one shown in Figure 70, and houses exactly on the same points. Further east of Akyokus, the trace turns, trending 60° for part of the way and gradually back to 80° near point 26. It follows the foot of a series of weathered scarps, some of them 20 to 50 metres long, covered with sod and thick grass resembling those connected with the 1957 rupture. The trace here is a single fracture, at point 26 showing a right-lateral strike slip displacement of 100 centimetres with a throw to the north of 50 centimetres. From point 26, numerous cracks on the downthrown side lead to the north trace previously described. The ground between this point and point 27 is severely broken, with numerous small pressure ridges and open cracks grouped rather erratically with no clear trend. At point 27 only marginal cracks can be followed, one of them shown in Figure 71, which run up a steel slope to the east and disappear on a saddle at an elevation of 750 metres.

The shaking of Akyokus lasted 4 to 5 seconds, and the main shock came from the west. People as well as burden animals and sheep were thrown to the ground, but the damage caused to houses was comparatively small. Out of 40 houses, four collapsed or were damaged beyond repair, all four of them being very old timber frame houses with rotten frames. The rest of the houses, some of them three storeys high situated about 40 metres from the trace, suffered very little damage (Figure 72); most of them did not even lose their brick tiles (Figure 73).

Access to the terrain for about 4 kilometres east of points 27 and 31 is exceedingly difficult and due to lack of time this part of the fault zone was only scanned superficially for surface features. Within this part of the zone numerous slides were noted, most of them old and reactivated by the shock. North and south of Yarbasi there was some indication of ground rupture but this was in places masked by local sliding. At one place, near point 41, there is evidence of slide-free movements amounting to 110 centimetres, right-lateral with a throw of more than 100 centimetres to the north, (Figure 74). Landslide scars connected with the 1957 earthquake can be found in the village as well as to the north of it; some of them were re-activated by the 1967 earthquake, which triggered new slides.

South of Giptiler, at point 28, a short scarp running along a mild slope showed signs of recent movement, perhaps connected with those of 1957. No fresh ruptures were noted in this area.

There is a long rupture trending 340° from point 102. This rupture was discovered by Mr. Taşdemiroglu, and it is of great interest because it coincides with the fault mapped a few years ago, separating lower Cretaceous flysch from Pliocene deposits. The trace is almost straight from point 101 southward, running up a thickly wooded slope from an elevation of 500 metres to over 600 metres. All along its length, the trace shows right lateral movements from 10 to 50 centimetres with the uphill (west) side downthrown. In places, the trace cuts through limestone with small displacements and near point 102 it makes a sharp turn, trending 80°. Here, compression features are enhanced, covering a wide zone to the north-east of point 102. At point 103, another trace can be followed along the axis of the plateau, bearing 130°. The north-westerly part of this trace is primarily a compressive mole-track with some indication of right-lateral strike slip movement; feeble vertical displacements show a small downthrow to the north. Near point 84, the trace is double and it develops grabens and complicated tension cracks showing right-lateral movements of a magnitude difficult to determine. Further east, the trace becomes discontinuous until at point 63 it reappears. The evidence of faulting here is rather obscure, distinguishable from secondary effects mainly due to its linear continuation independent of topography. The trace crosses a saddle at an elevation of 620 metres, and it can be followed for about 600 metres running down a slope. Here it consists of weak pressure ridges and short open cracks over a zone 5 to 20 metres wide. It is not possible to determine the nature of lateral movement because of the complicated tension cracks. This trace dies out on the slopes of Hill 731 before reaching the Mudurnu river.

Another rupture begins at Mandira to the north of point 63 and follows the same saddle only higher up. Near point 62 it shows 70 centimetres right-lateral strike slip displacements and a throw of 40 centimetres to the north, i.e. the uphill side is downthrown. On the downthrown side to the north numerous cracks, most of them tensional, form little grabens bounded to the north by a discontinuous fracture zone about 500 metres long. From point 62 the trace follows the base of a hill and as it approaches point 30 it gradually develops into a compressive moletrack, 2 to 3 metres wide composed of a series of soil plates humped up 100 to 150 centimetres high (Figure 75). The trace winds along the crest of a gentle slope, showing right-lateral displacements exceeding 150 centimetres (Figure 76). At point 30 it offsets the main road by 180 centimetres (Figure 77), and continues towards the river. No proof of vertical movement was found along this part of the trace. After crossing the road the trace passes between a wooden cabin and a house shown in Figure 77. Here the trace is on flat ground and shows a right-lateral strike slip movement of 70 centimetres, measured on roots, and a throw to the north of 40 centimetres (Figures 78 and 79). The cabin, five metres from the fault, was distorted and lost a few tiles. The house on the other side of the trace had its chimney thrown down but otherwise suffered little damage.

From this point the trace runs down a gentle slope towards the river (Figure 80). It consists of long en echelon cracks and pressure ridges showing right lateral displacements of about 180 centimetres. Approaching the Mudurnu river the trace widens and numerous parallel cracks branch off to the south (Figure 81).

The throw to the south noted on east-facing slopes here is of course local and contrary to the displacement of all the traces to the west, where the vertical movement was in general down to the north. This apparent reversal, shown in Figures 76, 80, 81 and 82 can be explained as fault exposures, associated with large horizontal movements on sloping ground. When the fault runs up or down a slope which faces to the right, a right-lateral fault movement will demonstrate an apparent throw which will face the observer. Other things being equal, the steeper the slope, the larger the apparent throw will be and under favourable conditions even a genuine vertical block movement may appear reversed. On very flat slopes the scarps may exhibit less consistency along the fault or they may even show discontinuously on one side only. In the latter case, compression features override those caused by the displacement of the slope (Figure 81). Returning to the point shown in Figure 82, it was possible to expose the fault plane 50 centimetres below ground level. It showed slickensided faces which were lined with sub-horizontal striations (Figure 83).

The trace approaches the river in the form of a moletrack composed of a series of soil slabs with gravel buckled up to 40 centimetres. Where it crosses footpaths, the trace has been trampled and only some ruts could be seen offset in a right lateral sense by 20 to 80 centimetres. The vertical movement is small. At point 42, crossing the flood plain of the river, the trace appears in the form of long pressure ridges. One of them has lifted up the river bed, damming the river (Figure 84). At the time of our visit, the river had just stopped flowing over the ridge and was in the process of cutting a channel at the eastern end of the uplifted river gravel. When this part of the fault was revisited ten days later the river had cut a wide passage and was eroding the east bank very fast.

According to local information, between points 30 and 42, the ground ruptures just described follow the trace of the fault break which was associated with the 1957 earthquake. In 1957 ground ruptures had been noticed next to the gendarmery post shown in Figure 79 and also in the vicinity of the point shown in Figure 84. In the first instance, an old scarp about 60 centimetres high facing north-west was found near the gendarmery which is now partly supported by a masonry retaining wall. The rest of the scarp has presumably been levelled off for the construction of the road.

The shock at Arpaseki and Taskeste was severe, throwing down people and burden animals. At Arpaseki three out of the 20 houses of the village were heavily damaged. At Taskesti the damage was very slight; a house partly on stilts, shown in Figure 85, was damaged. This house is situated about 15 metres from the fault break.

Between points 99 and 98, on the north side of Arpaseki, a long crack coinciding with the trace of the 1957 fault was discovered by Mr. Taşdemiroglu. It shows feeble right-lateral and vertical movements.

Returning to point 42, the trace crosses the Mudurnu river for the seventh time, cutting across the flood plain of the river where it can be followed only with difficulty. It crosses the river once more near point 50. Here, as in the previous crossing, there is evidence of pressure ridges having uplifted the river bed and upsetting the old course of the river. The trace cuts through a steep bank of marls on the east side of the river offsetting it by 190 centimetres (Figure 86), showing at the same time a small downthrow of about 20 centimetres to the north.

Past point 50, the trace trends 80°, crossing another gravel plain after which it follows the north side of the river for about 500 metres. Along this part of the fault, the south banks of the Mudurnu river composed of marls and gravels have collapsed. At point 87 the river turns sharply north, but the trace continues east, across the river for the ninth time, trending 80°, and cutting the east bank where it caused a lot of slides. From this point the trace, as a single crack, can be followed eastwards showing little deviation according by topography (Figure 87).

Another rupture, running almost parallel with and to the north of the trace between points 42 and 87 was noticed, skirting the foot of Hisar Tepe around which the Mudurnu river flows. It follows the 500 metre contour, showing a small throw to the south with little horizontal displacement (Figure 88). Near point 75 the trace turns gradually up the slope and disappears in a mass of shattered flysch. About 50 metres higher up the hill, between points 47 and 48 another trace was found in flysch. It consists of short cracks arranged en echelon which show a right lateral displacement of about 20 centimetres with the north-east (downhill) side uplifted by 10 to 30 centimetres (Figure 89). Here numerous stones, such as those shown in Figure 90, were thrown out of their seats and displaced from a few centimetres to 30 centimetres on flat ground. A search north-west of point 48 and east of 47 failed to produce any evidence that this rupture joins the main trace. There was landsliding in this area, particularly south of Caykoy. A short rupture about 80 metres long near point 43 just north of the village was found but no evidence of extensive faulting could be detected.

Returning to point 87, the fault, after crossing the river, passes through cultivated fields showing a right-lateral slip movement of 20 to 50 centimetres and a throw of 50 centimetres to the north. At point 45, a cross fault trending 150° runs up a steep slope showing small lateral movement and a throw of 10 centimetres to the east. At point 46, the trace makes a sharp turn and proceeds eastwards, following the 580 metre contour. The trace here is double and the block between the two traces is downthrown (Figure 91). Further east, the trace crosses thickly wooded slopes with very dense undergrowth which conceals the ground completely.

The trace between points 45 and 44 is not easily accessible and it was examined from a distance with binoculars where it was exposed in forest clearings. Near point 44 it follows the 600-620 metre contour and shows right-lateral movements with the north side downthrown. In the vicinity of Ortakoy and Yegendere local information indicates that the 1957 ruptures followed the same course as the 1967 faulting but they had shown smaller displacements. The villages on the north slope of the Elmacik valley suffered comparatively small damage. At Hamitler the damage consisted of a few timber houses, such as the one shown in Figure 92, being distorted. Houses with a more resistant ground-floor suffered no damage (Figure 93). At Yegendere the damage was even less; two brick structures housing the school of the village suffered some cracking (Figure 94).

Past the confluence of the Elmacik river with the Yegendere stream, the valley narrows and the south slopes become very steep, almost inaccessible. The trace can be seen in places but it was not followed up. At point 49, south of Sofular, the trace follows a narrow terrace and gradually widens out forming a zone of pressure ridges and open cracks about 20 metres wide. It shows right-lateral displacements of 20 to 40 centimetres and the sense of the vertical displacement is reversed (Figures 95a, 95b, 101). East of point 49 the zone steps left, showing strong tension cracks, and as a single crack runs up the side of the valley towards point 76. In so doing, the trace gradually grows smaller until west of point 100 it has become so faint as to be followed with difficulty. At point 100 the valley is very narrow, with constricted terraces of detritus occupying its right bank. The trace reappears here and continues up the right bank, showing right-lateral movement of 70 centimetres with a throw to the north of 40 centimetres demonstrating characteristics of a landslide feature. At this point outcropping limestones have been shattered, in places showing small displacements on old joints (Figure 96). To the east the trace bifurcates, one branch going up the slope, the other following the base. The upper trace continues, passing points 76 and 77, following the 780 metre contour all the way to Hacikoy and then to Igneciler. The lower trace soon ends, but other cracks can be followed near point 84, trending in various directions, indicating a major disturbance of the ground around this point.

Near Hacikoy at point 77, the trace appears as a single rupture showing 20 centimetres right-lateral displacement and a downthrow of the north side by 10 centimetres. From this point all the way to Guney, the trace is single and shows small displacements. The indication of movement on this part of the fault is always right-lateral with some indication of compression. The trace becomes more and more indistinct, until it is lost east of point 96 at an altitude of 900 metres. Numerous slides scar the sides of the valley (Figure 97), most of them triggered by the earthquake shock. The damage to villages in the vicinity of the fault was small.

Taşdemiroglu observed a long fracture between Tekirler and Harmanseki, on the south slopes of the Balaca river, about 1,000 metres to the south of the main fault.

Many other ruptures in alluvium were found, both north-west and south-west of the fault-break, as far as Pamukova and Adapazari. Almost all of these ruptures are due to lurching and slumping of the alluvium and they follow the flood plains of the Sakarya river. The authors mapped these, but only the more extensive ones will be described here.

One of the longest ruptures found outside the fault zone is that south of Cihadiye, about 500 metres north of the bank of the Sakarya river. This zone of cracks is about 1,500 metres long and it runs parallel with the river. It cuts across cotton fields and consists of long en echelon tension and compression cracks showing not only a right hand strike slip movement of 10 to 20 centimetres but also with the north side, i.e. the side away from the river, downthrown by 10 to 30 centimetres (Figure 98). Although the movements observed in this zone of ruptures would fit those of the fault zone, they are of doubtful origin. They may be explained as a mass movement of a part of the Sakarya flood plain on a very weak substratum. Along its whole length the rupture zone and the fields to the south are covered with a thin layer of silt and sand which has been ejected during the earthquake. Sand ridges deposited along ground cracks by the eruption of the ground water can be seen in places. According to local information, the valley here is normally under artesian pressure, and during the earthquake the part of the valley south of the fracture zone was flooded by the ground water which rose and remained above ground level, flowing towards the river for some time. North of the fracture zone the yield of the artesian wells increased temporarily, returning to normal a week after the earthquake. Along the banks of the river, sliding and slumping were noticed and large cracks were found open to a depth of 2 metres, wide enough for a man to stand in. The damage to the nearby village of Cihadiye was negligible.

Another system of cracks follows the banks of the Sakarya river from east of Adapazari to near Alancuma (points 58 and 59). They show very interesting features which taken alone can be most misleading as evidence of fault movement. One of the cracks is about 1,800 metres long running parallel with and to the east of the river, skirting the villages of Karakoy, Taslikoy and Kumkoy. Other cracks on the west bank were found running almost north-south, to the east of Gunesler. All these cracks developed from settling and lurching of the river banks and some of them were filled with mud-vent deposits (Figure 99). Near Alancuma, at point 59, a long crack about 1,500 metres long was found running parallel with and 200 metres to the east of the river. This crack is discontinuous and it consists of short en echelon conjugate sets of tension cracks and pressure ridges with the sod between them forming wedges (Figure 100). It is a pattern very similar to that observed in the fault zone, (see for instanc Figures 18 and 101), but here it shows left lateral movements of about 10 centimetres, with the side towards the river downthrown by 10 to 35 centimetres. A high-voltage pylon straddling this crack was distorted and had its diagonal bracing buckled (Figure 102).

Further south, at point 110, near Yukari Kirezce, the main road to Geyve was damaged by a transverse crack trending 60°. Here the road is on a small embankment which had spread out, causing some cracking in a north-south direction At the time of our visit the road had been repaired, but the transverse fracture zone could be followed for about 150 metres to the east (Figure 103). Here, cracks arranged en echelon indicate a small right lateral movement, but further west the ground has been harrowed and the trace could be found only in a few places on paths beaten by animals. On the east side of the road the trace was obscured by cultivation, but a series of mud-vents along a depressed zone in the field can be followed for a few hundreds of metres (Figure 104).

More slumping of the banks of the Sakarya river was found around Adliye (Figure 105). This is the southernmost part of the Adapazari valley. From about this point to the south, the Sakarya river is gradually hemmed in by rising mountains on either side and west of point 92 it enters the Balaban defile which it follows for about 20 kilometres. North of Kislacaykoy, about 200 metres above the Adapazari valley, a long crack trending 330° can be followed for about 400 metres. Throughout its length the crack is open, showing no movement and it soon develops into a slide zone.

Engineering aspects of the Mudurnu Valley earthquake

Almost all houses in the fault zone, from Abant to Sapanca, are of timber frame construction, one to three storeys high, with light timber walls infilled with clay and straw, adobe bricks, cobbles, or covered with wood sheathing. Pitched roofs over timber rafters are covered with tiles, corrugated aluminium sheets or planks. On steep slopes, one side of the house may be one-storey while the other side may be two or three storeys high. This type of house is supported partly by stilts and partly by a masonry foundation without any bracing or bolting to the foundation wall (Figure 85). On flat ground, where the soil permits, wooden stilts are driven into the ground and the ground floor is built 30 to 50 or more centimetres above ground level (Figure 72). Where the ground is too hard for wooden stilts to be driven in, a foundation wall of rubble masonry or of poor quality concrete is built on which the whole house rests with the minimum amount of bolting to the foundation wall (Figure 60). In most cases the foundation wall is either discontinuous, consisting of a number of plinths that serve as piers for the floor beams (Figure 106), or in lieu of proper foundation piers large stones are used on which the floor beams are placed without any other connection to the ground (Figures 92 and 107a). The latter kind of foundation is used particularly when part of the house is on stilts on sloping ground.

The use of timber for construction purposes was found to increase with decreasing distance of a village from the nearest free forest and to decrease with increasing wealth of the village; cement and bricks being more expensive than timber. Also there is a marked decrease in the use of timber along the fault zone, from east to west, particularly west of Samanpazari. As we proceed from east to west along the fault zone, houses with wood sheathed walls and cabins with interlocking corners are gradually replaced by houses with walls infilled with adobe or brick (Figure 107b). In this direction the number of houses of rubble and adobe construction increases and brittle construction of a more sophisticated plan begin to appear. Climatic conditions in the east part of the fault zone, where the altitude exceeds 1,000 metres, dictate smaller windows and rooms. In the western part, altitudes are under 100 metres and the number and size of exterior openings increases while the number of partition walls decreases. All these factors taken together result in producing structures with a resistance to lateral loading that decreases as we proceed from the eastern part of the fault zone westwards. This is reflected by the larger number of houses that collapsed completely in the western part of the zone. A typical example is Kislacay (Yenikoy), a small village at the western end of the fault zone. The shaking here was severe but no people were thrown down nor was there any indication of ground deformations. The village had almost all its houses either destroyed or damaged beyond repair. Adobe houses simply disintegrated, killing their inhabitants (Figure 108). Timber frame houses with mud-filled walls were damaged beyond repair. Figure 109 shows a typical house located about 50 metres east of the remains of the adobe house given in the previous figure. The difference in performance is striking; particularly when compared with the performance of the wood sheathed construction, typical in the east part of the fault zone, shown in Figure 72. Even more striking is the difference in performance between the adobe construction and the free-standing barn on stilts shown in Figure 110 which stands 15 metres west of the adobe ruins. One could put a hand into the hollow formed around the stilts in the ground by the rocking of the barn. Wherever found, adobe was seriously damaged and in the fault zone it was totally destroyed. On the other hand, timber frame construction showed various degrees of damage. Only when the timber was rotten or there were too many openings at ground floor level did it collapse.

In the fault zone very few unreinforced brick wall houses could be found, and there are no reinforced concrete structures at all. Two school buildings of brick construction at Yegendere, about 500 metres from the fault break, suffered only slight damage (Figure 94). In contrast, further away from the fault zone, at Dogancay a number of brick houses and the cami shown in Figure 111, together with the railway station, collapsed while near-by timber frame houses, one of them shown on the background of the ruins of the cami in Figure 111, suffered slight damage. Unreinforced brick construction suffered even more at greater distances from the fault-break. For instance, near Asagi Kirezce about 10 kilometres south of Adapazari the damage to brick houses was severe (Figure 112).

In the fault zone, wood frame houses in good condition built on stable ground withstood the earthquake with comparatively little damage, regardless of their proximity to the fault-break. Heavy damage to this type of construction was observed only when the timber was old and rotten or when the structure itself was either involved in landsliding or it straddled the fault. The degree of damage was noted to increase with increasing use of brittle infilling materials, particularly with cobble masonry, and with increasing weight of the roofing material.

During the last 60 years more than 60,000 people have been killed by earthquakes in Turkey, out of which 50,000 were in the Anatolian fault system (Figure 134). During the same period about 300,000 houses were destroyed and at least twice as many were damaged. These figures roughly correspond to an annual capital loss of £10,000,000 (adjusted to the value of sterling in 1960).

The distribution of damage and loss of life along the whole Anatolian fault system is not uniform. In spite of the decrease in density of population, the loss of life and damage to property increases from west to east. There are many factors that support this observation, and a partial explanation for the increase in damage in the eastern part of the fault zone is that of the gradual decrease of woods and the scarcity of timber in the east. Woods abound in the western part of Anatolia and village houses are of timber frame construction. In the east-central part of Anatolia, from about Amasya to Susehri, timber begins to be scarce and it is replaced by adobe and rubble masonry. East of Susehri to Lake Van timber becomes a rarity and adobe becomes the main building material, (Orman G.M. 1962, Ambraseys 1966).

Structural damage was surprisingly small for an earthquake with such extensive surface rupture and large magnitude. Variations in damage were more closely related to the quality of the building materials and the method of construction for each individual house rather than to proximity to the fault-break. Figure 113 shows the distribution of damage within an area of approximately 7,000 square kilometres. The data used is based partly on information supplied by the Ministry of Housing and partly on our own observations. The various

It is of interest to note that within the fault zone, here 2 to 4 kilometres wide following the fault-breaks from Abant to Akyazi, the distribution of damage is no different from that of the rest of the region. It remains local and it occurs in spots, varying erratically over short distances along the fault. A heavily damaged village might be surrounded by other villages which had insignificant damage. In some cases the latter straddled the fault trace. Even in the same village heavily damaged houses were found surrounded by other houses with negligible damage.

Our evidence shows that in the case of the Mudurnu Valley earthquake, proximity to the fault-break was not necessarily associated with heavier damage. This feature was investigated more precisely, in a qualitative way in the following manner. The percentage (D) of the total number of houses rendered useless in each village was calculated for the region shown in Figure 113. Also the number of villages (N) that suffered damage equal to or greater than (D) was calculated as a percentage of the total number of villages. A damage distribution plot was then constructed, shown in Figure 114, in which the abscissa is the percentage of the villages that suffered damage equal to or greater than (D), while (D) is the corresponding ordinate. Distribution A in this figure refers to the whole region shown in Figure 113, while distribution B shows the damage distribution within the fault zone, taken here as a zone 4 kilometres wide following the fault-break. On such a plot, a significant increase of damage in the fault zone should have led to much higher values of N for the B-distribution. Instead, there is a conspicuous similarity between distributions A and B which shows that the distribution of damage in the fault zone is a representative sample of the whole area and consequently independent of the proximity of the sample to the fault break.

Adapazari, a modern town with a population of over 90,000 inhabitants, is situated in a fertile low-lying valley of recent deposits and marshes of the Sakarya River, 15 kilometres north of the fault. A masonry bridge with eight arches built in 559 A.D. on the river Sakarya is now 4 kilometres west of the new bed of the river. The soil conditions at Adapazari are very poor for structural purposes and houses are constructed on very shallow mat or raft foundations. Most of the heavier older buildings are on timber rafts or on short wooden piles, some of them driven to depths of 10 to 20 metres. The water table in the town fluctuates seasonally between 50 and 200 centimetres below ground level and as a result of this there are no basements and the foundations are abnormally shallow; vibrations caused by passing vehicles can be felt at great distances.

The town has suffered from the earthquakes of 1878, 1894, 1943 and 1957. Particularly severe was the earthquake of 1943 which destroyed about 70% of the houses in the town; some of the houses that were damaged in 1943 and then repaired, collapsed during the 1967 earthquake.

The ground movements at Adapazari during the 1967 earthquake should have been slow with large amplitude. Water sloshed from ponds and water tanks of various sizes in the parks and in the Sugar Factory, and lime was thrown out of a soaking pit at a building site. Tall slender structures, such as chimney stacks and minarets swayed and some of them suffered various degrees of damage. A few short minarets of masonry construction were thrown down and a few brick chimney stacks had their top part whipped off. One of them, shown in Figure 115, was seen by a bodily on a joint near its base, coming to rest before the shaking was over. Timber minarets supported by a central wooden pole suffered no damage except when the pole itself was broken at the base (Figure 116). There was no serious damage to elevated water tanks and to high voltage pylons.

The 1967 earthquake damaged beyond repair about 900 houses in the town, in which 43 people were killed and 148 injured. Most of these houses were of old timber frame construction, suffering from previous earthquake damage, and in a poor state of repair. More substantial buildings constructed after the 1943 earthquake were damaged far less, while many properly constructed timber or reinforced concrete frame houses suffered only plaster cracks. No major engineering structures showed signs of excessive deformation.

Reinforced concrete structures in the town, about 60 in all of various sizes, suffered minor non-structural damage. The exception was seven of these structures, three of them under construction, that collapsed. One of them, shown in Figure 117 with its roof shoring still in place, was thrown out of plumb by the main shock. The aftershock on 30 July brought down the whole structure when its ground floor columns failed.

The regional factory of agricultural equipment (T.Z.D.K.) was initially built in 1940. It is said that the factory buildings were destroyed by the earthquake of 1943 and that the factory was rebuilt in 1944 on the same site. Today the factory consists of a complex of long sheds which house workshops, and of smaller buildings, one to two storeys high, which house the administration and stores.

The sheds have pitched roofs with light guage steel or timber roof decking and timber trusses on reinforced concrete columns. The roof is supported by an outer masonry wall and by a series of internal concrete columns connected with lightly reinforced concrete beams. One of the shop sheds, the steel workshop, was heavily damaged; the wall facing south-west was thrown out, pulling with it the roof, which in turn forced the reinforced concrete columns to bend over and fail. This induced severe bending moments at the top and bottom of the central columns, resulting in crushed concrete and bending or snapping of the reinforcing bars (Figure 118). Other sheds were damaged less, and a few gable walls were thrown down. Sheds with ring beams showed less damage than similar structures with roof beams on wall plates. Where the restraining effect of in-filled walls stopped at sill level, external columns were found damaged at midheight. A cast-iron, 12 centimetre pipe, buried 180 centimetres in the ground was pulled apart and concrete paving slabs 150 x 150 centimetres were forced by the ground movements to hump up and overlap each other by 2 to 3 centimetres.

The Prefecture of the Sakarya District (Sakarya Vilayet), a five-storey reinforced concrete structure, had its shear walls and two columns severely damaged (Figure 120). This structure has no basement and it is built on a reinforced concrete raft strengthened by heavy beams, on soft silty sand about 2 metres deep (Figure 119). The skeleton of the structure consists of twelve bays facing the main square of Adapazari, two bays deep. The floors of the structure are of precast slabs, 37 centimetres thick resting on beams of the same thickness. Partition walls are of hollow concrete blocks. Because of architectural requirements, the ground floor is open, except for the 8th, 9th and 10th bays which contain the lift-shaft, the stair-well and service rooms, and which are partly enclosed. Two transverse structural shear walls, 23 centimetres thick and 4.75 metres deep flank the staircase throughout the height of the building. A third, thin transverse shear wall which does not extend all the way down to the foundation, encloses the lift-shaft. At ground level there are also two longitudinal walls; one of them occupies the 9th and 10th front bays and the 10th central bay. This latter wall is weakened by a doorway next to column 10B. An incomplete longitudinal outer wall occupies the rear 8th as well as the rear and front 9th and 10th bays.

These walls added in an asymmetrical way to the lateral resistance of the ground floor and torsional effects would be expected. As a matter of fact the middle column, 10B, which was stiffened in its upper half by two weaker cross-walls, failed (Figures 121, 122). The other longitudinal shear wall of the front bays was slightly damaged, and the lift shaft was shattered; column 11B also showed signs of overstressing. The damage was also severe around the lift shaft on the first floor but it decreased with height. Apparently what happened was that the structure deflected in its longitudinal direction, which is the weaker one, and at the same time was forced to rotate about an axis located outside the back of the building. As a result of this combined action, column 10B, next to the incomplete shear wall, was loaded over the upper half of its length and was pushed out. Figure 123 shows the details of this failure. The rest of the columns on the ground floor suffered no structural damage.

Almost all central columns on the first floor were strained to the extent that the heavy gypsum plaster was detached from the concrete and fell off. In contrast, columns on the ground floor which were clad with copper sheets, when uncovered, showed no signs of overstressing. Longitudinal cracks were noticed in the outer beams of the north façade of the building at the 1st, 2nd and 3rd floor levels. On the first floor, external and partition transverse walls were damaged (Figure 119). This damage was aggravated by the shock of 30 July when some additional cracks appeared in the walls of the first floor and also in the ground, near the south end of the building.

The reinforced concrete work in the building was variable. The concrete of the shear walls was rather poor with coarse and uncemented aggregate. Cracks were noticed where tubing and conduits were embedded in the shear walls and along cold joints.

A five-storey reinforced concrete skeleton building under construction on the main street of Adapazari collapsed completely, leaving the floor slabs piled on one another (Figure 124a). The details of this failure were difficult to discern; the main framing apparently consisted of transverse reinforced concrete frames, each with four columns, the outer two of which had large aspects ratios (30 x 95 centimetres cross-section). For architectural purposes, at ground floor each second column of the transverse framing of the upper storeys was missing (Figure 124b). This column arrangement and the large aspect ratio of the columns resulted in a ground floor which was unstable in the longitudinal direction, in which the structure in fact collapsed. In contrast, adjacent houses suffered comparatively little damage.

Near the Railway Station, a group of four silos shown in Figure 125 suffered some non-structural damage. Each silo is supported independently by wooden piles, 50 centimetres diametrr driven 10 metres into the ground at 110 centimetres centres. These piles are capped with a reinforced concrete ring beam.

The steel connections of silos No. 3 and 2 with their ring beams were found strained, and some buckling in the steel connectors between these two silos and the central sieving cylinder was noticeable. These two silos at the time of the earthquake contained 500 tons of grain as compared with silos No. 1 and 4 which contained only 60 tons. Ground deformations near silos 3 and 4, resembling slumping, were noticed but it was not possible to establish whether these resulted from the shaking or from the settlement in the back-fill of a near-by drainage trench.

At Arifiye, a single-storey reinforced concrete house, under construction at the time of the earthquake, was thrown out of plumb by the shock and had its columns damaged. After jacking the structure back to its original position a few of its columns were opened up for inspection and repair. One of them is shown in Figure 126. It shows that of four bars in a column, only two extended into the foundation. Moreover, at the beam junction these two bars are bent away from the face of the column.

A reinforced concrete building on the main road to Istanbul at the east entrance to Izmit was completely destroyed (Figure 127). It is a three storey building on a heavy raft, three bays wide and ten bays long. For some unknown reason stirrups were used only in the upper half of the ground floor columns, the lower half of the columns including their extension into the raft below ground floor level did not have any stirrups at all. Apparently this was noticed before the earthquake and all internal columns of the gound floor were reinforced with 100 mm I-beam stilts connected with flanges to the beams and floor (Figure 128). Shorter stilts, about 20 centimetres high, were used to shore up the connexions of the columns with the raft. As a result of the earthquake, the lower half of the internal columns at ground floor level burst open and if it were not for the stilts this building would have collapsed (Figures 128, 129, 130, 131). The stilts buckled and the structure was unsafe to enter. An inspection of the space between the ground floor and the raft as well as of the upper storeys showed no signs of damage, nevertheless, this structure was made useless. The ground movements in Izmit were rather weak; they caused no damage.

The earthquake did comparatively little damage to the Istanbul-Ankara railroad along a length of just over 18 kilometres in the Balaban defile (Figure 132). At Alifuatpasa, the railway station, a two-storey stone masonry structure built in 1893, showed numerous cracks and some deformation of its outer walls. Since its construction this building has survived numerous strong earthquakes with minor damage. At Alifuatpasa (0,000) the central pier of a two-span truss bridge moved relative to its shoes by 3 centimetres in a north-south direction; the west abutment also moved relative to its shoes by 1.8 centimetres but caused no interruption of the traffic. Near-by, an old masonry arch bridge built in 1495 suffered no damage except for a 2 centimetre displacement of its south-east abutment with respect to the new road deck.

Between 5,200 m and 6,800 m the railway line was damaged by rock falls and was replaced. Between 7,200 m and 8,320 m the ballast, which is on solid rock, cracked in places and settled, and between 8,250 m and 8,700 m the line slid to the south-east by 30 centimetres and the ballast had to be repaired at locality 90 (Figure 13.1). Between 13,500 m and 14,700 m the line was distorted into a succession of S-shapes, in places sharp enough to cause discomfort to passengers. Finally, near Adliye, between 16,200 m and 18,200 m, rock falls in places caused some concern.

The region between stations 0,000 m and 18,000 m is perhaps the area most severely affected by the aftershocks.

Intensity distribution in the fault zone

The writers doubt the existence of isoseismal lines and the value of intensity scales within the epicentral region of a strorg earthquake. The criteria incorporated in intensity scales are obviously open to criticism but, even if they are exact, the writers believe that the estimates of the epicentral intensity in any one place in a developing country, are so variable that it is impossible and misleading to trace isoseismals particularly when a fault-break is involved (Zatopek 1968b, Ambraseys 1968b). The only isoseismals that the writers would have traced here are those showing intensities of VII(MM) or less.

The damage caused by the Mudurnu earthquake followed a typical pattern met elsewhere (Ambraseys 1963, 1968a, Zatopek 1968a). Wherever adobe was found in the epicentral area it was totally destroyed; in contrast, timber frame houses suffered comparatively little. The fact that only these two types of construction with their widely different inherent resistance were available for observation in the region, made it practically impossible to assess epicentral intensities. For instance, at Akyokus the fault displacements were large, and the trace passed through the village. Out of 40 houses, two straddling the fault-break were badly distorted and two more were thrown out of their foundation plinths. The remaining 36 houses of the village suffered little damage (Figure 73). In other places, for instance near Samanpazari and Caykoy, the fact that "objects were thrown into the air and lines of sight and level were distorted" (Richter 1958) implies an intensity XII (MM). Yet, on purely vibrational criteria the maximum intensity that can be assessed did not exceed VIII to IX (MM).

The intensities at a considerable number of places in the fault zone were assessed independently by as many as six observers. Their estimates varied by as much as four degrees, depending on the particular criteria of the (MM) scale that each observer considered to be most suitable for the occasion. The writers finally agreed that it was practically impossible to assess epicentral intensitites without becoming unduly subjective.

Discussion

The Mudurnu Valley earthquake of 1967 occurred in the west-central part of the Anatolian fault zone and it was associated with surface faulting. The fault trace is slightly arcuate, trending almost east-west. About 25 kilometres of the eastmost part of the fault-break lie in a zone ruptured ten years earlier but the new ruptures do not seem to follow the trace which is associated with the 1957 earthquake (resheared part of the fault zone). The next 20 kilometres of faulting lie within a zone where geologic evidence suggests very recent tectonic movements but here again the new ruptures do not follow mapped faults (revived part). The rest of the 1967 fault-break, which extends to the west for another 40 kilometres occurred in a region where there was no indication prior to this earthquake of very recent faulting (ruptured part); and although one might have suspected a west-trending continuation of the fault zone, there was no clear evidence of this.

The surface ruptures are neither continuous along the whole length of the fault-break, nor do they follow precisely mapped faults. They rather seem to follow a path of least resistance within a comparatively broad shear zone, one to three kilometres wide and 50 kilometres long, shifting laterally from one shear plane of weakness in one part of the zone to another. Of particular interest here is the well-developed large-scale en echelon pattern. Along a length of 35 kilometres en echelon shear planes showing conspicuous tensional features formed at an acute angle to the axis of movement, stepping to the left, with their apex pointing in the direction of relative displacement, a pattern consistent with right lateral strike-slip movement of the fault zone. This is shown in Figure 133 in which it can be observed that the en echelon shears are connected by almost continuous displacement ruptures which are shown in thick lines. Tensional features and grabens are connected with the en echelon shears and there is at least one case of compressional features found on the displacement ruptures. The axis of relative displacement is arcuate and the angle it forms with the en echelon shears does not exceed 15 degrees on the average. The shear pattern shown in the lower half of Figure 133 was drawn on the basis of a 1:25,000 scale mapping of the fault trace. Mapping on a smaller scale would tend to obliterate the details of the shear pattern and the trace would appear continuous and smooth; on a larger scale the pattern remains the same. It is of interest that in spite of the non-homogeneity of the fault zone the trace shows a regularity in pattern.

The sense of movement along the fault-break is right lateral with the north side in general downthrown. The magnitude of relative displacements varies from a few centimetres to 190 centimetres right-lateral and up to 120 centimetres of throw. These measurements were taken on single ruptures or across narrow fracture zones. Unfortunately there was neither time for repeated measurements nor facilities for the re-triangulation and re-levelling of the fault zone. There is some indication, however, that the cumulative strike-slip movements across the fault zone were much larger than those measured in the immediate vicinity of the fault-breaks. For instance, a high voltage electric line runs parallel with and to the north of the fault-breaks on pylons spaced between 200 and 500 metres apart. Where this line crosses the fault at an acute angle from WNW to ESE the wires were found sagging far more than a two-metre shortening of the distance between pylons would account for.

Most of the features of faulting were noted in alluvium, in detritus or in a thin mantle of topsoil overlying bedrock. These features reflect the permanent deformations of the underlying bedrock as modified by the presence and by the dynamic response of the overburden to the sudden readjustment of the bedrock. The fact that wherever found, relative horizontal displacements in bedrock were far smaller than in alluvium suggests not only that displacements in alluvium contain a certain dynamic element but also that some of the ruptures observed might have resulted from shaking and from restraints offered by the relief of the bedrock. Tension cracks are easier to detect and perhaps the first features to form. Pressure features are difficult to discern and become conspicuous only at comparatively large displacements.

During the preliminary survey of the fault zone, a reversal in the lateral movements, from right to left-lateral, was noticed on ruptures between localities 16, 15 and 18 (see for instance Figures 55 and 56). Also, according to local information which was not possible to authenticate, these ruptures were associated with the major aftershock of 30 July. This suggested the possibility of a right-lateral strike slip associated with the main shock, followed by a reversal during the major aftershock. A closer inspection, however, of this and of a few other parts of the fault-zone where local reversals had been noticed, revealed that the features that indicated reversals were due to secondary effects (gravity, rotation of large soil slabs, apparent throws etc.)

The instrumental epicentre of the main shock has been located by the ITU somewhat north of the eastern end of the resheared part of the fault zone (Figure 10). It is interesting that most of the aftershocks, recorded and felt, are concentrated at the other end of the zone, in the extreme west, where the observed fault-break is discontinuous.

In the immediate vicinity of the fault-break, the damage caused by shaking is equal to or less than that caused ten to twenty kilometres away from the zone. The ground accelerations in the fault zone should have been very high and the maximum vertical ground acceleration in places exceeded that of gravity.

Estimates of intensity in the fault zone were so variable that it was impossible to trace isosismals, particularly near the fault-break. The only isoseismals that the writers would have traced are those showing intensities of VII (MM) or less.

Proximity to the fault-break was found to be an unjustified criterion for higher intensities. Damage in the immediate vicinity of the fault-break was equal to but more often less than at some distance away, the controlling factors being the foundation stability and type of construction, rather than proximity to the fault-break.

General recommendations for restoring housing in earthquake areas

The following notes concern the measures that a developing country should take in order to restore housing and community facilities in an earthquake disaster area. (Ambraseys 1966).

The problem of reducing earthquake damage and of restoring housing after an earthquake can be divided into two stages:

(i) Planning before an earthquake

(ii) Emergency action after the event.

Both stages should be studied in advance by a special national agency, whose task would be to investigate methods and study techniques for the prevention of disasters caused by earthquakes.

After an earthquake it is found very difficult to establish an effective central agency for the direction and control of the rehabilitation and reconstruction of the affected area, and much effort and funds are usually diffused in disparate activities. In economically developing countries, after a disaster, there is always the difficulty of deciding on the spur of the moment, how local and foreign aid should be best used and what priority should be given to the innumerable needs of the area. Invariably, this problem is left to the loca authorities to resolve or to an ad hoc committee without much deliberation. Often a large proportion of the aid is misused. The lack of regional developmen plans and the absence of any planning policy may result either in regrettable reconstruction errors, or in long delays which might have detrimental repercussions on the efforts for restoring housing.

To facilitate the establishment of such an Agency, a country should have an Act or Ordinance passed by the central legislature. This act would, inter alia, empower the agency to carry out research, make building regulations pertinent to earthquake problems, and to apply any or all of them in any desired area. Also, the agency should be kept informed and up to date on rural, urban, town and country planning developments, should participate in formulating the country's economic policy in the event of a disaster, and should direct emergency and permanent housing.

Planning, before an earthquake, is extremely important in reducing earthquake damage and in minimizing earthquake after effects. It must be understood from the outset that such planning, no matter how well it may apply in one part of the world, may prove completely insufficient or even detrimental in another. It must be made quite clear that such planning should be intended as a starting point, that it should be studied and amended as need be by the agency's professional staff who are familiar with the problems involved. There is no way of producing rules-of-thumb which will be generally applicable or effective, without adapting them to local conditions which may vary even within the same country from district to district, and from year to year.

The most important item in the planning stage is education. The relief of a country crippled by a natural disaster is largely based on the efforts of its inhabitants. In most of the economically developing countries the majority of the population is ignorant about the dangers that natural forces have in store for them, and those who do know, have no idea of their causes or their effects.

Superstitions, misinterpretations of well known natural phenomena, and ignorance often lead to additional disasters.

In a seismic country, the population must be educated about natural phenomena and their effects, at an early stage of their lives. Secondary school education must include such a study so that the absurdity of superstition may be brought out. Instructions on earthquakes should be given in the form of public lectures and of pamphlets. The destruction caused by earthquakes should be explained, pointing out that improperly built houses are death-traps; their owners should be made aware of what may happen during an earthquake.

It is not so much what one can prescribe for those afflicted by an earthquake, but one's understanding of particular needs and one's success in gaining the co-operation of the inhabitants that is important.

Properly planned courses in earthquake engineering should be included in Technical University curricula.

Building control is concerned with the health and safety of people, particularly the occupants of buildings. This control is exercised by determining, enacting and enforcing certain minimum standards below which no person is permitted to build. It is assumed that anyone adopting lower standards would endanger the health or safety of others.

Experience has shown that nearly all countries need several sets of building regulations. The first set should apply to all buildings and be intended for use by professional designers. In most developing countries professional de designers deal with only a few per cent of the total housing capacity of the country.

The second set, which concerns the majority of the housing capacity of the country, would be intended for use by small builders. These small builders cannot be overlooked; they build the houses in which more than 90% of the population live. Regulations (for the use of builders) to satisfy certain economically minimal rules for earthquake resistance must be simply phrased and the deemed-to-satisfy clauses must be brief specifications. This set of regulations would cover buildings of one or two storeys in villages, towns and in the countryside (see for instance Daldy 1964).

A third set of regulations may be needed to control houses built of temporary materials, or of prefabricated elements; these are often necessary to replace, at minimum cost, after an earthquake, uncontrolled shanty towns or emergency camps.

In the planning stage, regulations for the earthquake-resistant design of all types of structures should be studied. These regulations should be the tast of a special committee, which should study and elaborate new methods and materials of construction, and keep these regulations up to date, taking into consideration local conditions, the economy of the country, and the seismicity of various populous areas.

For the stage of relief, the agency should have plans made well in advance for assessing the damage and the needs of the damaged area. On the basis of these assessments the central agency should mobilize its reserves of first-aid supplies (food, medicaments, tents, etc.) and dispatch them within a very short period of time. The Armed Forces of the country should be prepared to co-operate with the agency, particularly in transporting first-aid material, in the rescue work, and in the clearance of rubble. However, the agency should guide the demolition units in their work in order to avoid additional destruction caused by uncontrolled actions.

The agency, at this stage, should be in a position to assess its needs and make proper use of the foreign aid. A lot of valuable time and badly needed money is usually wasted in erratic actions of a multitude of charitable bodies which act without any centralized control. Tens of nations and of welfare bodies often contribute independently with absolutely no central organization, and without any knowledge of what is really needed. Even from the same country, aid is often fragmented and relief actions are taken independently, wasting part of their efforts and confusing their recipient. The central agency should be in a position to know shortly after the earthquake what is needed and where. Such co-ordination action would avoid useless repetition and waste of funds.

Temporary housing after disastrous earthquakes in economically developing countries often follows a pattern detrimental to long-term planning, particularly where there is no regional planning. After a short period of enthusiasm for ambitious restoration plans, the interest in the application of various schemes begins to die out, as the available funds are found to be insufficient, some of them having been already squandered, and as the problems which rehabilitation poses become more involved and less exciting.

The usual pattern is that as with time the interest of the authorities begins to decrease, many rehabilitation sites are left unfinished and poorly equipped. Villages and small towns turn into ghost settlements and their inhabitants begin to migrate to the nearest city, leaving the less active members of their community behind (see for instance reference United Nations 1966).

In most cases the authorities decide at this stage to relieve the stricken area by issuing free building materials for repairs or, more often, by granting loosely termed loans.

Since this method of relief is not always the best, the results are often unsatisfactory. What happens sometimes is that the materials are either misused, since villagers and townsfolk are far from able to do a proper job of repair, or they are sold for cash. The loans are often used partly for the purpose intended and partly to finance small businesses or to help members of the family to emigrate and settle in another part of the country.

Although in some cases the issuance of loosely termed loans to destitute villagers is the only alternative, the authorities should not forget that as supervision of the use of the loans becomes more slack, abnormally high profits are sometimes made at the expense of funds raised for relief and rehabilitation. Moreover, when there are no more funds available, the half-finished houses are patched up, to be damaged or destroyed by the next earthquake or by heavy rain.

It has been said that granting loans will stimulate the "self-help" of the population. This does not seem to be always the best solution. Ready cash is always spent more easily, even by persons who have no means of paying the loan back. High profits are made by the local builders and by those who sell locally building materials. Also, loans will cause locally an increase in prices, which, though temporary, will affect the living standards irreversibly.

Proper emergency planning should consider raising the local living standards through the increase of the productivity of the region (by stimulating with large funds the main sources of income) rather than by giving cash.

The agency should study the possibility of producing en masse a variety of prefabricated houses. With the financial support of the State and of private sources, a number of small factories for the production of suitable prefabricated units should be established; particularly in areas of seasonal unemployment, since this will boost the local economy. Surplus of prefabricated units could be exported to neighbouring countries or sold to welfare bodies who would like to donate them to earthquake striken areas.

Acknowledgements

The mission was composed of Dr. N. Ambraseys, Imperial College University of London, and Professor A. Zatopek, Charles University, Prague. To the mission, the Ministry of Housing and Reconstruction in Ankara attached Mr. M. Taşdemiroglu and Mr. A. Aytun of the Department of Research and Development. Mr. G. Cologlu, seismologist of the Kandilli Observatory, and Mr. U.Guclu, geologist of the Institute of Earth Sciences, Technical University of Istanbul participated at the invitation of the mission in the field trip between 16 and 22 August. Miss R. Can, seismologist of the Kandilli Observatory also joined the mission and spent the period 25 to 28 September in the field. Professor G. Berg of the University of Michigan spent 11 and 12 August with the mission.

Whatever success the writers have had in carrying out their objective was made possible only by the generous assistance provided by many individuals and institutions in Turkey. The Vali of Sakarya and Mr. Fikret Ungan, Director of the Department of Reconstruction of the Ministry of Housing and Reconstruction in Ankara gave the writers the full backing of their offices and extended every courtesy in providing access and information. Mr. Riza Altin and Mr. Ziya Barut, of the same Ministry, also gave freely of their time during the extremely busy weeks that followed the earthquake.

The writers are most grateful to Dr. S. Abdusselamoglu of the Geological Faculty, Istanbul Technical University and to Dr. N. Canitez of the Institute of Physics of the Earth, ITU, for valuable comments.

The writers would also like to record their indebtedness to the United Nations' staff in Ankara, and in particular to Mr. T. M. Unwin, Deputy Resident Representative, for his generous co-operation and for the facilities afforded during the course of the mission.

Appendix

Extract from Öçal (1959):

"(p.3) The damage was particularly heavy in the villages on either sides of the Mudurnu river and in the Dokurcun valley, i.e. in Serafiye, [illegible], Beldibi, Mansular, Gokceler, Dutlar, Hayderler, Madenler, Yagcilar, Cengeler, Sepetinler. Damage was less severe in Kayabasi and in Tasgil. Out of 18 houses in Caylar (Topekoy), 5 collapsed and the rest were heavily damaged; no doubt this is one of the two ends of the fault line.......

(p.4) After entering the road to Abant from the state highway, we observed that the school, a timber frame construction with infilled brick-walls built on solid foundation, had collapsed. Also we noticed cracks and landslides on the Abant road, fallen trees and damage to the Soguksu forestry building. We concluded that we must be near the epicentre. The fissure found at the 20th kilometre was quite different from those connected with landslides. This gave us the impression that we must be on the other end of the fault that caused the earthquake. A villager from Dereceviran stated that the fault line associated with the 1944 earthquake of Bolu reappeared again this time. This supports our view that the active fault of the present earthquake is a continuation of the 1944 fault..

(p.6) We climbed up the slopes on the north side of the lake (Abant) where we found three parallel fractures, spaced 40 to 50 metres apart, forming steps, and bearing NE-SW. The first two show a throw to the north and the third to the south. The throw of the north crack was about 40 cm. and its opening was 70 cm. The azimuth of the fault was N 50-60 E on a slope making an angle with the vertical of 75 to 80 degrees. The secondary fractures between these cracks were different; we thought that they must be due to landsliding. This fault line, having one end fixed on the Abant road, extends to the SW, following the hills on the north side of the Abant Lake and extends to the Dokurcun valley where the damage is maximum....

(p.7) Thus we have secured one end of the fault in Caylar and the other on the Bolu-Abant road. We observed its overwhelming appearance on the north slope of the Abant Lake. Since the damage is maximum, and the water has dried up in springs and houses have collapsed in a characteristic manner in the villages of Guney, Igneciler, Elmacikdere, Sofular, Yegendere, Ortakoy, and Suvakoy, these must be located just on the fault line; the ground fissure (160 cm. strike slip and 35-40 cm throw) we found is not local but it must extend to Elmacikdere to the west and to Seymandere to the east....

(p.10) As a result of our studies we found faults extending from the north of Abant to the Dokurcun valley, being parallel to each other. One of them which should be considered as the main fault, extends from Abant to the Seymen valley and crosses Igneciler, Guney, Elmacidere, Yegendere, Ortakoy, Suvekoy, and then it follows the Mudurnu valley and continues up to Caylar. The other (fault) extends along the valleys and slopes which contain the villages of Karacomak, Madenpasalar, and Arpaseki".

References

Abdüsselâmoğlu, M.A. (1959). Almacikdaği ile Mudurnu ve Göynük civarinin jeolojisi, Üniv. Istanbul Fen Fakult. Monografileri, 14, Istanbul.

Agamennone, G. (1900). Liste des tremblements de terre observés en Orient et en particulier dans l'Empire Ott pendant l'année 1896. Beitrage zur Geophysik 4, 118-199, Leipzig.

Ambraseys, N. (1963). The Buyin-Zara earthquake of September 1962, Bull. Seism. Soc. Am. 53, 705-740.

Ambraseys, N. (1966). Seismic environment; the Skopje earthquake of July 1963, Revue de l'Union Internationale de Secours, No. 5, 62-81, Geneva.

Ambraseys, N. (1968a). An engineering seismology study of the Skopje earthquake of 26 July 1963, Publ. Unesco, The Skopje Earthquake, 35-89, Paris.

Ambraseys, N. (1968b). A note on the intensity of earthquake motion, Symposium on Regional Seismicity, 14th IUGG Assembly, Institut Fiziki Zemlii, Moscow (in press).

Ambraseys, N. and Zátopek, A. (1967). Earthquake reconnaissance mission to east Anatolia, Unesco Publ. WS/0267, Paris.

Ambraseys, N. and Zátopek, A. (1968). The Varto-Üstukran earthquake of 19 August 1966, summary of a field report, Bull.Seism.Soc.Am. 58.

Anonymous (1851). Notice of the occurrence of an earthquake at Bursa, Quart. Journ. Geol. 7, 19, London.

Anonymous (1878a). Nature 18, 514, London.

Anonymous (1878b). Nature 18, 77, London.

Anonymous (1884). Nature 29, 272, London.

Anonymous (1884a). Nature 50, 273, London.

Anonymous (1894b). Nature 50, 581, London.

Anonymous (1953). Nature 152, 382, London.

Anonymous (1957). Nature 180, 121, London.

Anonymous (1968). Nature 217, 14-15, London.

Birand, Ş. A. (1940). Dikili zelzelezi, Yüksek Ziraat Enst. 51, Ankara.

Blumenthal, M. (1943). Zur Geologie der Landstrecken der Erdbeben von Ende 1942 in Nord-Anatolien und dortselbst ausgeführte makroseismische Beobachtungen, Maden Tetkik ve Arama Mecmuasi 8, 33-58, Ankara.

Blumenthal, M. (1945a). Die Kelkit-Dislokation südlich Niksar und ihre tektonische Rolle, Maden Tetkik ve Arama Mecmuasi 10, 372-386, Ankara.

Blumenthal, M. (1945b). La ligne sismique de Ladik Vilayet de Samsun, Maden Tetkik ve Arama Mecmuasi 10, 153-174, Ankara.

Burky, C. (1940). Le desastre seismique d'Anatolie, Revue pour l'Etude des Calamites 3, 89, Geneva.

Canitez, N. and Ucer S. (1967). Computed determinations for the fault-plane solutions in and near Anatolia, Tectonophysics 4, 235-244.

Constantinescu L., Ruprechtova L., and Enescu D. (1965). Mecanismul cutremurelor Mediteraneene-Alpine si implicatiile lor seismotectonice, Studia S. Cercet. Geol. Geofiz., Seria Geofizica 2, 173-191, Bucuresti; also, Geoph. Journ. R. Astr. Soc. 10, 347-368, London.

Daldy, A.F. (1954). Notes on model regulations for small buildings, and model regulations for small buildings in earthquake and hurricane areas, Building Research Station, Tropical Division Notes B.268, B.269, Garston, Watford.

Davison, C. (1896). The Constantinople earthquake of July 10, 1894, Natural Science 8, 47, London.

Dilgan, H. and Hagiwara T. (1953). Le tremblement de terre de Yenise le 18 mars 1953. Unpublished Rep. Seism. Inst. Univ. Istanbul.

Dilgan, H. and Hagiwara T. (1955). Le tremblement de terre de Yenice le 18 mars 1953, Publ. Bureau Centr. Intern. Seism., Trav.Sci. A, Strasbourg.

Duck, J. (1904). Die Erdbeben von Konstantinopel, Die-Erdbebenwarte 3, 121-139, 177-196, Laibach.

Dybowski, X. (1894). Tremblement de terre de Turquie observe a Adaparzari, La Nature 22, 289-291, Paris.

Eginitis, D. (1894a). Sur le tremblement de terre de Constantinople du 10 juillet 1894, Comptes Rend.Acad.Sci. 119, 480-483, Paris.

Eginitis, D. (1894b). Le tremblement de terre de Constantinople du 10 juillet 1894, Geographie General, Annales de Geographie 4, 151-166, Paris.

Erentoz, C. (1966). Contribution a la stratigraphie de la Turquie, Bull. Mineral Res. Explor Inst. 66, 1-22, Ankara.

Erentoz, C. and Kurtman F. (1964). Report sur le tremblement de terre de Manyas survenu en 1964, Bull.Mineral Res. Explor.Inst. 63, 1-5, Ankara.

Ergin K., Cuclu U., and Uz Z. (1967). A catalogue of earthquakes for Turkey and surrounding area 11 AD to 1964 AD, Publ. Arz Fizigi Enstitusu No. 24, Istanbul.

Fouche, M. and Pinar N. (1940). Meteorologie du tremblement de terre d'Erzincan du 27 decembre 1939, Revue Fac. Sci. Univ. Istanbul, Serie B 5, 245-255, Istanbul.

Fouche, M. and Pinar N. (1942). Birinci kanun Erzincan yer sarsintisinin meteorelojisi, Fen Fakultesi Monografileri 2, 1-18, Istanbul.

Fouche, M. and Pinar N. (1943). Etude geologique et meteorologique due tremblement de terre d'Adapazar du 20 juin 1943, Revue Facult. Sci. Univ. Istanbul 8, 1, Istanbul.

Fuchs, C.W. (1886). Statistik der Erdbeben von 1865 bis 1885, Sitzungsb. Kais. Akad. Wissens. Math. Nat. Classe 92 215-625, Wien.

Hoff, K. von (1841). Chronik der Erdbeben und Vulkan-Ausbrüche etc. Gesch. Ueberlieferung nachgew. natürl. Veränder. Erdoberfläche, 4 Vols, Gotha.

Ketin, I. (1948a). Über die Tektonisch-mechanischen Folgergungen aus den grossen anatolischen Erdbeben des letzten Dezenniums, Geol. Rundschau 36, 77-83.

Ketin, I. (1948b). Son on yilda Turkiye'de vukua gelen büyük depremlerin tektonik ve mihanik neticeleri hakkinda, Türkiye Jeol. Kurumu Bülteni 2, 1, Ankara.

Ketin, I. (1948c). Die Grossen Anatolischen Erdbeben in den letzten zehn Jahren, Urania 11, 6, Jena.

Ketin, I. (1957). Kuzey Anadolu deprem fayi, Istanbul Teknik Univ. Dergisi 15, 49-52, Istanbul.

Ketin, I. (1959). The orogenic evolution of Turkey, Bull.Mineral Res. Explor.Inst. 53, 82-88, Ankara.

Ketin, I. (1961). Umumi jeoloji kisin I, arz kabugunun ic olaylari, Ikinci baski Univ. Teknik Istanbul, No.360, University Publication.

Ketin, I. (1964). Géotectonique de Turqui, Tectonique de l'Europe, Published by the Commiss. Carte Geol. du Monde, 258-262, Moscow.

Ketin, I. (1966a). Erdbebenspalten in der gegend von Manyas in Nordwest-Anatolien, Turkiye Jeol. Kurumu Bülteni 10, 44-51, Ankara.

Ketin, I. (1956b). Tectonic units of Anatolia, Bull.Mineral Res. Explor. Inst. 66, 23-34, Ankara.

Ketin, I. and Roesli F. (1953). Macroseismische Untersuchungen über d s nordwestanatolische Beben vom 18 Marz 1953, Eclogae Geol. Helvetiae 46, 187-208.

Kirillova I., Ljostih E., Rastvorava V., Sorski A. and Hani V. (1960) Analiz geotektonicheskogo razvitiya i seismochnosti Kavkaza, Publ. Akad. Nauk, Institut Fiziki Zemli, 306-318, Moscow.

Kluge, E. (1858). Die Räktionen des Erdinnern gegen die Edroberfläche in den Jahren 1855 und 1856, Petermann Geograph. Mitth. 4, 236-251.

Labrouste, H. (1953). Etude microséismique des tremblements de terre du 23 juillet 1949 et du 13 août 1951 en Turquie, Bull. Inform. UGGI No. 2, 267.

Leuchs, K. (1940). Das jungste Grossbeben in Anatolien, Geol. Rundschau 31, 70-76.

Mackenzie, M. (1754). The late earthquake in Constantinople, Philos. Trans. 48, 819, London.

Mallet, R. (1852-1854). Report on the facts of earthquake phenomena, British Assoc. Adv. Sci., London.

Milne, J. (1911). Catalogue of destructive earthquakes, British Assoc. Adv. Sci. 1911, 653-654, London.

Moureaux, T. (1894). Sur le tremblement de terre de Constantinople, Comptes Rend. Acad. Sci. 119, 251-252, Paris.

Muscovei, G. (1912). Sur le tremblement de terre de la mer de Marmara le 9 aout 1912, Bull.Acad. Roumaine Sect.Sci. 1, 4-53, Bucuresti.

Öcal, N. (1959). 26 mayis 1957 Abant zelzelesi, Report Kandilli Rasath. Sism. No. 4, Istanbul.

Öcal, N. (1961a). 1850 yilina kadar I> VII intensiteli Türkiye zelzeleri kataloğu, Report Kandilli Rasath.Sism. No. 7, Istanbul

Öcal, N. (1961b). Determination of the mechanism of some Anatolian earthquakes Publ.Dominion Observ. 24, 365-370, Ottawa.

O'Reilly, J. (1885). Catalogue of the earthquakes recorded as having occurred in Europe and adjacent countries, Trans. R. Irish Acad.Sci. 28, 489-708, Dublin.

Özcicek, B. (1964) 18 eylul 1963 dogu Marmara zelzelesinin etüdü, Unpublished Report, Seism.Inst. Univ. Istanbul

Özocak R. and Erdoğan T. (1966). Varto-Hinis depremi ile ilgili jeolojik inceleme, Unpublished Report, Maden Tetkid ve Arama, Ankara.

Pamir, H. (1944). Kuzey Anadolu'da bir deprem çizgisi, Istanbul Univ. Fen Fakult. Mecmuasi 9, 3, Istanbul.

Pamir, H. (1948). Les seismes en Asie Mineur entre 1939 et 1944; la cicatrice Nord-Anatolienne, Proc. Internl.Geol. Congress 3, 214-218, London.

Pamir, H. and Ketin I. (1940). Das Erdbeben in der Türkei von 27/28 Dezember 1939, Geol.Rundschau 31, 77-78.

Pamir, H. and Ketin I. (1941). Das anatolisch Erdbeben Ende 1939, Geol. Rundschau 32, 279-287.

Pamir, H. and Akyal I. (1943). Corum ve Erbaa depremleri, Türk Cografya Dergisi 1, 1-7, Ankara.

Peréjas E., Akyol I., Altinli E. (1941). Le tremblement de terre d'Erzincan du 27 Decembre 1939, Revue Fakult. Sci. Univ. Istanbul 4, 187-222, Istanbul.

Peréjas E., Akyol I., Altinli E. (1942). 27 birinci kanun 1939 Erzincan yerdepremi, Istanbul Üniv. Fen Fakult Jeoloji Enstit. 10, Istanbul.

Perrey, A. (1843-1871) General Catalogue (49 papers listed in Davison's The founders of seismology, 50-52, Cambridge 1927).

Pinar N. (1951). 13 agustos 1951 Kurşunlu depreminin makrosimik ve jeolojik etüdü, Istanbul Univ. Fen Fakult. Mecmuasi 18, 131-142, Istanbul.

Pinar N. (1953). Preliminary note of the earthquake of Yenice-Gönen, Turkey, March 18 1953, Bull.Seism.Soc.Am. 43, 307-310.

Pinar N. (1955). Le séisme du 18 mars 1953 de Yenice-Gonen en relation avec les éléments tectoniques, Publ. Bureau Centr.Internl.Seism., Travaux Xci. 19, Strasbourg.

Pinar, N. and Lahn E. (1952). Türkiye depremleri izahli kataloğu, Bayindirlik Bakanliği, Imar Isleri Reisliği Yayinlarindan 6, Ankara.

Porter J. (1755). An account of the several earthquakes of late felt at Constantinople, Phil. Trans. 49, 115-123, London.

Ramsay, W. (1890). The historical geography of Asia Minor, Suppl.Papers R. Geograph.Soc. 4, London

Richter, C. (1958). Elementary seismology, Ed. Freeman, 138.

Roesli, F. (1953). 18-3-1953 tarihinde vukua gelen Yenice-Gönen zelzelesin ait ilk rapor, Unpublished Rep. No. 10 and No. 11, Istanbul Tekn. Univ. Sism. Enstit., Istanbul.

Salomon-Calvi, W. (1940a). 21-22 eylûl 1939 tarihinde vua gelen Dikili Bergama zelzelesi, Maden Tetkik ve Arama Mecmuasi 5, 3, Ankara.

Salomon-Calvi, W. (1940b). Les tremblements de terre d'Erzincan du 21 novembre et du 27 décembre, Revue pour l'Etude des Calamités 3, 178-180, Geneva.

Salomon-Calvi, W. (1940c). Anadolu jeolojik inkişafinda zelzelelerden istifade, Maden Tetkik ve Arama Mecmuasi 5, 61, Ankara.

Schmidt, J. (1879). Studien uber Erdbeben, Alwin Georgi Ed., Leipzig.

Sieberg A. (1932). Erdbebengeographie, in B. Gutenberg's Handbuch der Geophysik, 804-809, Berlin.

Shirokova, E. (1967). General mechanism and orientation of principle stresses at the source of earthquakes in the Mediterranean-Asiatic seismic belt, Fiziki Zemli 1, 23-36, Moscow (in Russian).

Sobouti, M. (1963). Sur le mechanism au foyer dans l'arc séismique entre l'Hindou-Kouch et la Mediterranee, Ann.Geophysique 19, 51-62, Paris.

Stein,E. (1949). Histoire du Bas-Empire, Ed. Desclee Brouwer, 420-421, Paris.

Taşman, C. (1944). Gerede-Bolu depremi, Maden Tetkik ve Arama Mecmuasi 9, 134-136, Ankara.

Taşman, C. (1946). Varto ve Van depremleri, Maden Tetkik ve Arama Mecmuasi 11, 287-291, Ankara.

Tillotson, E. (1940). Nature January 6 1940.

Tokay, M. (1952). Contribution à l'étude géologique de la région comprise entre Ereğli-Alapli Kiziltepe et Alacaağzi, Bull. Mineral Res. Explor.Inst. 42, Ankara.

Tomaschek, W. (1891). Zur historischen Topographie von Kleinasien im Mittelalter, Sitzungsb. Kais. Akad. Wissens. Phil.-Hist.Classe 124, part 7, Wien.

Tromp, S. (1947). A tentative classification of the main structural units of the Anatolian orogenic belt, Journ.Geol. 4, 362-368.

United Nations (1966). Report on the rehabilitation and reconstruction of housing and community facilities in cases of natural disasters, UN Economic and Social Council, E/C.6/52, Part II, New York.

Uz, Z. (1965). 6 ekim 1964 Manyas depremi hakkinda rapor, Report, Istanbul Tek. Univ. Sism. Enst. no. 2.

Uz, Z. (1966). 6 ekim 1964 Manyas zelzelesi üzerinde bir inceleme, Maden Mecmuasi 3, 17-21, Istanbul.

Wallace, R. (1968). Earthquake of August 19, 1966, Varto area, Eastern Turkey, Bull.Seism.Soc.Am. 58,

Weismantel, O. (1891). Die Erdbeben des vorderen Kleinasiens in geschichtlicher Zeit, Dissertation, H. Phil. Fakultät Univ. Marburg (Unpublished) also Univ und Stadt Biblotek Köln No. 1890/91: 72 Phil.

Wutzer, M. (1857). Das Erdbeben vom 28 Februar und vom 11 April 1855, Sitzungsb.Niederrh.Gesell.Natur-Heilkunde, Bonn. 14, 34-38, Bonn.

Zátopek, A. (1968a). The Skopje earthquake of 26 July 1963 and the seismicity of Macedonia, Publ. Unesco, The Skopje Earthquake, 90-129, Paris.

Zátopek, A. (1968b). Sur la determination des intensites macroseismiques, Symposium on Regional Seismicity, 14th IUGG Assembly, Institut Fiziki Zemli, Moscow (in the press).

Original Historical Sources

(Note. Byzantine historians are quoted by pages of the Corpus Scriptorum Historiae Byzantinae (CSHB) 1828-1897 Bonn edition. Other sources are quoted by pages of the Patrologia Latina (PL), or Patrologia Greca (PG), Migne's edition).

Agathias, Agathiae Myrinaei Historiarum (CSHB)

Anastasius, Anastasii bibliothecarii Epistolae (PG)

Ammianus Marcellinus, Ammiani Marcellini Rerum Gestarum, Loeb Edition 1956

Attaliotes, Attaliotae Michaeli Historia (CSHB)

Cedrinos, Historiarum Compendium (CSHB)

Chronikon Pascalinon (CSHB)

El Macin, Jirgis el-'Amid, Historia Saracena-Arabice olim extrata a Elmakina etc. Lugduni Batavorum, Erpenius Th. 1625.

Eusebius, Chronikon (PG)

Glycas, Michaeli Glyca Annales (CSHB)

Idatius, Consules (PL)

Leo Diaconus, Leonis Diaconi Historia (CSHB)

Malalas, Chronographia (CSHB)

Marcellinus Comes, (PL)

Scylitzes Curoplates, Excerpta ex brevario Historico (CSHB)

Socrates, Historia Ecclesiastica (PG)

Theophanes, Chronographia (CSHB)

Zonaras, Annales (CSHB)

Maps

Maden Tetkik ve Arama (1964) 1:500,000 Zonguldak sheet
(1966) 1:100,000 Kocaeli Sheet (38-2)
1:100,000 Bolu sheet (39-1)

Orman General Müdürlüğü Yay. (1692) "Türkiyede orman ağaç ve ağaçciklarinin yayilişi" Harita Gen.Müd., Ankara. also Turkiye Cumhuriyetinin vilâyet taksimatile şehirler arasindaki yol, orman ve madenleri irae eder Haritadir" scale 1,000,000 Ankara 1931.

P = Press Reports

TABLE 1

No.	Year	Date	Time (GMT)	Epicentre	M	L	S	H	V	References
1	1909	Feb. 9	1124	40°N - 38°E	6¼	-	-	-	-	Ergin et al (1967), ST
2	1912	Aug. 9	0129	40¼ - 27¼	7¼	10	-	-	-	Muscovei (1912), Ergin et al (1967), ST, P,
3	1935	Jan. 4	1441	40¼ - 27½	6¼	-	-	-	-	Ergin et al (1967), ST
4	1935	Jan. 4	1620	40 - 27½	6	-	-	-	-	Ergin et al (1967), ST, P,
5	1937	Jul. 6	0652	39½ - 26	6	-	-	-	-	Ergin et al, (1967), ST
6	1939	Sep. 22	0036	39 - 27	6½	-	-	-	-	Birand (1940), Salomon-Calvi (1940a), ST, P,
7	1939	Nov. 21	0848	39.9 - 39.7	6	-	-	-	-	Salomon-Calvi (1940b)(1940c), Pamir and Ketin (1941)
8	1939	Dec. 26	2357	39.7 - 39.7	8	350	RH	370	200	Burky (1940), Salomon-Calvi (1940b)(1940c), Leuchs (1940), Tillotson (1940), Fouché and Pinar (1940), (1942), Pamir and Ketin (1940), (1941) Peréjas et al (1941),(1942), Pamir (1944),(1948), Ketin (1948a) (1957) Ergin et al (1967), ST, P,
9	1941	Nov. 12	1004	39.8 - 39.3	6	-	-	-	-	Ergin et al (1967), ST,
10	1942	Dec. 20	1403	50.7 - 36.6	7.3	34+(36)	RH	175	100	Blumenthal (1943), (1945a), (1945b), Pamir and Akyol (1943), Pamir (1948) Ketin (1948a),(1957), Ergin et al (1967), ST, P,
11	1943	Jun. 20	1532	40.8 - 30.4	6¼	-	-	-	-	Nature (1953), Fouché and Pinar (1943), ST, P.
12	1943	Nov. 26	2220	41.0 -34.0	7.6	270	RH?	small	150	Blumenthal (1945b), Pamir(1948), Ketin (1948a) (1957), ST, P.
13	1944	Feb. 1	0322	41.0 -33.0	7.6	190	RH	350	100	Tagman (1944), Pamir (1948), Ketin (1948a)(1948b) (1957)(1961), ST, P.

14	1944 Oct. 6	0235	39.4 - 26.7	7.2	-	-	-	-	Ergin et al, ST, P.
15	1946 May 31	0312	39.3 - 41.2	$5\frac{3}{4}$+	-	-	-	-	Taşman (1946), P
16	1949 Aug. 17	1844	39.4 - 40.9	6.5	-	-	-	-	Ergin et al, ST,
17	1951 Aug. 13	1833	40.8 - 33.2	$6\frac{3}{4}$	(40)	?	?	?	Pinar (1951), Labrouste (1953), ST, P.
18	1952 Mar. 19	0127	40.0 - 28.8	$5\frac{1}{2}$+	-	-	-	-	Ergin et al (1967), ST
19	1953 Mar. 18	1906	40.0 - 27.5	7.4	58	RH	430	small	Roesli (1953), Dilgan and Hagiwara (1953)(1955), Pinar (1953)(1955), Ketin and Roesli (1953), Ketin (1957), ST, P.
20	1953 Sep. 7	0358	41.2 - 32.8	$6\frac{1}{4}$	-	-	-	-	Ergin et al (1967), ST
21	1954 Aug. 19	2103	41.1 - 36.3	6	-	-	-	-	Ergin et al (1967), ST
22	1957 May 26	0633	40.6 - 31.2	7.1	(40)	RH	160	40	Öcal (1959), Ketin (1957), Nature (1957), ST, P.
23	1957 May 26	0936	40.7 - 31.2	6.0	-	-	-	-	ST, Öcal (1959)
24	1957 May 27	1101	40.7 - 31.2	$6\frac{1}{4}$	-	-	-	-	ST, Öcal (1959)
25	1959 Oct. 25	1557	39.1 - 41.6	6.0	-	-	-	-	Ergin et al (1967), ST,
26	1963 Sep. 18	1658	40.9 - 29.2	6.0	-	-	-	-	Özcicek (1964), Ergin et al (1967), ST
27	1964 Oct. 6	1431	40.3 - 28.2	6.5	(?)	-	-	-	Erentöz and Kurtman (1964), Uz (1965)(1966), Ketin (1966), ST, P
28	1966 Aug. 19	1222	39.2 - 41.6	6.8	(30)	RH	(30)	small	Özocak and Erdoğan (1966), Ambraseys and Zátopek (1967)(1968) Wallace (1968)
29	1967 Jul. 22	1656	40.6 - 31.0	7.1	80	RH	190	125	Nature (1968), Present report
30	1967 Jul. 26	1852	39.5 - 40.3	6.0	-	-	-	-	ST, P

Note: M = magnitude; L = length of faulting in kilometres; S = RH right-lateral movement; H = strike-slip movement in centimetres; V = throw in centimetres; ST refers to date obtained from various seismological stations; P refers to press-reports and unpublished information.

TABLE 2

Year	Date	Locations affected	References
69	Jan. 2	Izmit	Malalas x-335
121	- -	Izmit, Iznik	Eusebius 283
192	May -	Sakarya Valley, Izmit, Mudurnu	Malalas xii-380
296	- -	Gebze, Izmit	Malalas xii-395
358	Aug. 24	Pontus, Izmit	Ammianus xvii-7, Cedrinos 530, Idatius 51-909
359	- -	Izmit	Eusebius 185, Chronikon 293, Theophanes 5850,
363	Dec. 2	Izmit, Iznik	Ammianus xxii-13.5,
368	Oct. 11	Iznik	Malalas xiii-36, Socrates 67.481, Chronikon 301
437	Sep. 25	Izmit, Istanbul	Malalas xiv-66, Cedrinos 599, Glycas 260, Theophanes 5930 Evagrius 17,
447	Nov. 6	West southwest of Izmit	Chronikon 586, Marcellinus 51.927, Evagrius i-17,
468	- -	Izmit	Evagrius ii-14,
526	- -	Izmit, Iznik9	Zonaras iii-263, Glycas 493,
536	- -	Bursa (?), Taskopru (?)	Theophanes 336, Glycas 266, Anastasius 62,
554	Aug. 15	Izmit, Istanbul	Cedrinos 384, Agathias 95, Malalas 486, Theophanes 229,
740	Oct. 26	Karamursel, Iznik, Izmit, Istanbul	Cedrinos 458, Theophanes 345, Anastasius 78, Zonares xv-343,
967	Sep. 2	Bolu, Gerede, Cerkes	Cedrinos 660, Zonaras 206, Leo 41,
989	Oct. 25	Pontus, Izmit, Istanbul	Leo 175, Scylitzes 438, Glycas 576, Elmacin 989,
1035	May 3	East of Gerede, Bayindir, Hamamli	Cedrinos 514, Glycas 316,
1036	Dec. 18	Bayindir, Hamamli	Cedrinos 515
1063	Sep. 23	Iznik, Erdek, Murfete, Tekirdag, Istanbul	Cedrinos 817, Scylitzes 816, Glycas 325, Zonaras 274, Attaliotes 184,
1417	- -	Bursa	Pinar and Lahn (1952)
1668	Jul. 18	Bolu, Gerede, Kastamonu	Dresdner Gelehrt Anzeige no. 12 (1756),
1672	May 25	Izmit	Pinar and Lahn (1952)
1674	- -	Bursa	Pinar and Lahn (1952)
1719	May 25	Izmit, Sevenit, Istanbul	Porter (1755), Mercure Francais no. 7, 113; no. 8, 103, Journal Historique 1719, p. 185.
1754	Sep. 14	Izmit, Istanbul	Porter (1955), Mackenzie (1954)

1866	Feb. 24	0315	Bursa	I	Schmidt (1879), Fuchs (1886), P
	Feb. 25	-	Bursa	-	Fuchs (1886)
	Feb. 28	-	Bursa	-	Fuchs (1886)
1871	Feb. 24	01-	Bursa	-	Schmidt (1879)
1872	Jan. 17	-	Bursa	-	Schmidt (1879)
	Jan. 23	-	Tuzla	-	Schmidt (1879)
1876	Apr. 17	11-	Suki, Bursa	-	Schmidt (1879), P
	May 31	14-	Gemlik	-	Schmidt (1879)
1878	Apr. 19	21-	Esme, Sapanca, Adapazari, Izmit	III	Anonymous (1878a)(1878b), Fuchs (1886), Schmidt (1879), P
	May 10	08-	Izmit	I	Fuchs (1886), Schmidt (1879), P
1881	Dec. 30	-	Bursa	-	Fuchs (1886)
1883	Dec. 2	-	Sadikli, Bursa	I	Fuchs (1886), P
	Dec. 31	0330	Sadikli	-	Fuchs (1886)
1884	Jan. 2	-	Sadikli, Bursa	I	Anonymous (1884), Fuchs (1886), P
1886	Sep. -	-	Bursa	-	Ergin et al (1967)
1887	Sep. -	-	Bursa	-	Ergin et
1894	Jul. 10	1233	Geyve, Adapazari, Karamursel Istanbul, Izmit	III	Dybowski (1894), Eginitis (1894a)(1894b), Davison (1896), Duck (1904) Anonymous (1894a)(1894b), P
	Jul. 13	-	Bursa	I	Ergin et al (1967)
	Jul. 19	-	Mudanya	-	Ergin et al (1967)
1895	Jan. 16	-	Iznik	-	Ergin et al (1967)
1896	Jan. 3	1235	Bilecik	-	Agamennone (1900)
	Jan. 15	0928	Gemlik	-	Agamennone (1900)
	Jan. 23	1104	Bilecik	-	Agamennone (1900)
	Feb. 29	0609	Pazarkoy	-9	Agamennone (1900)
	Mar. 2	1052	Bilecik	-	Agamennone (1900)
	Mar. 6	1046	Tuzla	-	Agamennone (1900)
	Apr. 14	0905	Pazarkoy	-	Agamennone (1900)
	Apr. 16	0940	Bursa, Izmit	I	Agamennone (1900), P
	Apr. 22	07-	Pendik	-	Agamennone (1900)
	May 10	1112	Pazarkoy	-	Agamennone (1900)
	Oct. 25	0220	Gemlik	-	Agamennone (1900), P
1897	Dec. -	-	Bilecik	I	Ergin et al (1967)
1898	Feb. -	-	Yenisehir, Bilecik	I	Ergin et al (1967)
1899	-	-	Bursa	-	Ergin et al (1967)

Note: i = maximum intensity as defined by Milne (1911). Time is given as reported.

TABLE 3

Year	Date	Time	Localities affected	i	General References
1850	Apr. 19	2330	Muhelitsa, Kirmasti, Bursa, Lubat	II	Anonymous (1851), P
1852	Apr. 16	16-	Bursa	I	Schmidt (1879)
1853	Aug. 18	-	Bursa	I	Schmidt (1879)
1855	Feb. 28	03-	Bursa, Uludag	III	Schmidt (1879), Wutzer (1857), Kluge (1858) Weismantel (1891), P
	Apr. 11	20-	Bursa, Uludag	I	Schmidt (1879), Wutzer (1857), Kluge (1858)
	Mar. 6	-	Bursa	-	Schmidt (1879)
	May 29	0025	Bursa	-	Schmidt (1879), P
	Aug. 16	-	Bursa	-	Schmidt (1879), P
	Dec. 15	-	Bursa, Istanbul	I	Schmidt (1879), P
	Dec. 16	-	Bursa	-	Schmidt (1879)
1856	Feb. 17	00-	Bursa	I	Schmidt (1879), P
1857	May 21	-	Bursa	I	Perrey, P
	Sep. 17	-	Bursa	I	Perrey, P
	Dec. 27	-	Bursa	I	Perrey, P
1858	Apr. 19	0905	Bursa	I	Perrey, P .
	Apr. 20	-	Bursa	-	Perrey,
	Apr. 21	-0	Bursa	-	Perrey,
1859	Oct. 20	16-	Yalova	-	Perrey,
1860	May 16	0730	Bursa	-	Perrey,
	May 28	16-	Bursa	-	Perrey,
	May 31	2330	Bursa	-	Perrey,
	Jun. 1	1130	Bursa	-	Perrey,
	Jun. 4	0030	Uludag, Bursa	I	Schmidt (1879), Weismatel (1891), Perrey, P
	Jun. 5	0215	Bursa	-	Schmidt (1879), Perrey, P
	Jun. 7	1830	Bursa, Iznik	I	Schmidt (1879), Weismatel (1891), Perrey, P
	Aug. 4	2215	Bursa	-	Perrey,
1862	Jan. 11	09-	Bursa	-	Schmidt (1879), Perrey, P
	Mar. 18	21-	Iznik (small tsunami)	-	Perrey, P
	Nov. 24	0530	Iznik	-	Perrey,
1863	Apr. 7	0830	Bursa	-	Perrey,
	Nov. 6	1010	Oumurbey, Gemlik, Bursa	II	Perrey, P
	Nov. 24	-	Bolu	II	Perrey, P

TABLE 4

Year	Date	Time	Epicentre	I_o	M
1901	Mar. 31	-	41.0° - 29.0°	VII	-
1902	Oct. -	-	40.7 - 31.6	VI	-
1905	Apr. 15	-	40.2 - 29.0	IX	-
	Oct. 22	03	41.0 - 31.0	VI	-
1907	Aug. 21	0250	40.7 - 30.1	VII	-
1923	May 29	1134	41.0 - 30.0	-	-
1925	Jun. 24	0000	41.0 - 31.0	-	-
1926	Dec. 16	1750	40.8 - 30.4	VI	-
	Dec. 20	1030	39.0 - 31.0	-	-
1927	Jan. -	-	40.8 - 30.4	VI	-
1928	Jan. 24	0736	41.0 - 31.0	-	-
1929	Apr. 27	2218	41.0 - 31.0	-	-
1932	Oct. 15	2220	40.9 - 30.6	-	-
1933	May 15	0321	40.9 - 30.6	-	-
1939	Sep. 15	2316	40.2 - 29.5	VII	5.6
1940	Jun. 13	1102	41.0 - 30.0	-	-
1940	Aug. 10	-	40.0 - 30.0	-	-
1941	Feb. 9	0923	41.0 - 29.0	-	-
1943	Jun. 20	1533	40.6 - 30.5	IX	6.3
	Jun. 20	1648	40.8 - 30.4	VI	-
	Sep. 8	1335	40.7 - 30.4	VI	-
1944	Feb. 10	1205	41.5 - 31.4	VIII	-
	Mar. 11	0919	40.8 - 32.2	VIII	-
	Apr. 5	0404	40.6 - 30.9	VII	5.5
1945	Feb. 8	0624	40.7 - 31.6	VI	-
	Feb. 9	0228	40.5 - 31.2	VI	-
1948	Nov. 13	0444	40.8 - 29.9	VI	5.3
1949	Feb. 5	0028	39.9 - 29.2	VII	-
	Nov. 28	1847	40.5 - 30.9	-	-
1952	Jan. 22	2315	40.8 - 30.4	V	-
1953	Jun. 3	1605	40.1 - 28.8	VIII	5.8
1956	Feb. 20	2032	40.0 - 30.2	VIII	6.0
	Jul. 14	1901	40.3 - 31.0	-	4.5
1957	May 26	0633	40.6 - 31.2	IX	7.1
	May 26	0855	40.5 - 31.0	-	5.0
	May 26	0914	41.0 - 31.0	-	4.5
	May 26	0937	40.7 - 31.2	-	6.0
	May 27	0705	41.0 - 31.0	-	-
	May 27	1101	40.7 - 31.2	-	6.3
	May 28	0010	40.5 - 31.0	-	-

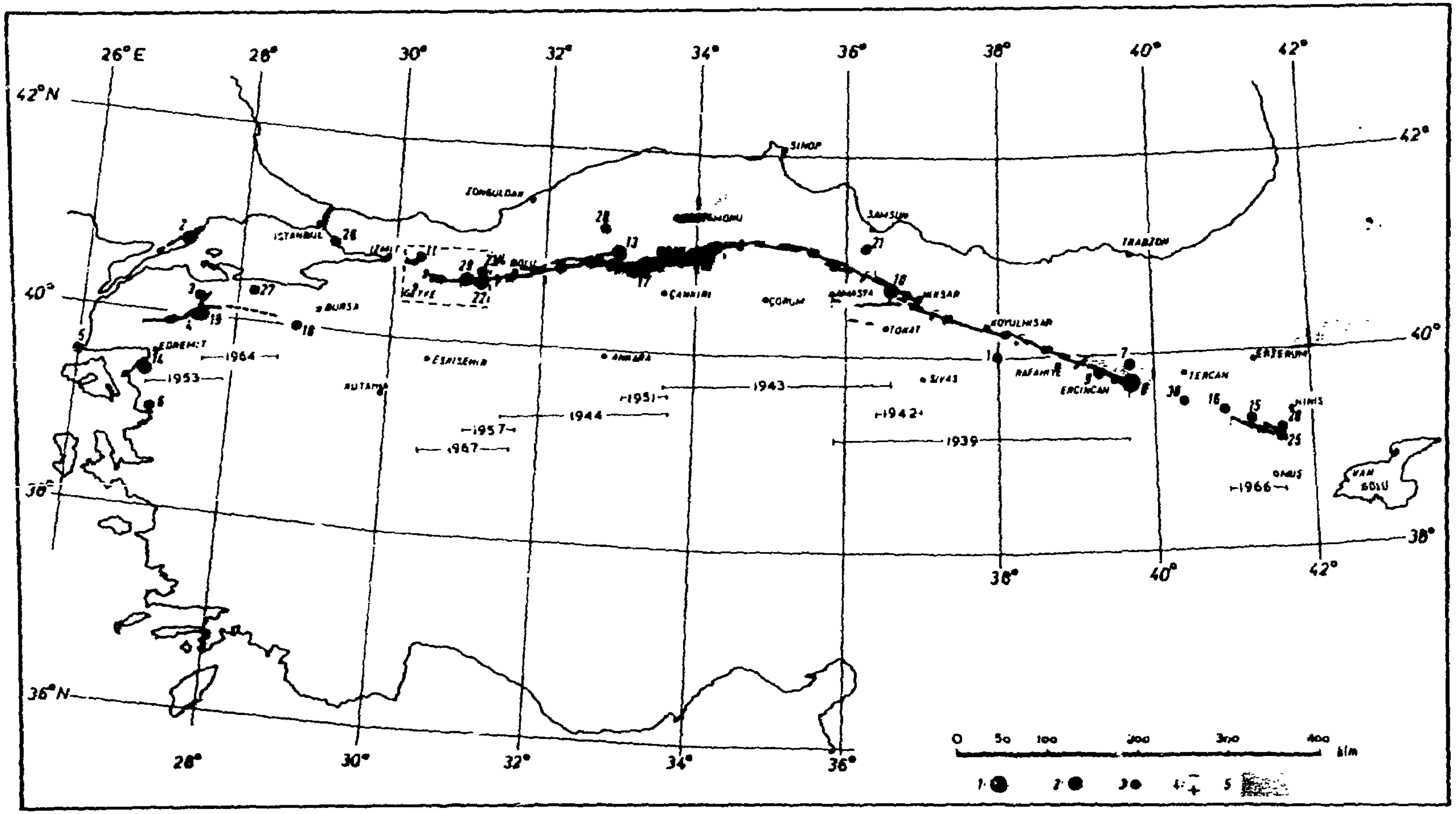
Year	Date	Time	Epicentre	I_o	M
1957	May 29	1047	40.8 - 30.8	-	5.0
	Jun. 1	0526	40.7 - 30.8	-	4.5
	Jun. 1	2108	40.7 - 30.9	-	4.5
	Jun. 2	0112	40.8 - 31.2	-	4.0
	Oct. 24	0233	40.3 - 29.8	VI	5.0
	Dec. 26	1501	41.0 - 29.7	-	-
1958	May 20	1248	40.4 - 29.1	-	4.0
	Nov. 23	1307	40.6 - 30.8	-	-
1959	Apr. 2	0434	40.1 - 29.5	VII	-
1960	Nov. 13	1355	40.7 - 30.2	-	3.5
1961	Jan. 7	0107	40.8 - 29.9	V	-
	Mar. 28	0044	40.5 - 30.5	VI	4.7
	Sep. 28	0535	40.5 - 29.6	V	4.1
	Dec. 5	0221	40.4 - 31.4	VI	-
1963	Jun. 14	-	40.1 - 29.2	VI	-
	Sep. 18	1658	40.9 - 29.2	VIII	6.0
	Sep. 24	0210	41.0 - 29.8	-	4.6
1964	Apr. 18	2153	41.1 - 29.0	-	-
	Dec. 13	0025	41.1 - 30.2	-	4.5
	Dec. 13	1409	40.7 - 31.0	-	4.0
	Dec. 15	2103	40.0 - 28.9	-	4.9
1965	Jan. 19	2151	40.2 - 29.1	-	(4.0)
	Feb. 18	0538	40.7 - 30.4	-	(4.3)
	Feb. 18	0818	40.7 - 30.5	-	(4.5)
	Feb. 24	0056	40.6 - 31.6	-	(4.0)
	Mar. 12	0818	40.8 - 30.9	-	(4.5)
	Mar. 14	1234	40.6 - 31.6	V	4.5
	Apr. 7	1152	40.8 - 30.7	-	(4.0)
	May 18	0238	40.2 - 29.8	-	-
	May 22	0626	40.7 - 31.6	-	(4.0)

Note: I_o : maximum observed intensity in epicentral area

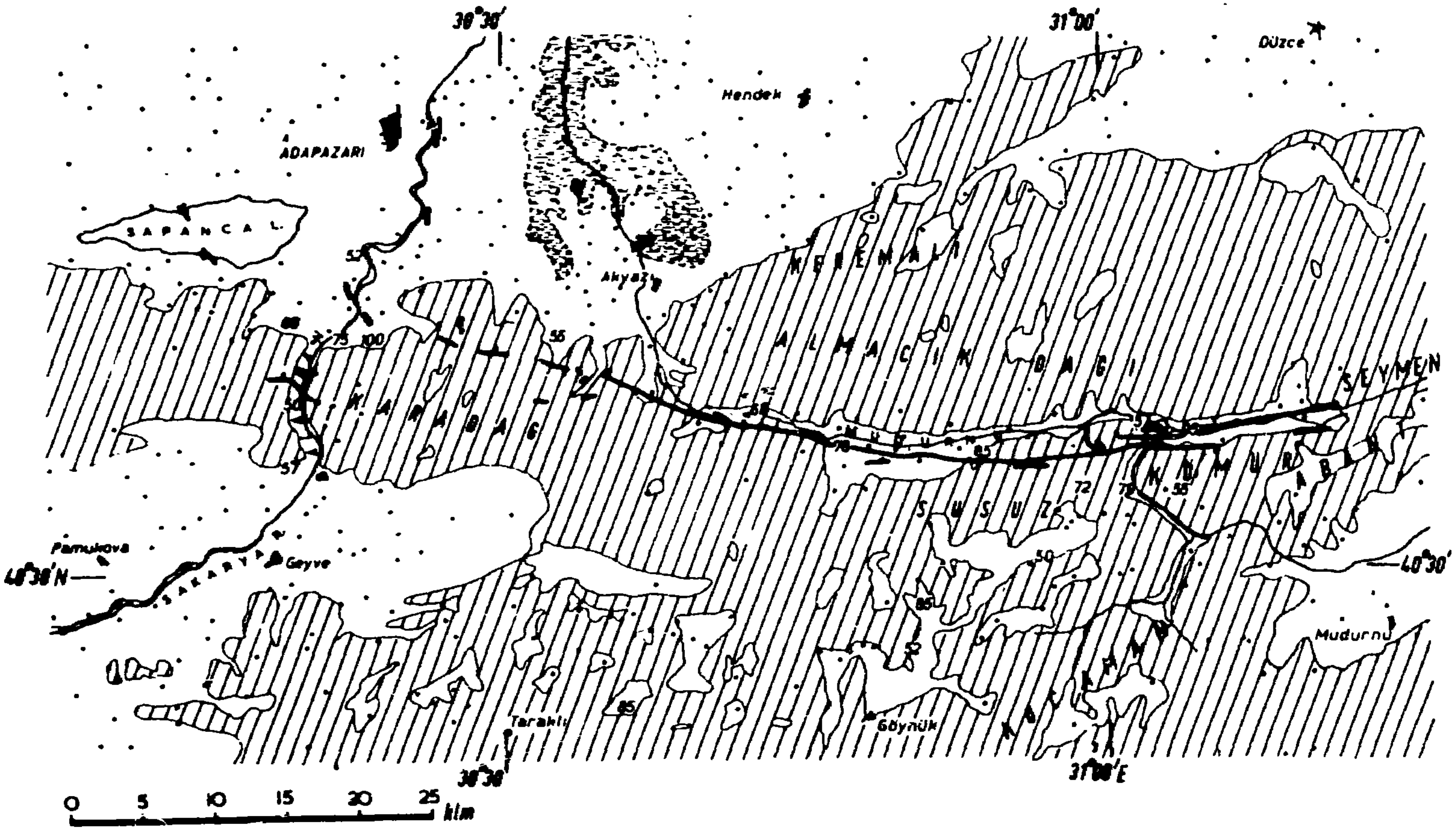
M : magnitude

TABLE 5

No.	Date	Time (GMT)	Epicentre	M	h	P
1.	22 Jul.	165652	40.6°N - 31.0°E	7.1	10	D
2.		165656	40.6 - 30.4	-	-	-
3.		171408	40.5 - 30.5	-	-	-
4.		173011	40.4 - 30.2	-	-	-
5.		174806	40.6 - 30.7	5.0	26	-
6.		180953	40.6 - 30.4	5.0	n	-
7.		194726	40.8 - 30.9	4.6	n	C
8.		203541	40.7 - 30.5	4.5	16	D
9.		212134	40.5 - 30.5	4.4	-	C
10.		220830	40.7 - 30.7	4.5	13	C
11.		234156	40.7 - 30.6	4.7	n	D
12.	23 Jul.	002958	40.5 - 30.5	-	-	-
13.		022537	40.8 - 30.6	4.0	27	C
14.		040339	40.6 - 30.6	4.5	21	C
15.		044850	40.5 - 30.5	4.0	-	C
16.		074222	40.8 - 30.8	4.1	19	C
17.		140446	40.7 - 30.4	-	-	-
18.		155709	40.7 - 30.6	4.4	n	C
19		194133	40.5 - 30.0	-	-	-
20		230658	40.7 - 30.4	-	-	C
21		231914	40.6 - 30.7	4.3	15	D
22	24 Jul.	034020	40.8 - 30.8	4.2	-	C
23		080733	40.7 - 30.5	-	-	-
24	26 Jul.	091606	40.8 - 30.6	4.5	n	D
25	30 Jul.	013100	40.7 - 30.6	5.7	16	C
26		015716	41.1 - 30.3	-	-	C
27		185805	40.7 - 30.8	-	-	-
28		185842	40.7 - 30.5	4.5	n	C
29	1 Aug.	001335	40.8 - 30.4	4.5	-	D
30		010511	40.8 - 30.3	4.3		
31	2 Aug.	153322	40.7 - 30.6	4.5	n	C
32	6 Aug.	140927	40.7 - 29.8	-	-	-
33	7 Aug.	234709	40.7 - 30.5	-	-	D
34	8 Aug.	.043630	40.7 - 30.5	-	-	D
35		043844	40.6 - 31.1	-	-	C
36	14 Aug.	200926	40.7 - 30.5	4.7	n	-
37	18 Aug.	194920	40.7 - 30.5	-	-	-
38		233936	41.0 - 30.2	4.4	n	-



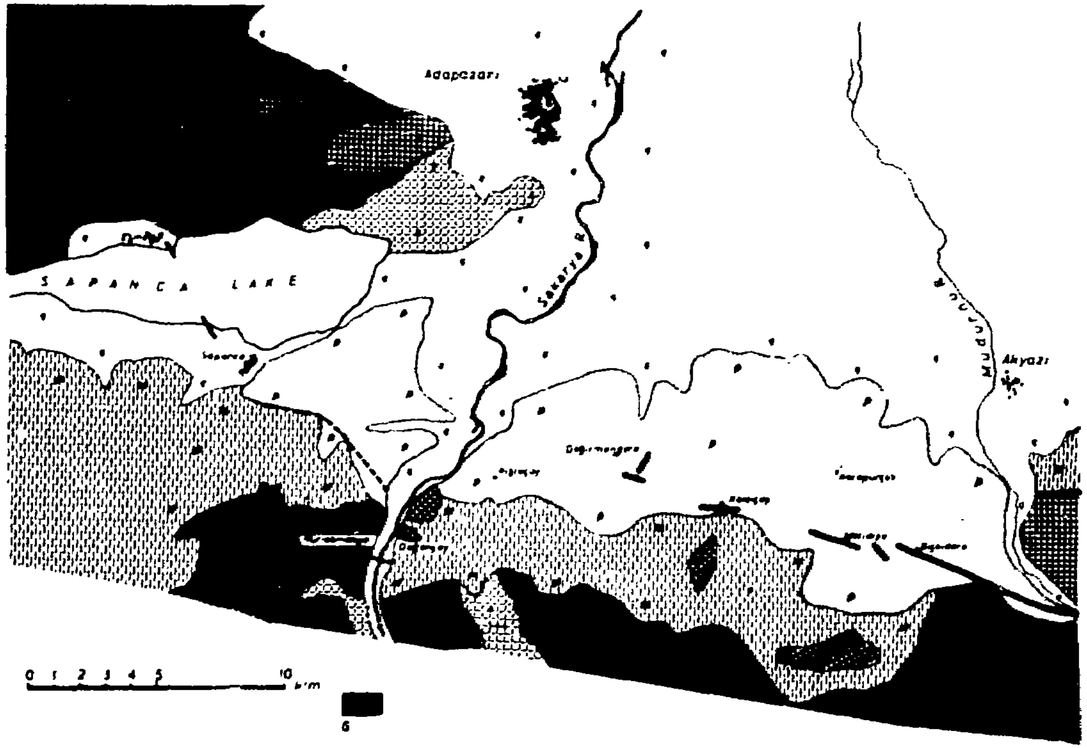
1. Extent of faulting in the Anatolian Fault Zone since 1938. Earthquake epicentres with 1 : $M \geqslant 8$; 2 : $8 > M > 7$; 3 : $7 > M \geqslant 6$; 4 : sense of throw; 5 : regions of early earthquakes, probably associated with faulting. (This figure supersedes Figure 1 in Ambraseys and Zatopek 1967 and 1968). Insert shows area studied in this report.



2. Epicentral area of the Mudurnu earthquake. Shaded area shows forests and mountains. Dots represent location of villages. Numbers refer to villages that showed damage greater than 50 per cent and indicate percentage of houses destroyed or damaged beyond repair.

3.1

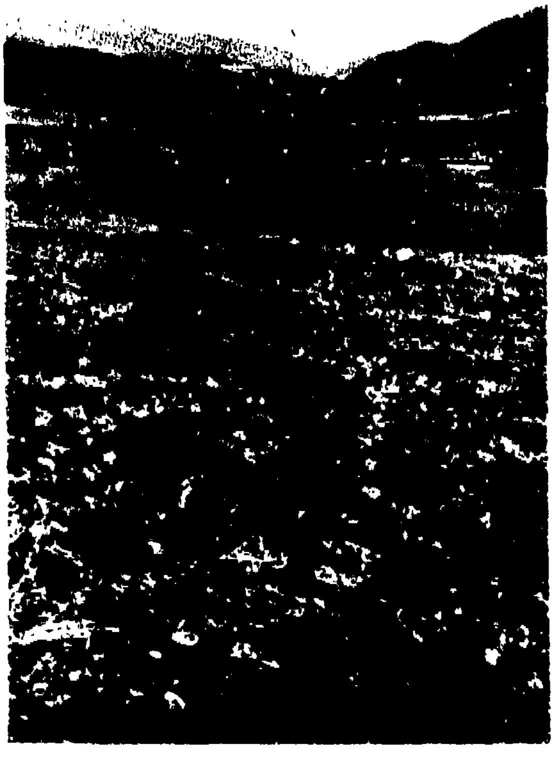
3.2



3. Generalised geologic maps of the fault zone showing faults and new ruptures.
T = Terraces, d = Slope debris,
q = Quaternary, p = Pliocene,
E = Eocene, k = Upper Cretaceous,
K = Lower Cretaceous, J = Upper Jurassic, PC = Permo-Carboniferous,
D = Devonian, M = Metamorphics,
S = Serpentines, g = Intrussives,
a = Extrussives, G = Gneiss, F = 1967 ground ruptures, f = faults.

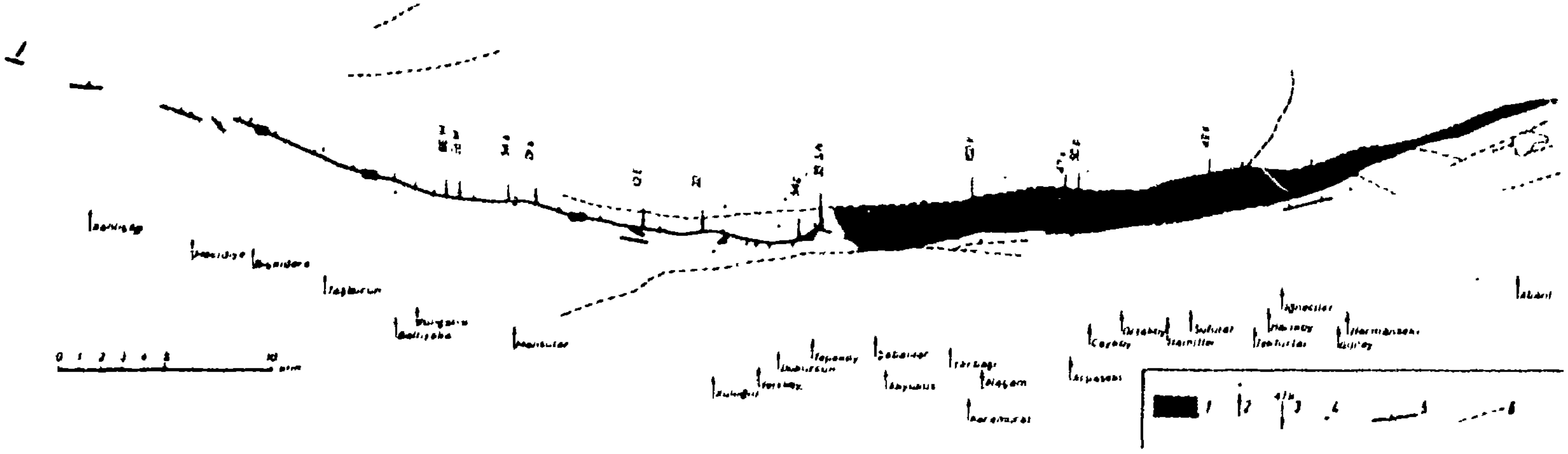
4

5

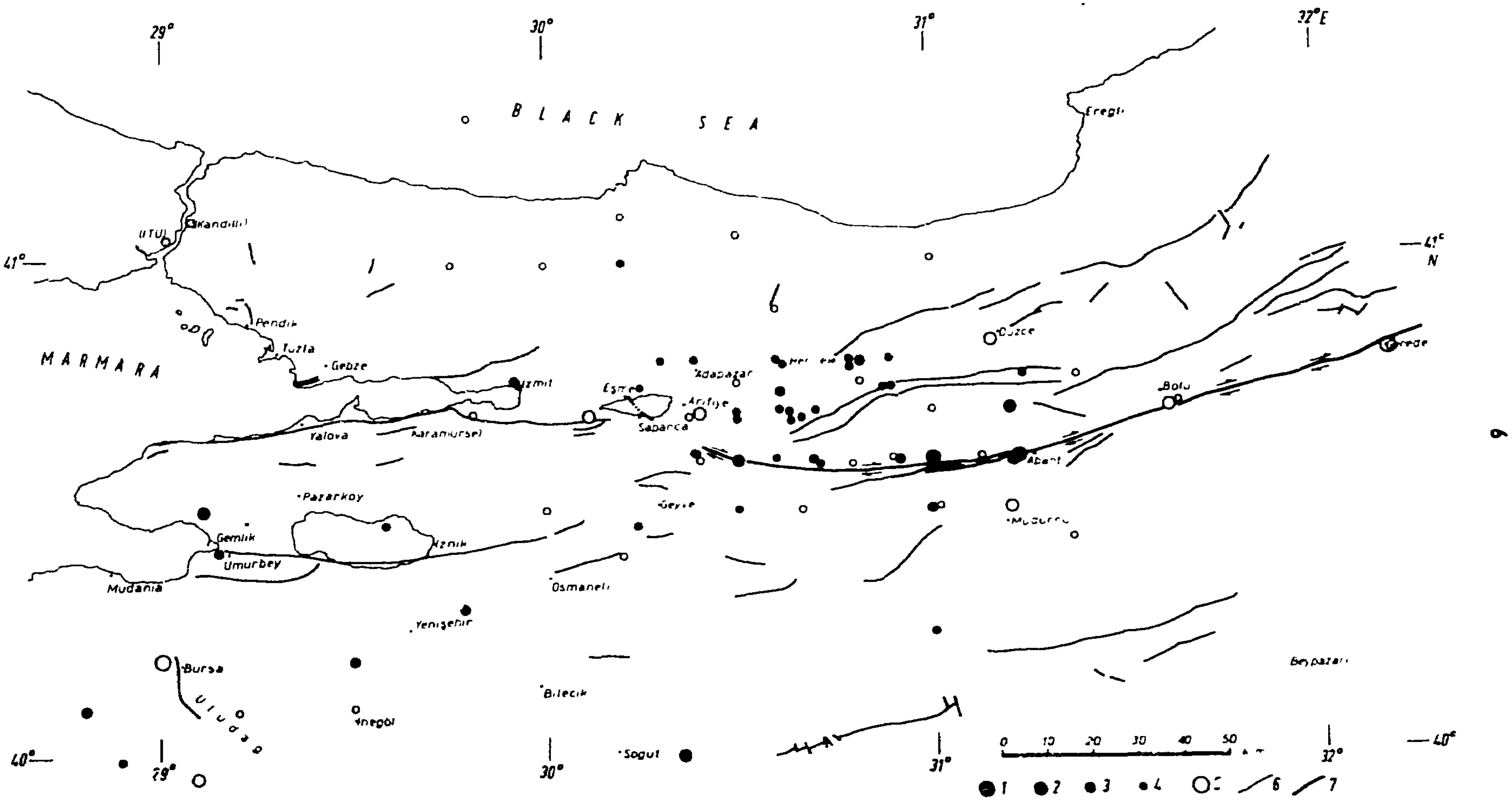


4. General view of fault zone from point 46, looking west.

5. General view of fault zone from point 42, looking east.



6. Location of fracture zone of Mudurnu earthquake (east) with respect to geologic faults and rupture zone of 1957 earthquake.
1 : Rupture zone associated with the Abant earthquake of 1957 (approximate); 2 . Location of villages closest to fault break;
3 : points where ruptures cut through rock, Numbers refer to location on the fault and letter to age of rock (see figure 3);
4 . location of villages
5 : 1967 ground ruptures with indication of throw;
6 : geologic faults.

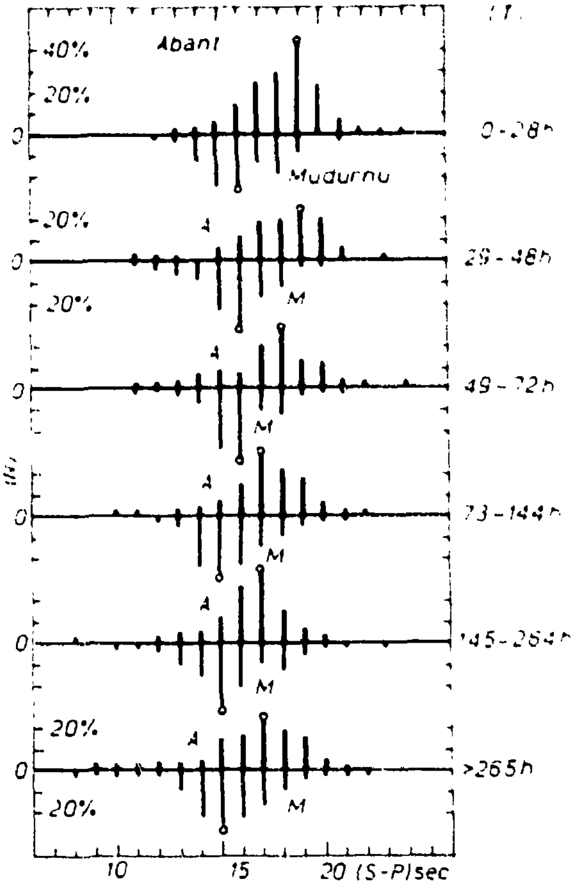


7. Map of epicentres in the west part of the Anatolian fault zone. 1 : $M \geq 7$; 2 : $6 \leq M < 7$, 3 : $5 \leq M < 6$, 4 : $5 < M$, 5 : Macroseismic epicentres (see Tables 2 to 4); 6 : Geologic faults, 7 : recent ruptures.

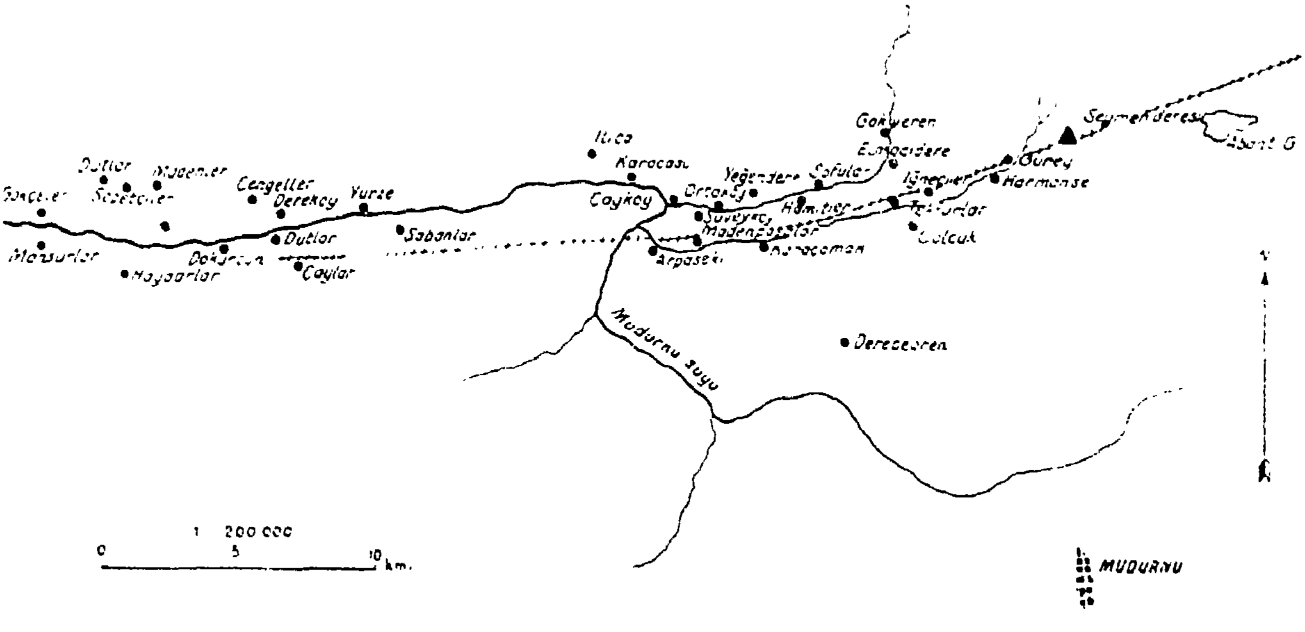
8. Frequency distribution of the Abant (1957) and Mudurnu (1967) aftershock, (S-P) intervals from Istanbul. N = percentage of total number of aftershocks during the interval T in hours that showed (S-P).

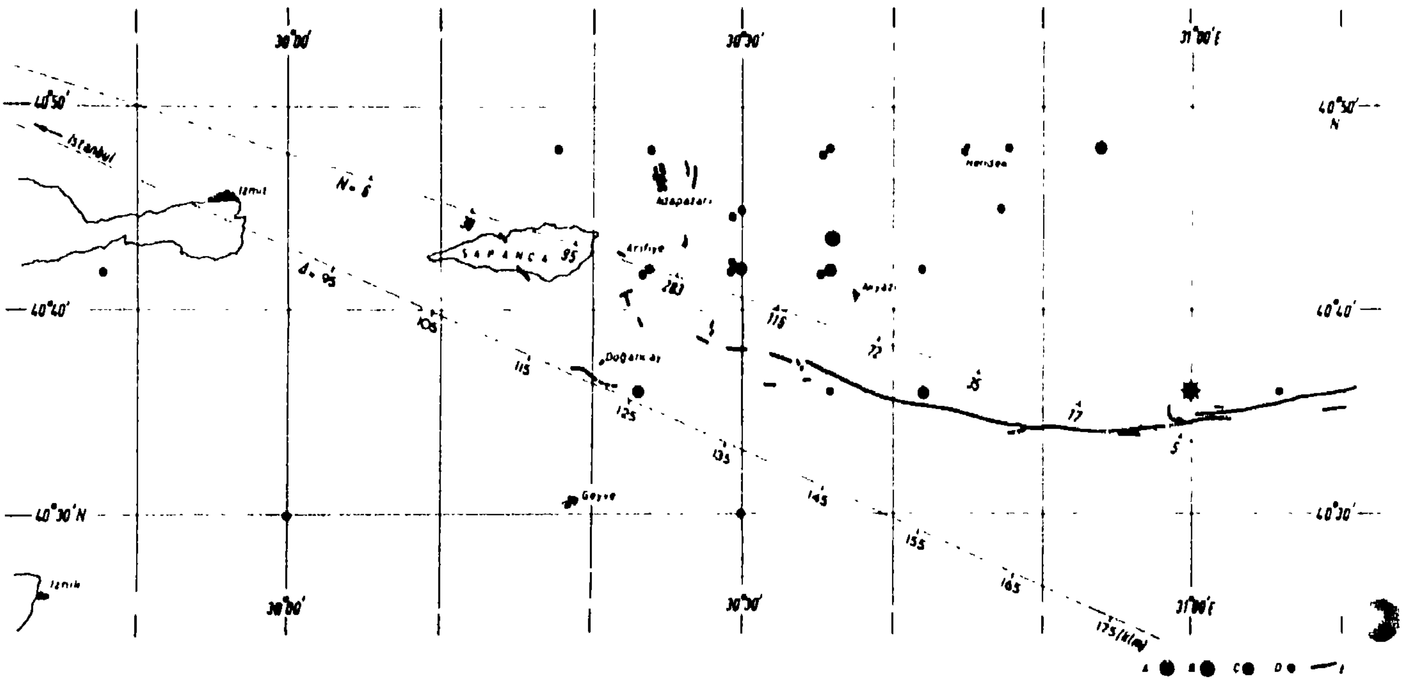
9. Location of fractures associated with the 1957 Abant earthquake (after Öcal 1959).

8



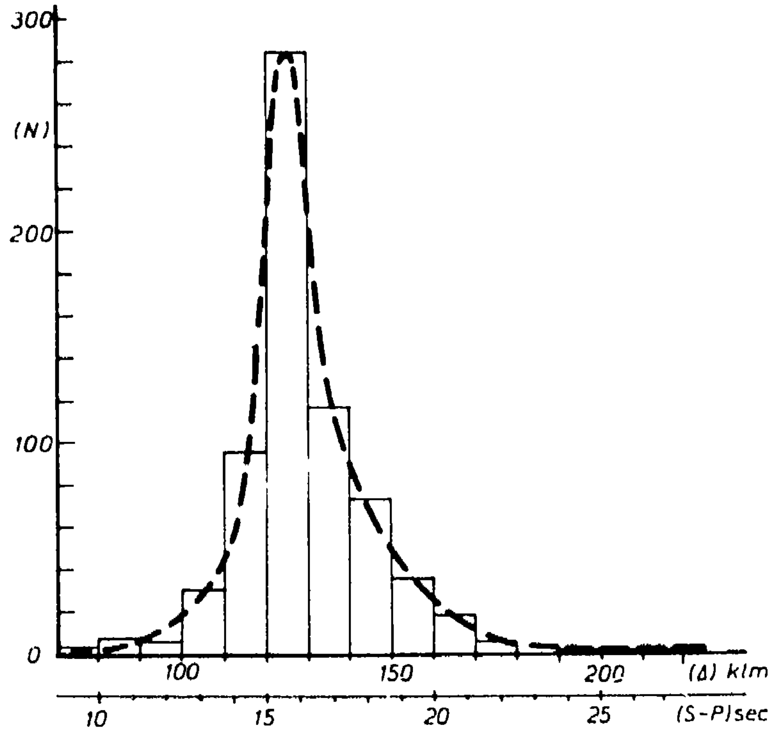
9





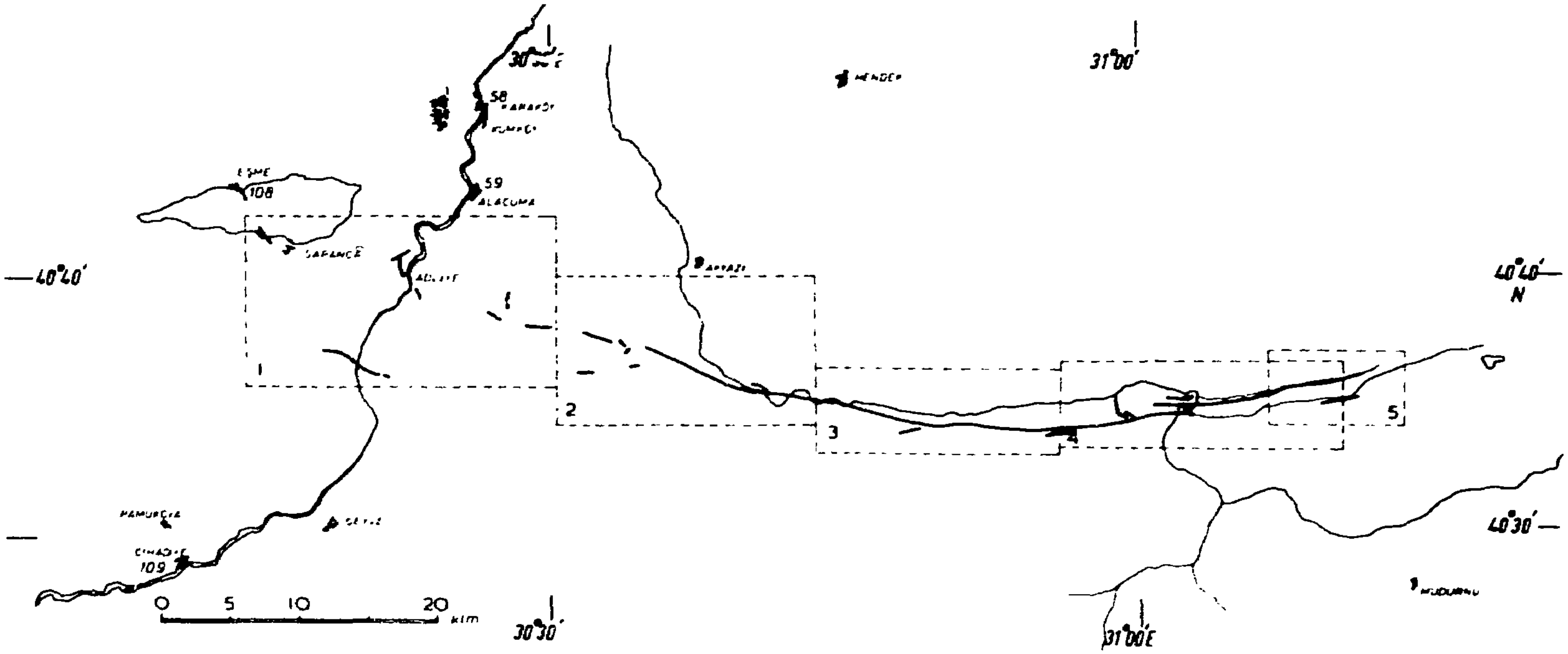
10

11

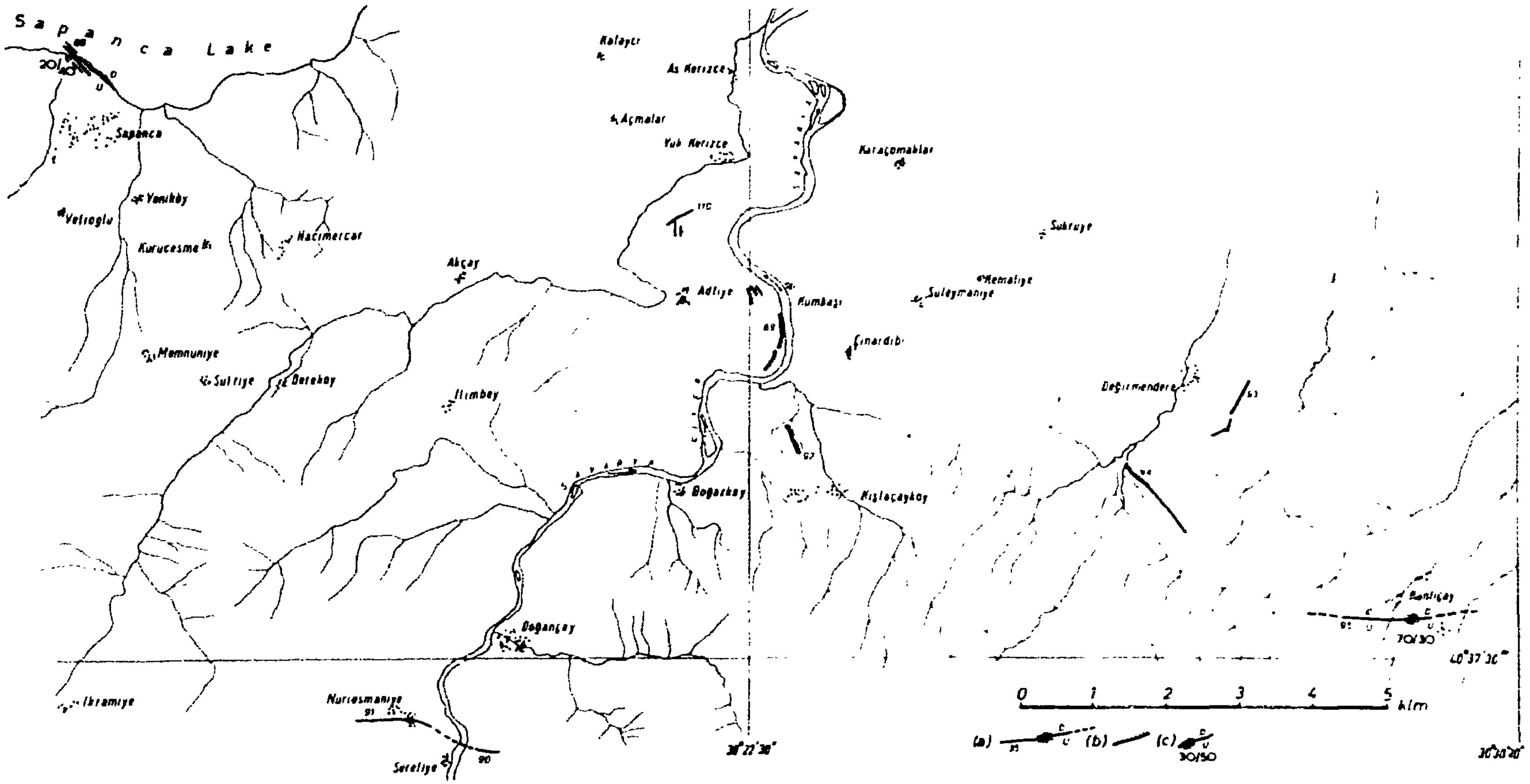


10. Aftershock distribution of the Mudurnu earthquake for the period 22 July 1967 - 18 September 1967. A : M ≥ 5½; B : 5½ > M ≥ 5; C : 5 > M ≥ 4½; D : 4½ ≥ M; E : fracture zone; N = number of aftershocks within a zone of ± 5 kilometres from D.

11. Distribution of aftershocks of the 22 July 1967 earthquake for the period 22 July - 18 September 1967. D measured from Istanbul.

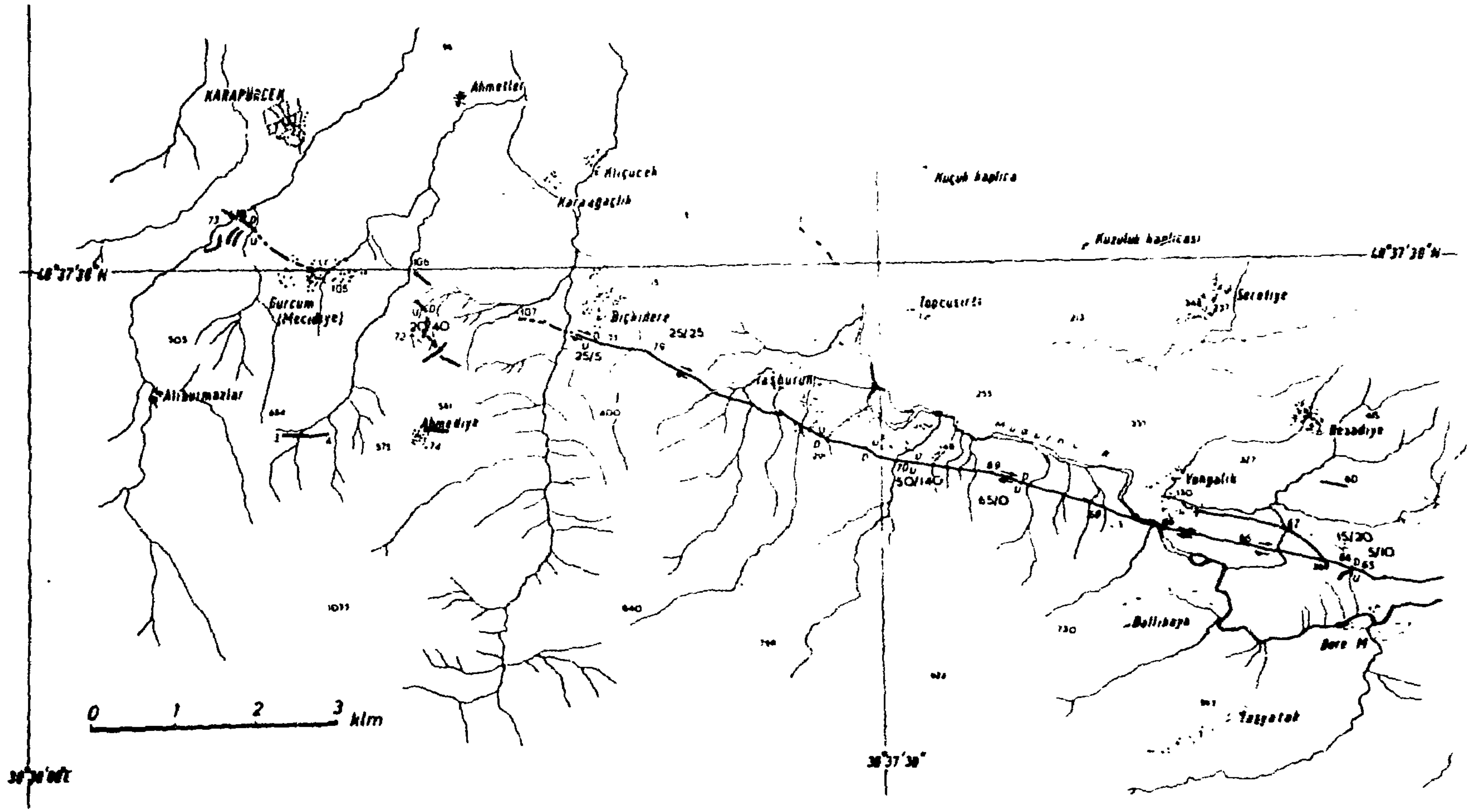


12. Location map of Figures 13.1 to 13.5.

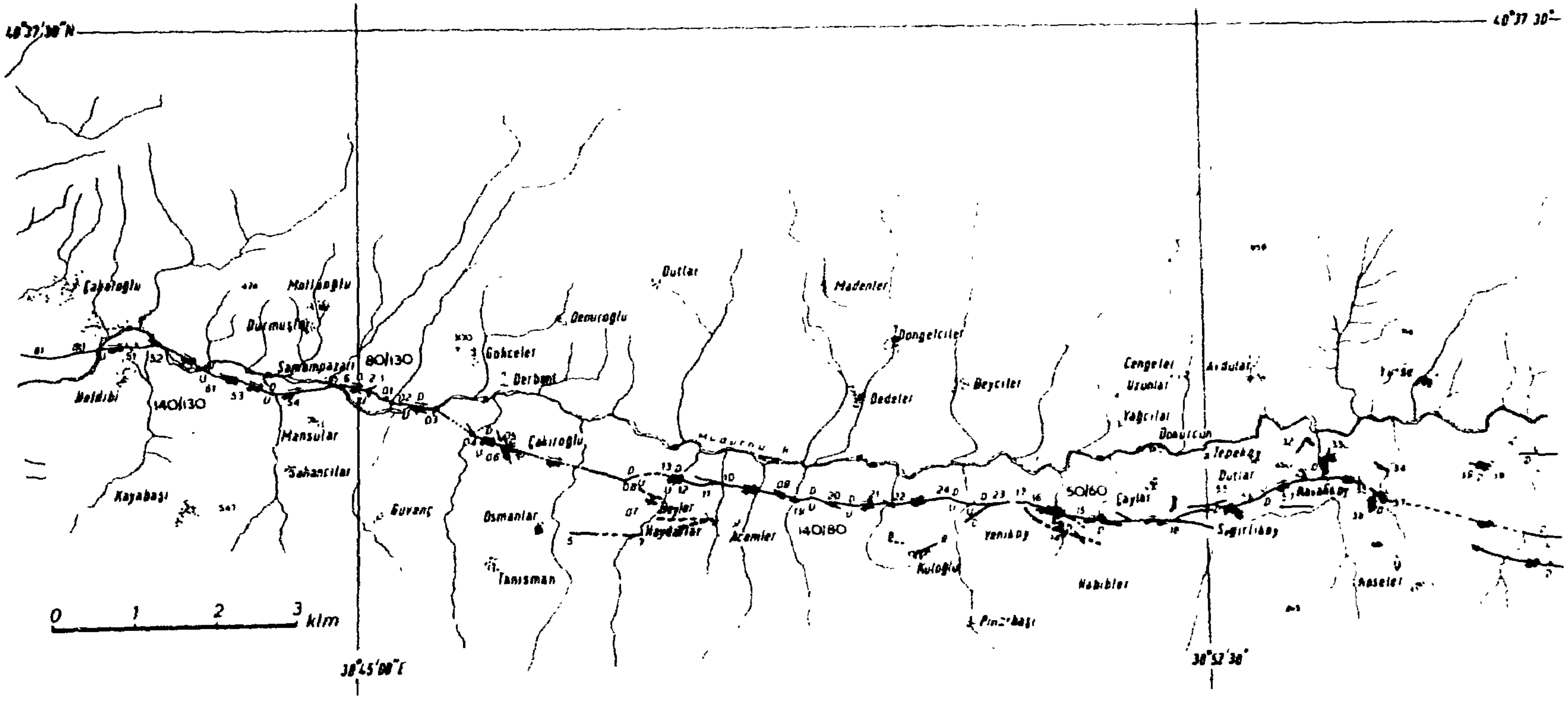


13.1

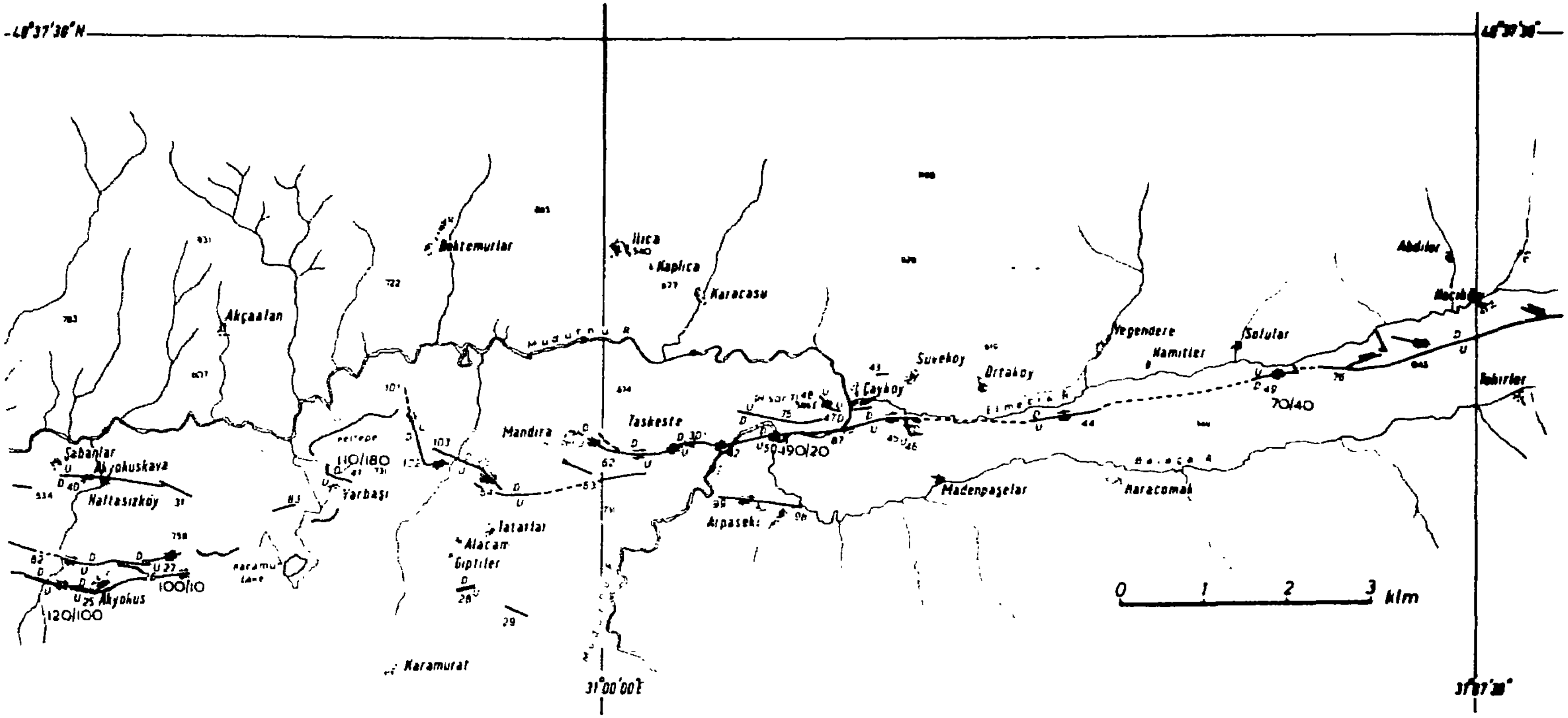
13. Maps of the Mudurnu Valley fault zone showing ground ruptures produced by the earthquake of 22 July 1967. (a) Ground ruptures; arrows indicate relative movement : U = up, D = down; numbers refer to specific localities mentioned in the text; (b) Boundary of landslides, (c) Horizontal displacement/ Vertical displacement in centimetres. Three and four-figured numbers refer to altitude of ruptures.

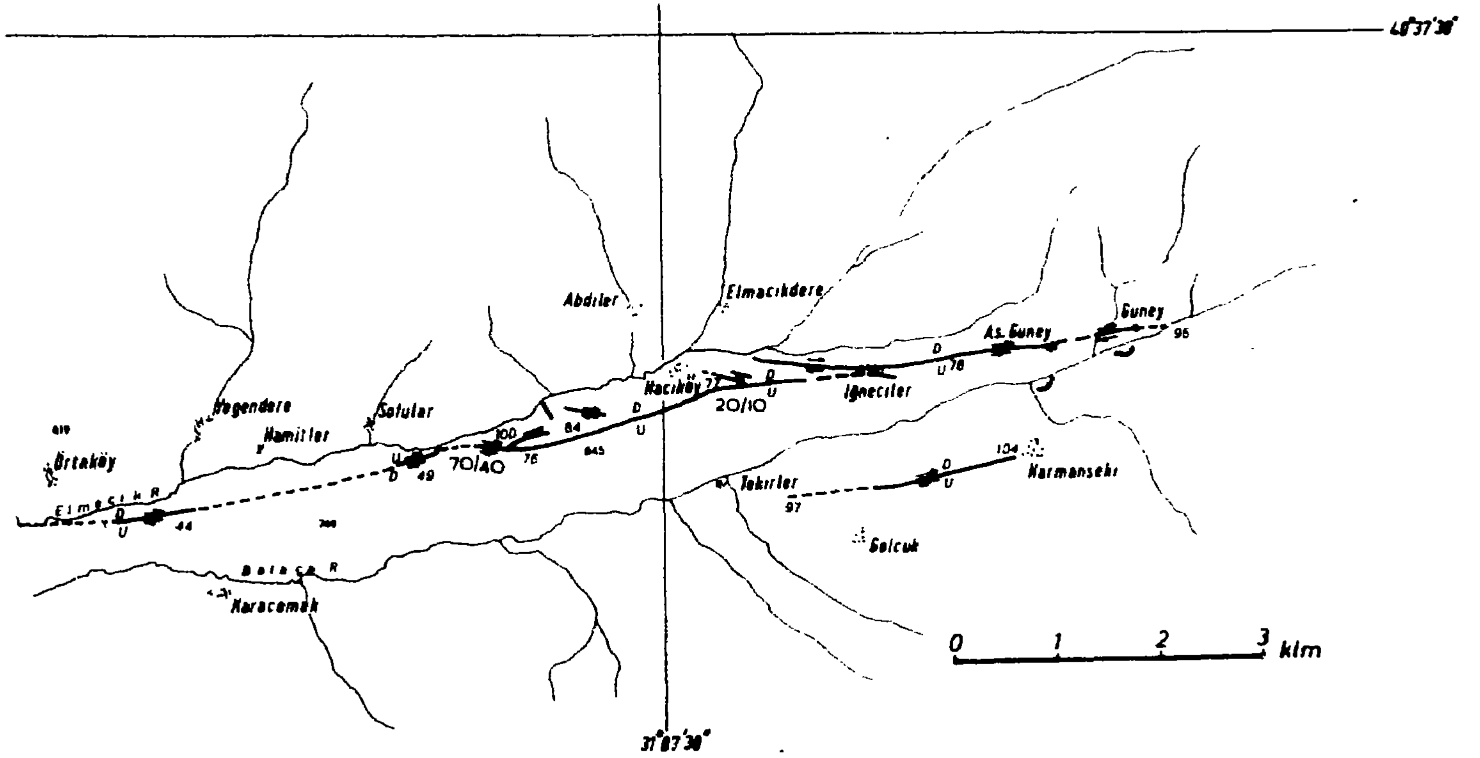

KARAPÜRÇEK
Ahmetler
Kılıçucek
Karaağaçlık
Küçük kaplıca
Kuzuluk kaplıcası
40°37'30"N
40°37'30"N
Gurcum (Mecidiye)
Bıçkıdere
25/25
25/5
20/40
Alibutmazlar
Ahmediye
Taşburun
Topcusırtı
Sarıalıye
Reşadiye
Yongalık
70
50/140
65/0
15/20
5/10
Ballıkaya
Bere M
Taşyatak
0
1
2
3
klm
38°30'00"E
38°37'30"

13.2

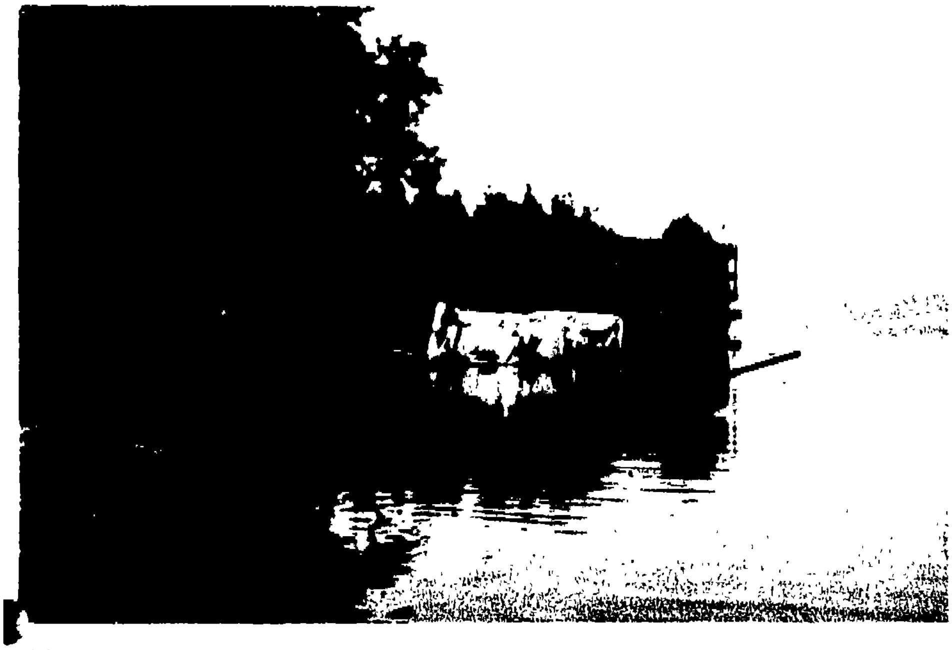

40°37'30" N
40°37'30"
38°45'00" E
38°52'30"
Çakaloğlu
Mollaoğlu
Durmuşlar
Sarıcapazarı
Beldibi
140/130
80/130
Mansular
Sahancılar
Kayabaşı
Gökceler
Derbent
Demiroğlu
Dutlar
Çakıroğlu
Güvenç
Osmanlar
Tanısman
Beyler
Kayadibi
Acemler
140/180
Madenler
Döngelciler
Dedeler
Beyciler
Kuloğlu
Pınarbaşı
Yeniköy
50/60
Çaylar
Cengeler
Uzunlar
Yağcılar
Dolurcun
Tepekaş
Dutlar
Ardıçlar
Karaköy
Sağırlıkay
Habibler
Koseler
0
1
2
3
klm

13.3


40°37'30"N
Sabanlar
Akyokuskava
Naftasızköy
Akçaalan
Yarbaşı
Akyokus
120/100
100/10
110/180
Karamurat
Tatarlar
Alacam
Giptiler
Boktemurlar
Ilıca
Kaplıca
Karacasu
Mudurnu R.
Mandıra
Taşkeste
90/20
Arpasek
Çayköy
Suveköy
Ortaköy
Yegendere
Hamitler
Solular
Abdiler
Hacıbey
Tahirler
70/40
Madenpaşalar
Karacomak
0
1
2
3
klm
31°00'00"E
31°07'30"

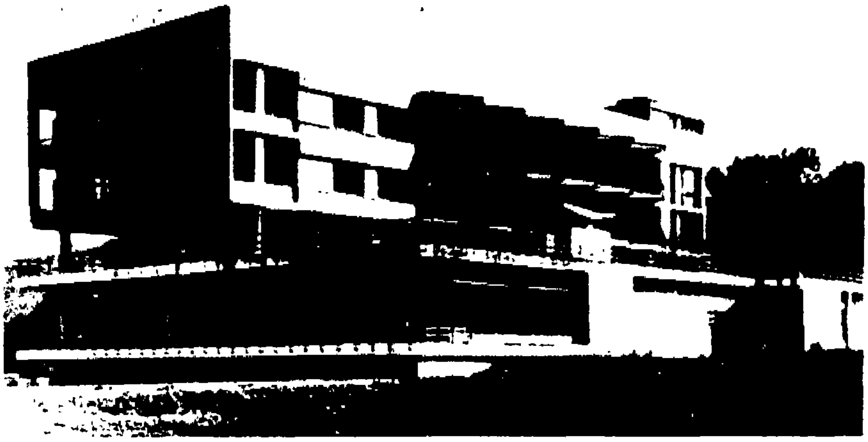

40°37'30"
Abdiler
Elmacıkdere
Güney
As. Güney
96
D
U 78
Hacıköy
77
D
U
20/10
İgneciler
Hogendere
Hamitler
Solular
619
Örtaköy
100
84
D
U
U
D
49
70/40
76
645
104
D
U
Narmanşehı
Tekirler
97
Elmacık R
D
U
44
744
Gölcük
Balaca R
Karacemek
0
1
2
3
klm
31°37'30"

13,5

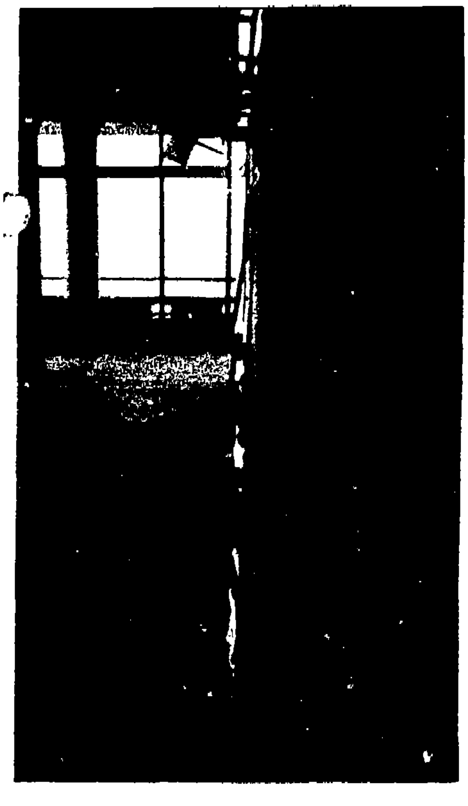


14

15



16



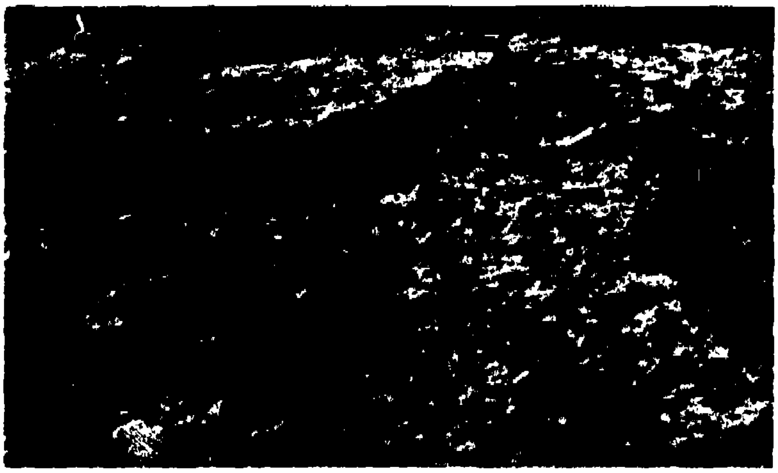
14. Sapanca Lake. Shore-line near point 88 after earthquake. Arrow shows extension of rupture zone into lake. Kumbaz Hotel in the background.

15. Sapanca Lake. Kumbaz Hotel before the earthquake.

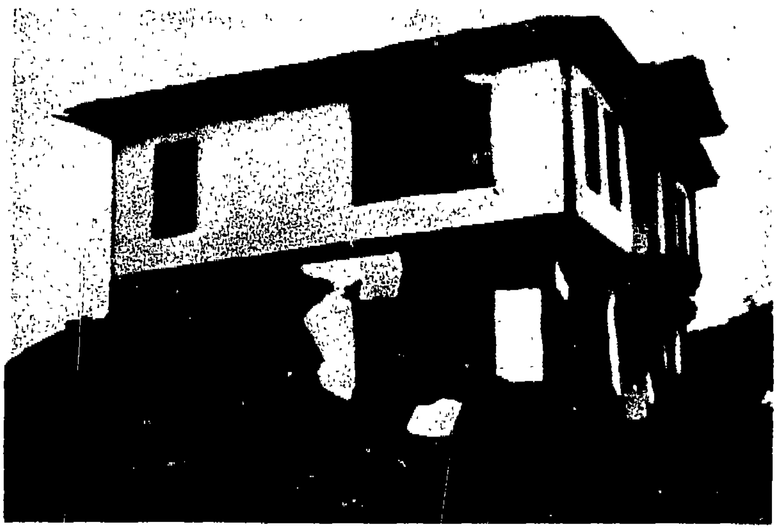
16. Construction joint in Kumbaz Hotal, Sapanca.

17

18



19

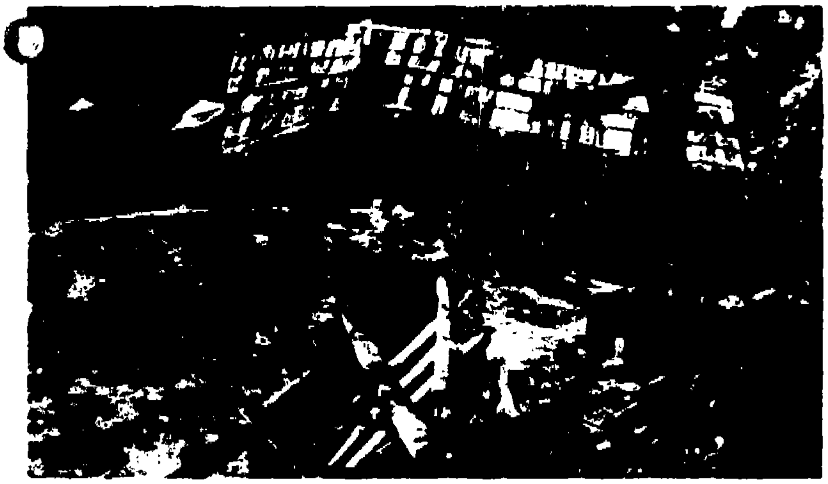


17. Rupture zone and mudvent deposits in Sapanca. House settled; depression filled with fine sand issued from vents.

18. Raised and thrust wedge of soil with corresponding gap near locality 71.

19. Continuation of the trace shown in Figure 18 at Bickidere; en echelon fractures pass under house.

20



21

22

20. Detail of fractures shown in Figure 19.

21. Barn straddling fault trace near locality 70.

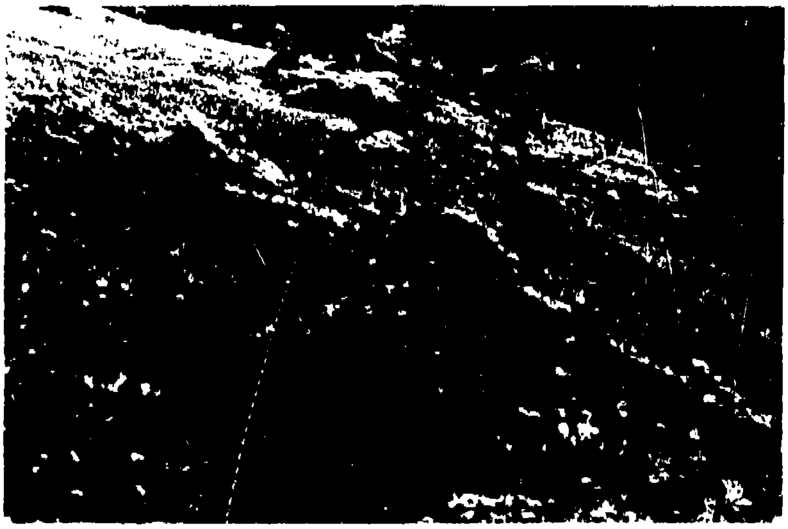
22. Fault trace and graben near point 68.

23. House straddling fault trace near locality 67. This house is built partly on old fault scarp and partly on stilts.

24. Compressional features of fault trace near point 81.

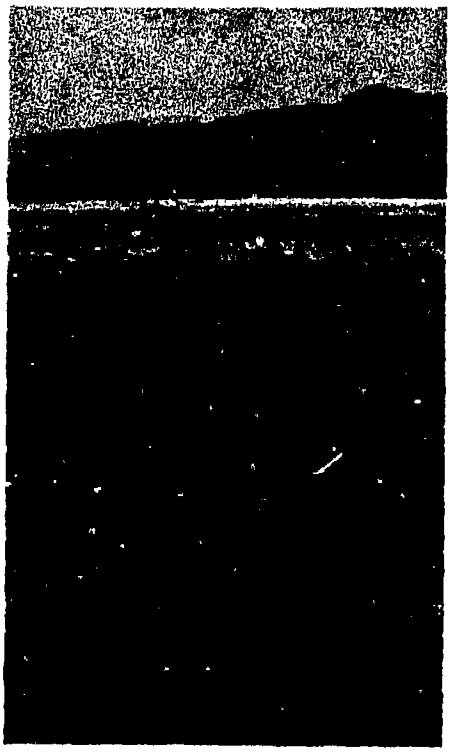
25. Fresh scarp near locality 80.

23



24

25



26

27

28

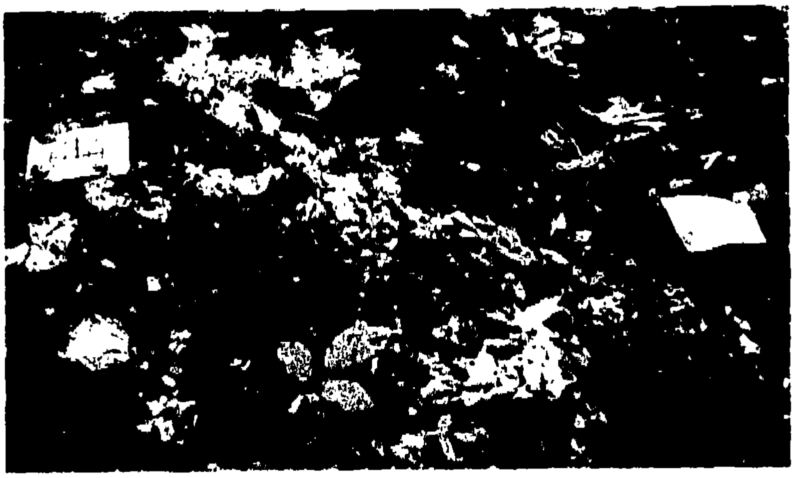
26. Ground ruptures near point 61, looking east.

27. Mole-track scarp near point 53, looking west-northwest.

28. Timber-braced mosque at Samanpazari, 150 metres from main fracture, looking north.

29

30



31

29. Small graben near point 4, looking east. Point A shows location of old fault scarp.

30. Strike slip of 145 centimetres near point 01, shown by thick root pulled apart. Matching markers show tips of broken root; axes of markers point north.

31. Displaced fence exhibiting 150 centimetres of strike-slip near point 01, looking south.

32

33

32.
House straddling a branch of the main rupture 80 metres north of fence shown in Figure 31, looking south.

33.
Dislodged cable near point 01; white mark on compass points north.

34. Root pulled apart near point 02 showing apparent left-lateral movement.

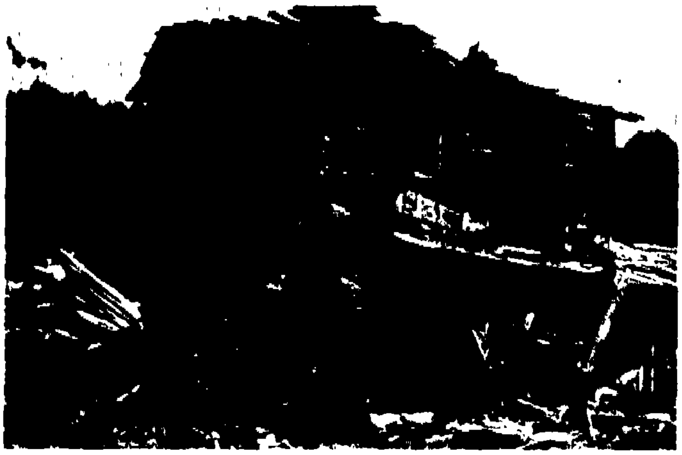
35. Ground rupture near point 03, looking south. East side of rupture terminates on steep river bank involved in sliding.

36. Remains of timber-sheathed old house in Derbent, looking north.

37. Typical elevated barn next to house shown in Figure 36, looking northwest.

34

35



36

37

38. Roots broken by buckling near point 04.

39. Approach road to Cakiroglu between localities 05 and 06, looking west-northwest. Note displacement of axis of road.

40. Severe cracking in terrace crossed by ground ruptures at point 06, looking east-southeast.

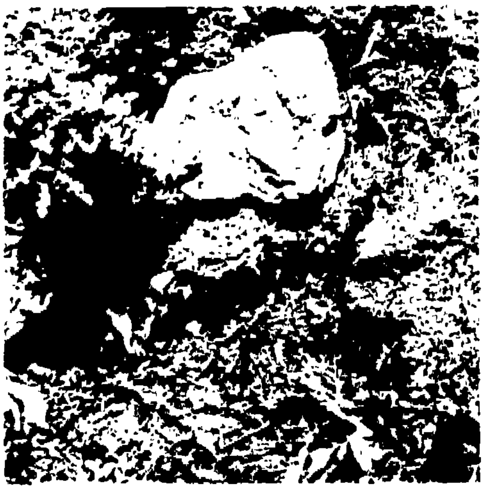
38

39

40

41

42



43

44

41. Buckled and broken root crossing rupture zone that otherwise showed little evidence of ground displacements; near locality 13, looking west.

42. Large mole-track with pressure ridges in compact alluvium near point 13, looking east.

43. Dislodged cobbles and small boulders showing original sockets, near point 13.

44. Displaced boulders near point 13 showing relative displacements of 10 to 20 centimetres; white mark on compass points south.

45. Scarplets in compact soil near point 09.

45

46

48

47

49

46. Offset ridge near locality 09, looking south.

47. Elevated barn 40 metres from main fracture. In the background, water-mill offset 100 centimetres by main fracture; point 19.

48. Offset roots at locality 19.

49. North wall of small graben formed at point 21, looking east.

50. Rock-fall between points 21 and 22 blocking narrow gorge.

51. Ground ruptures leading to point 16; looking west.

52. Rotated block of soil between adjacent fractures at locality 16.

50

51

52

53. Offset fence at west side of cemetery at Yenikoy.

54. Pressure ridges of soil slabs humped up at the cemetery in Yenikoy.

53

54

55. Sketch of fracture at Yeniköy cemetery (scale approximate).

56

57

58

56. Left-hand strike-slip exhibited along fractures associated with sliding north of Yenikoy (taken from point A in figure 55).

57. En echelon fractures near location 15, looking east-northeast.

58. Offset fence at point A of figure 57.

59

60

59. Details of old damaged house at Yenikoy.

60. Timber house at Yenikoy. Frame portion only slightly damaged; typical construction.

61. Damage to local construction at Sigirlikoy.

61

62

63

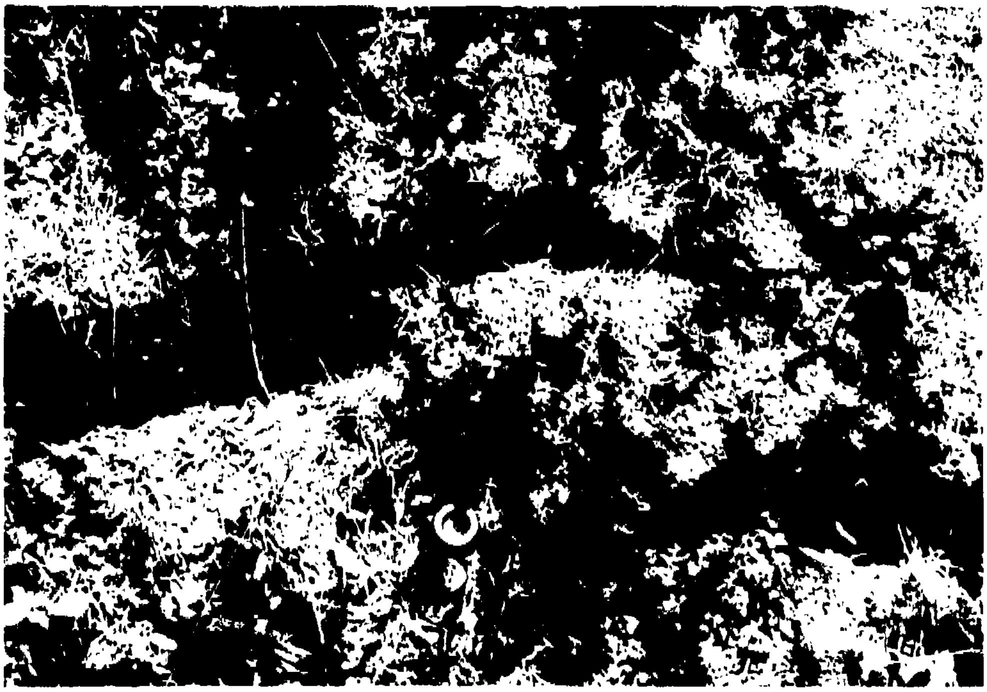
64

62. Deformation of fence straddling fault trace near point 56.

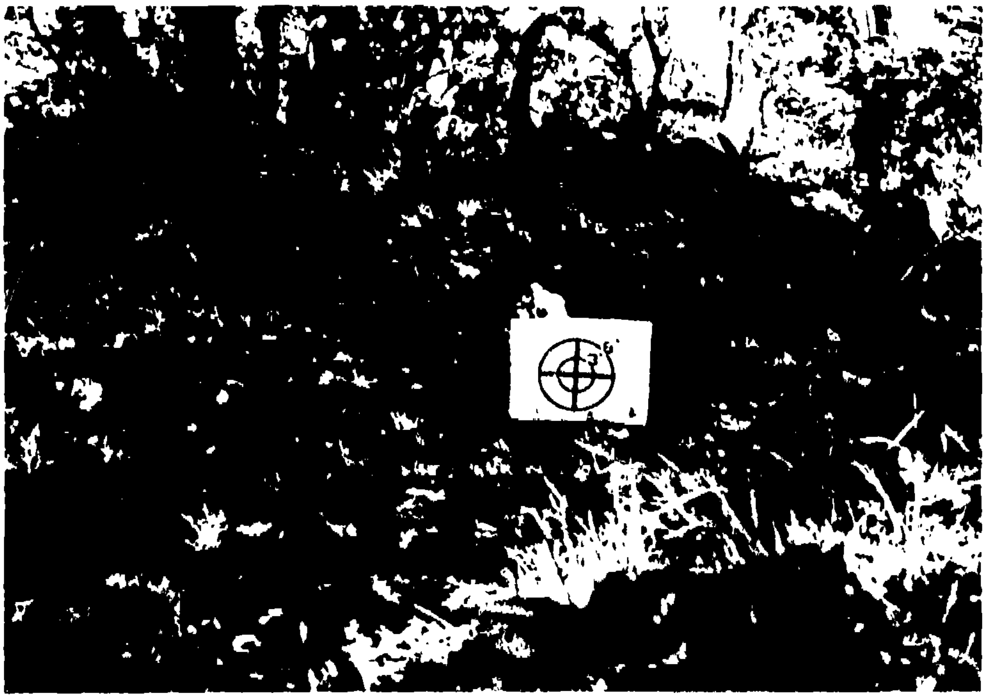
63. Arrow shows eroded scarplet, reportedly associated with 1957 earthquake. Smaller arrows show fresh ground rupture near locality 33.

64. Panoramic view towards point 34 taken from point 36. Arrows shown main ground ruptures.

65



66



65. Rotated block of soil between adjacent en echelon cracks showing left-lateral movement near point 38.

66. Normal faulting near locality 39.

67

68

69

67. Collapse of two-storey house on trestles at Skyokuskaya.

68. Typical timber house at locality 40. Only slight damage to central trestles.

69. 1957 and 1967 fault scarps at point 25. Upper scarp reportedly associated with the Abant 1957 earthquake.

70

70. Offset fence at Akyokus. Fence displaced at same point in 1957.

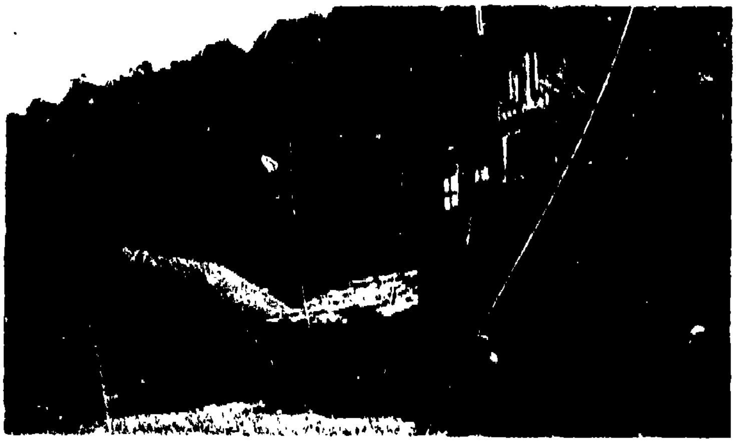
71. Fault trace at locality 27, looking west-northwest.

72. Group of large timber houses at Akyokus, situated 40 metres from rupture zone; no damage.

73. The village of Akyokus after the earthquake, looking north-northeast.

71

72



73

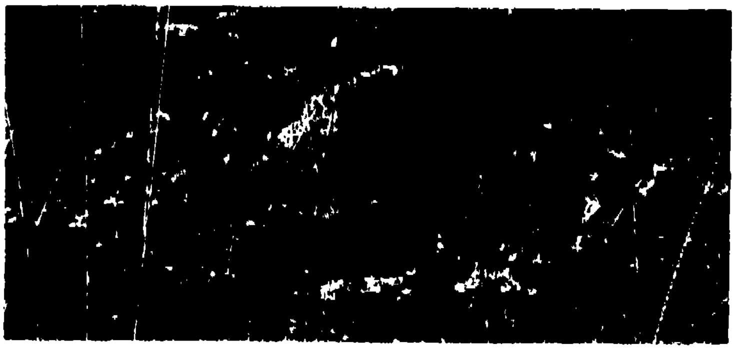
74. Fault scarp at point 41, outskirts of Yarbasi.

75. Large mole-track with wedges of soil humped up, west of point 30.

76. Fault trace approaching Arpaseki, looking west-southwest.

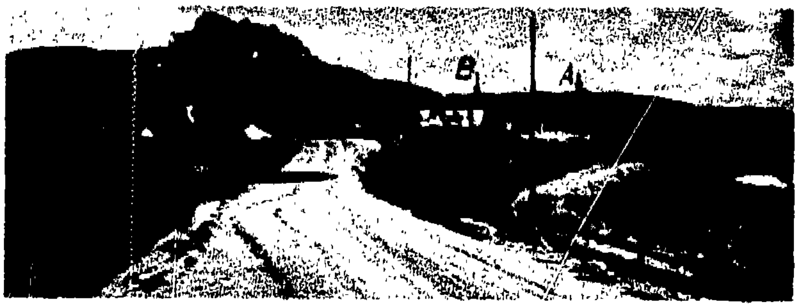
74

75



76

77



78

77. Offset of road axis at locality 30. Points A, B, C and D shown in Figure 85, 79, 78 and 82 respectively.

78. Fault scarp between points B and C of Figure 77; looking east-southeast.

79. Fault scarp between points B and C of Figure 77; looking west; note lack of damage to local house.

79

80

81

80. Fault trace near point 30 looking east towards point 42. Compare with Figure 5. Fault in places is a zone of en echelon scarps facing south.

81. Continuation of fault trace shown in Figure 80, looking north. Note secondary fractures with their apex pointing in the direction of relative displacement.

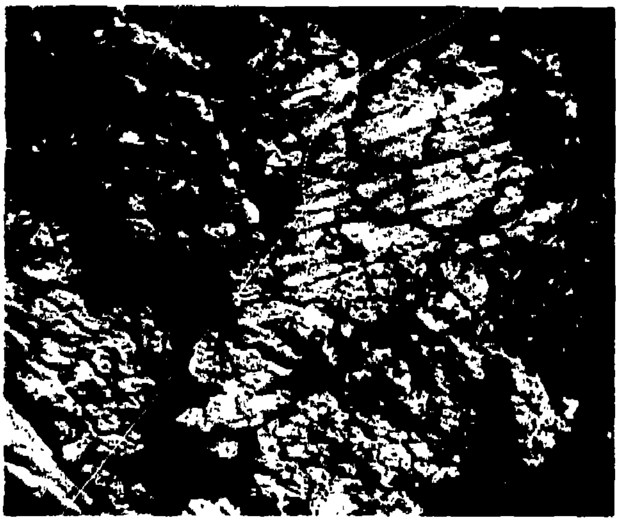
82. Large strike-slip displacements at point 30 (point D in Figure 77).

82

83. Slickensided face of shear zone.

84. Pressure ridge in the foreground dammed the river at point 42, looking east. Note uplifted gravel bed.

85. Typical local house at point A of Figure 77; situated 10 metres from fault-trace.



83

84

85

86

87

88

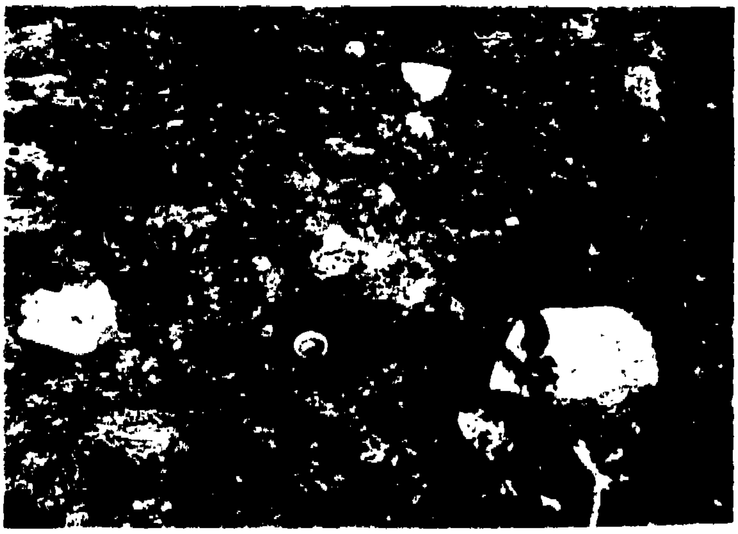
89

86. Fault scarp at point 50, looking north; strike slip displacement 190 centimetres in marls.

87. Fault trace viewed from point 47, looking east.

88. Fault trace at locality 75.

89. En echelon fractures at Hisar Tepe, looking north-east.



90

91

92

90. Cobbles thrown out of their seats at Hisar Tepe.

91. North and central fractures of small graben at point 45, looking west. Compare with Figure 4.

92. Distorted timber construction at Hamitler; note open ground floor.

93

94

95a

93. Undamaged timber construction at Hamitler.

94. Brick building at Yegendere.

95a. Fault trace near Sofular.

95b

95b. En echelon heavy fractures in surface of secondary road, 1500 metres east of Sofular, looking west.

96. Open joints in outcropping limestone at locality 49.

97. Rejuvenated landslide scar on the Abant-Guney road.

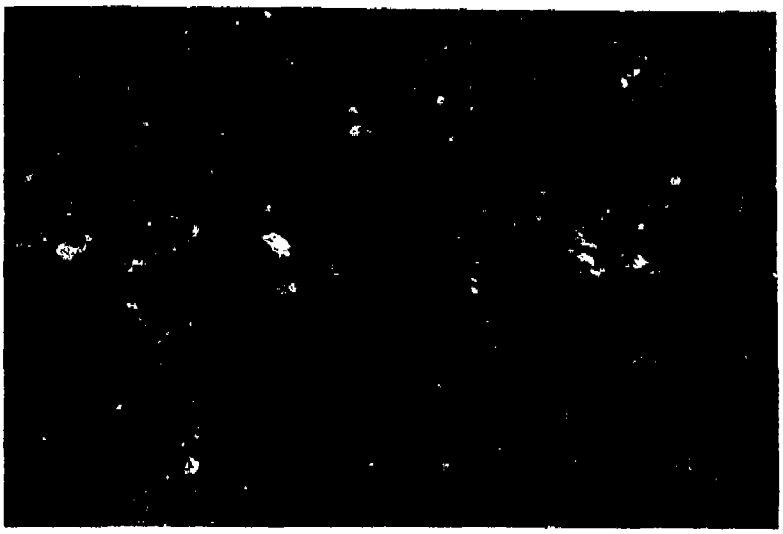
98. Ground cracks Cihadiye, looking east-southeast. Sakarya river in the background.

99. Tension cracks with mudvents bordering the Sakarya river near locality 59; looking east.

100. Wedges of soil in en echelon fracture near Alancuma, looking west northwest, by the Sakarya river (see Figure 12).

102. Damaged sway-brace of high-voltage pylon straddling ground ruptures at point 59.

96

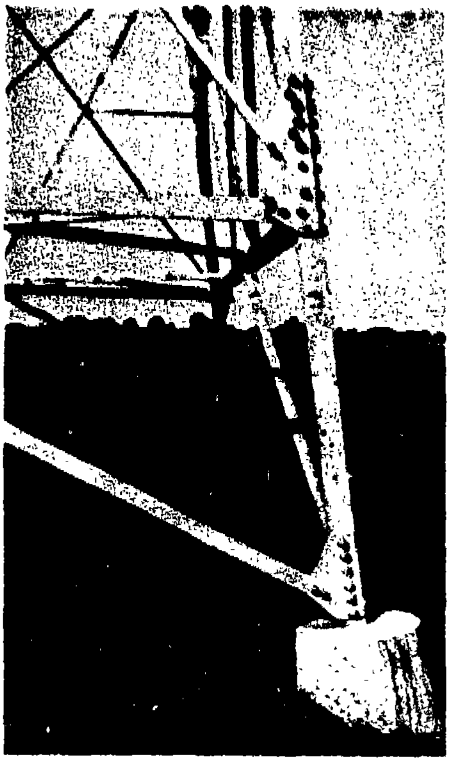


97

100

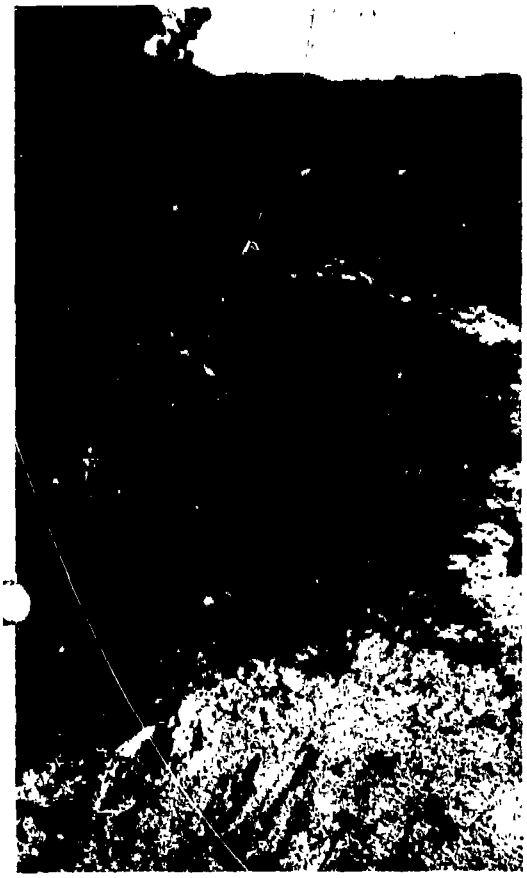
98

99



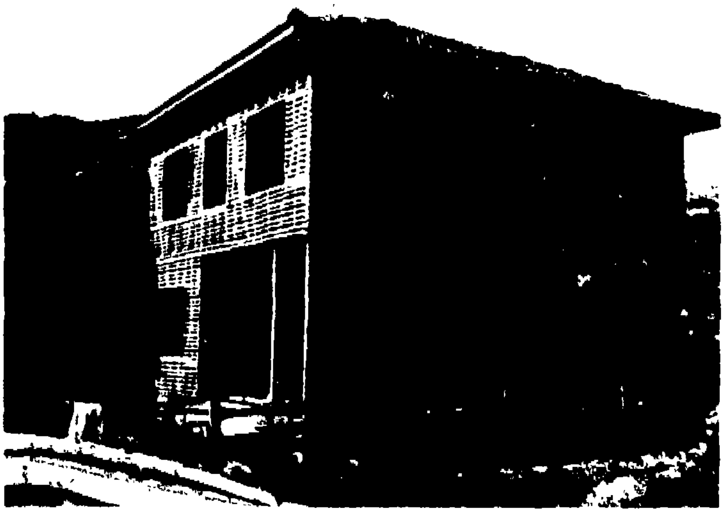
102

101. Detail of wedges of soil humped up and thrust near locality 76.



103

104



106

105

103. En echelon ground ruptures near point 110, looking west. Extension of cracks to the east responsible for damage to the main Adapazari-Geyve highway.

104. Eastward extension of cracks shown in Figure 103, looking east; mudvent silt and sand with crater in temporarily flooded fields.

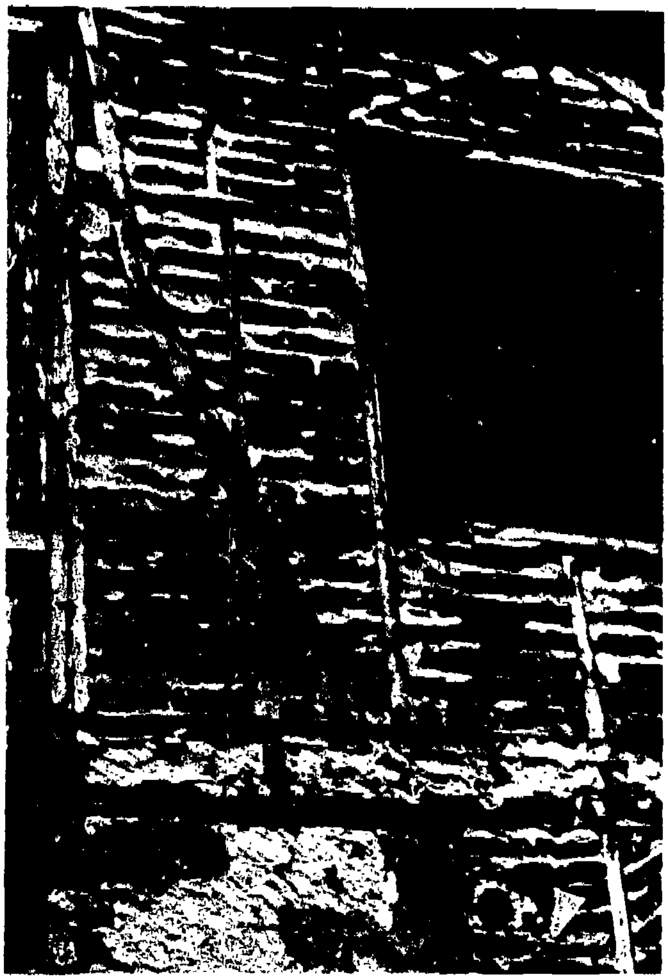
105. Slumping of the Sakarya at Adliye, looking east near locality 89.

106. Typical new "bagdati" construction at Dokurcun.

107a. Similar old construction in Samanpazari 50 metres from fault. Note cornerstone.

107b. Typical timber braced construction, at Kurtkoy, Sapanca.

107a



107b

108

109

108. Heap of rubble, remains of adobe house at Kislacaykoy south of locality 92.

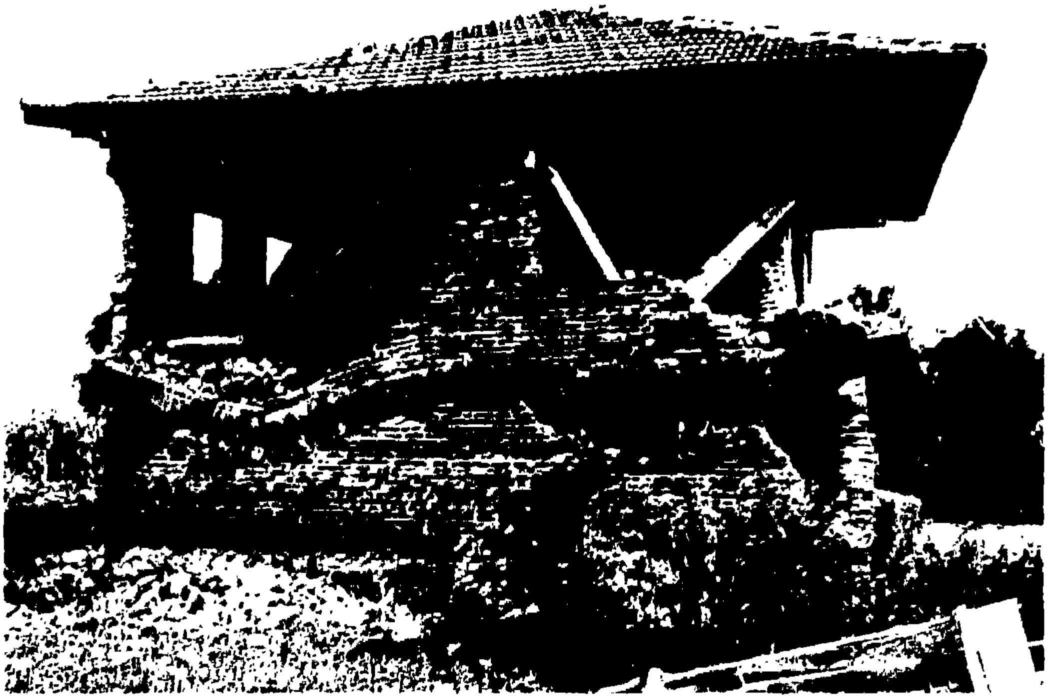
109. Heavily damaged old timber-frame construction at Kislacaykoy, 50 metres to the east of adobe house shown in Figure 108.

110

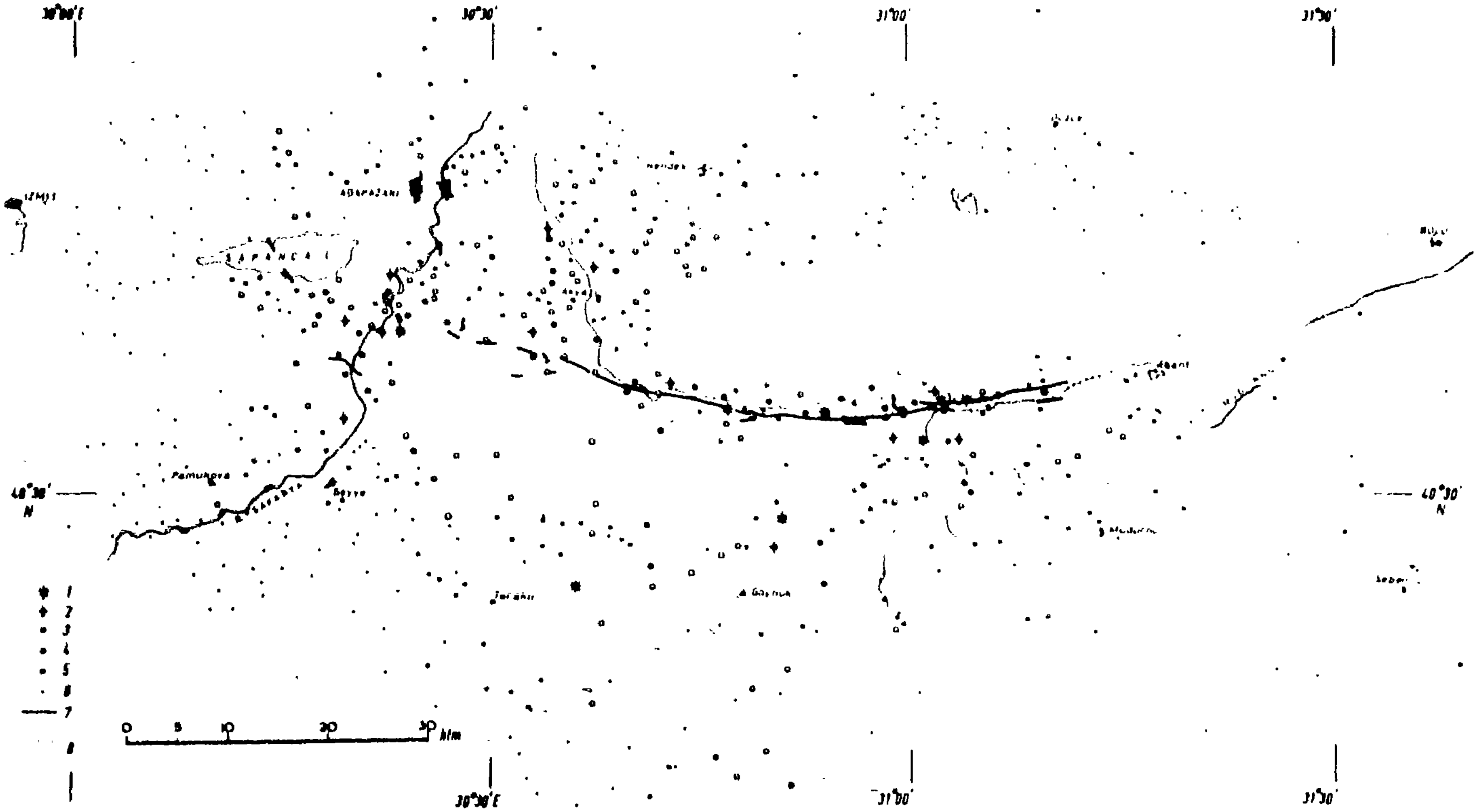
111

110. Elevated timber barn situated 20 metres west of adobe house shown in Figure 108; no damage.

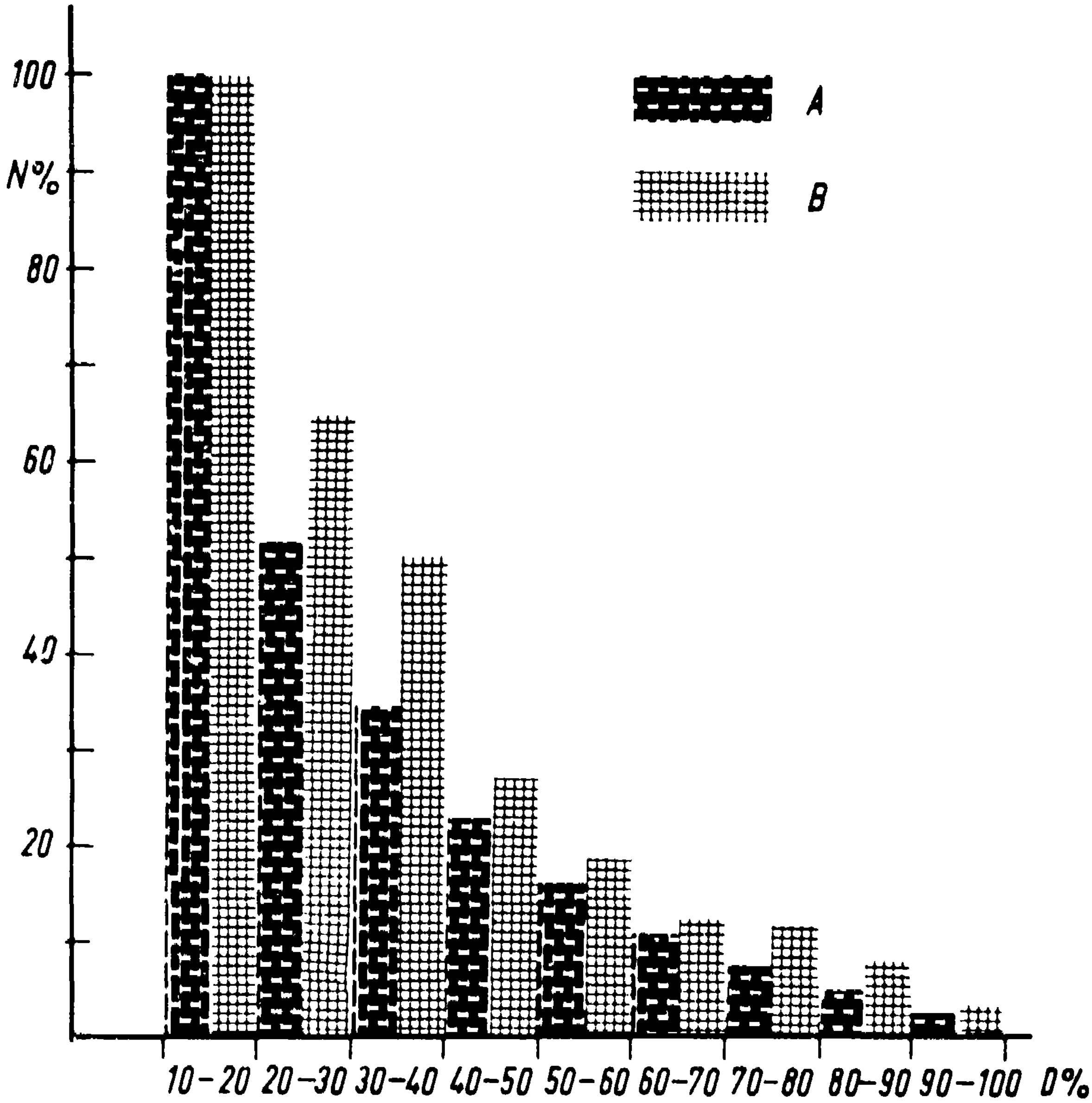
111. Destroyed adobe mosque at Dogancay. In the background timber braced house suffered small damage.



112. Remains of brick house near Asagi Kirezce.



113. Damage distribution map. D – ratio of number of houses destroyed or damaged beyond repair to total number of houses in village, 1 : 75 < D ≤ 100; 2 : 50 < D ≤ 75; 3 : 25 < D ≤ 50; 4 : 10 < D ≤ 25; 5 : D ≤ 10; 6 : no damage; 7 : fault break, 8 : fault zone of 1957 earthquake.

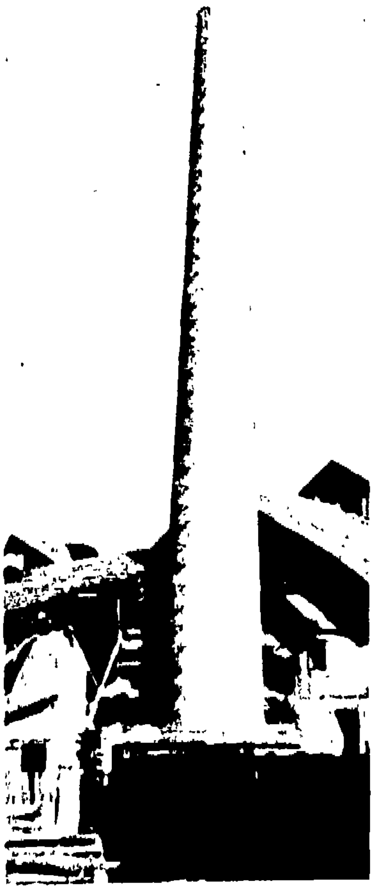


114. Damage distribution, A in epicentral area, B in fault zone. N = percentage of villages within A or B that suffered damage D.

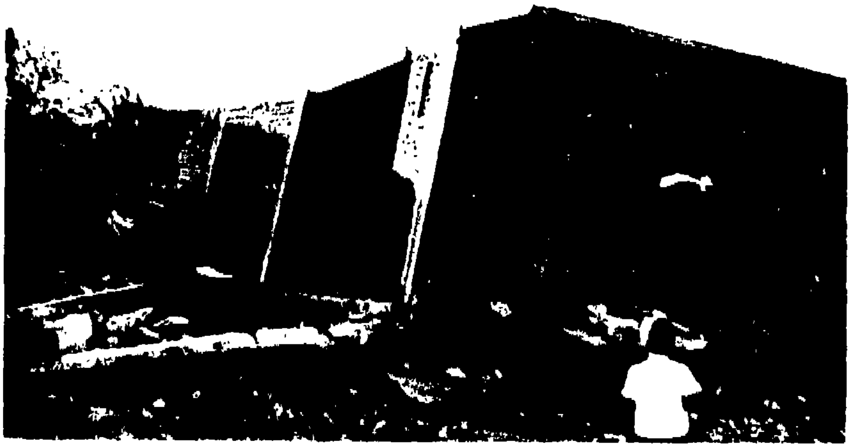
115. Factory stack in Adapazari.

116. Boztepe mosque, stone masonry completely destroyed. Timber minaret help up by central timber pole.

115



116

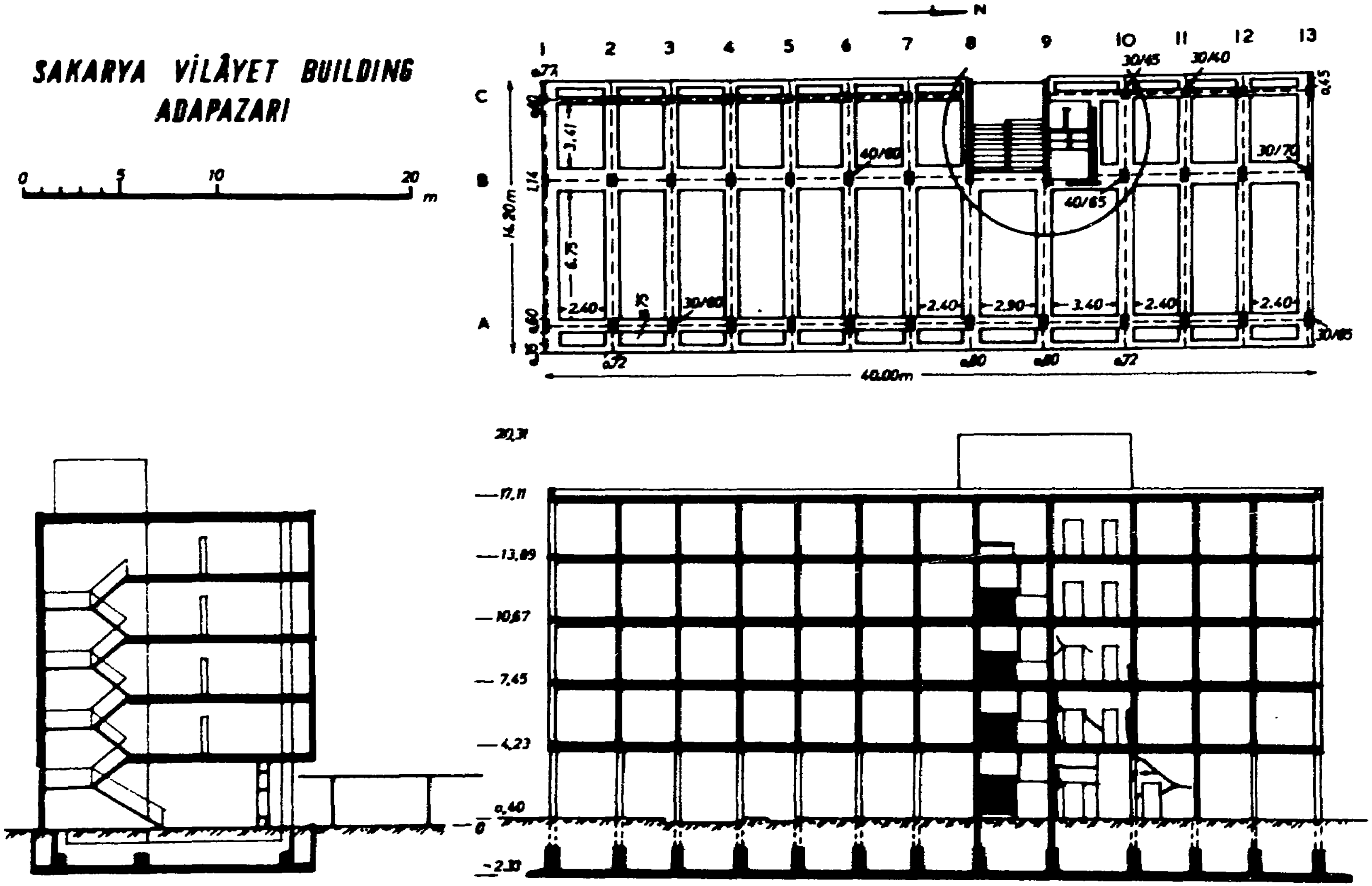


117

118

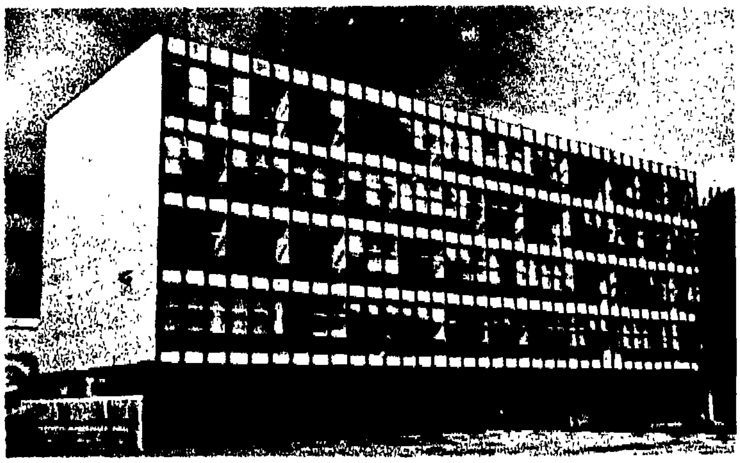
117. Two-storey reinforced concrete house in Adapazari under construction, damaged by the main shock and thrown down by the main aftershock of 30 July.

118. Column failure at Agricultural Equipment Factory, Adapazari. Column 39 × 39 centimetres, 4 Ø 14-millimetre bars, Ø 6-millimetre stirrups.

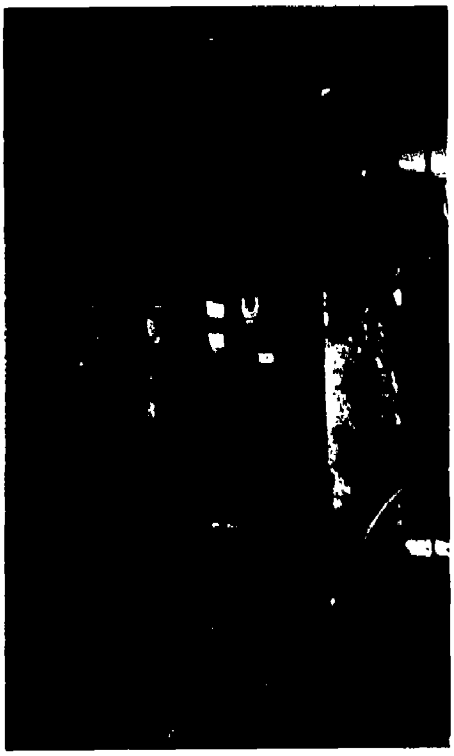


120. Sakarya Vilayet, Adapazari. Circle indicates area of damage at ground-floor and first-floor levels.

119



121



122

123

119. General view of Sakarya Vilayet, Adapazari.

121. Details of damaged column B10 and shear wall at ground floor.

122. Damage to lift-shaft and column B10- Sakarya Vilayet, Adapazari.

123. Detail of damage to column B10.

124a

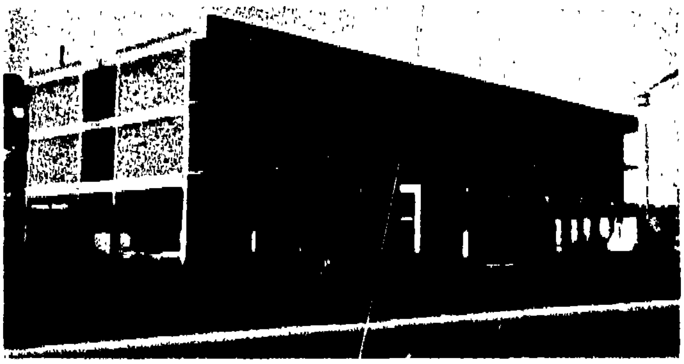
124b

124a. Collapse of five-storey reinforced concrete block of flats, under construction at the time of earthquake.

124b. Details of large aspect ratio column of first floor; notice that this column does not continue into the ground floor.

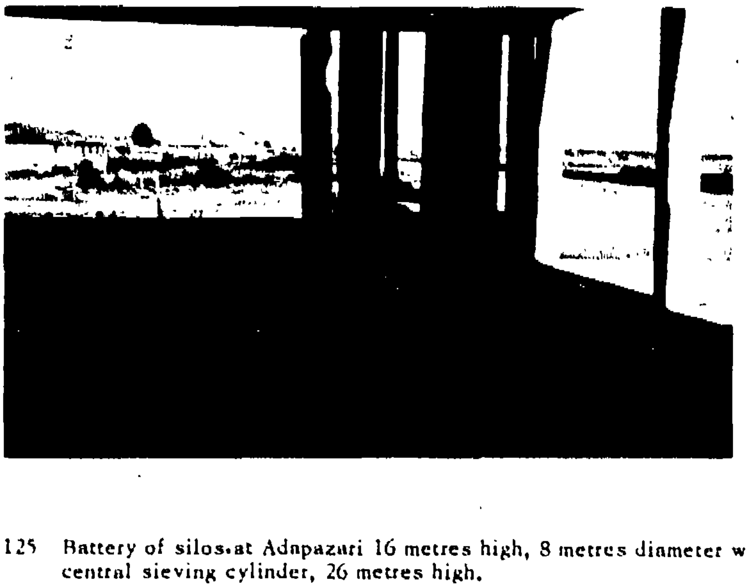
125

127



126

128



125 Battery of silos at Adapazari 16 metres high, 8 metres diameter with central sieving cylinder, 26 metres high.

126. Details of reinforcement of columns at Arifiye. Note bars hooked at the bottom of storey with only two bars extending into the foundation after being bent away from the face of the column.

127. Heavily damaged building at Izmit.

128. Failure of columns at ground floor.

129

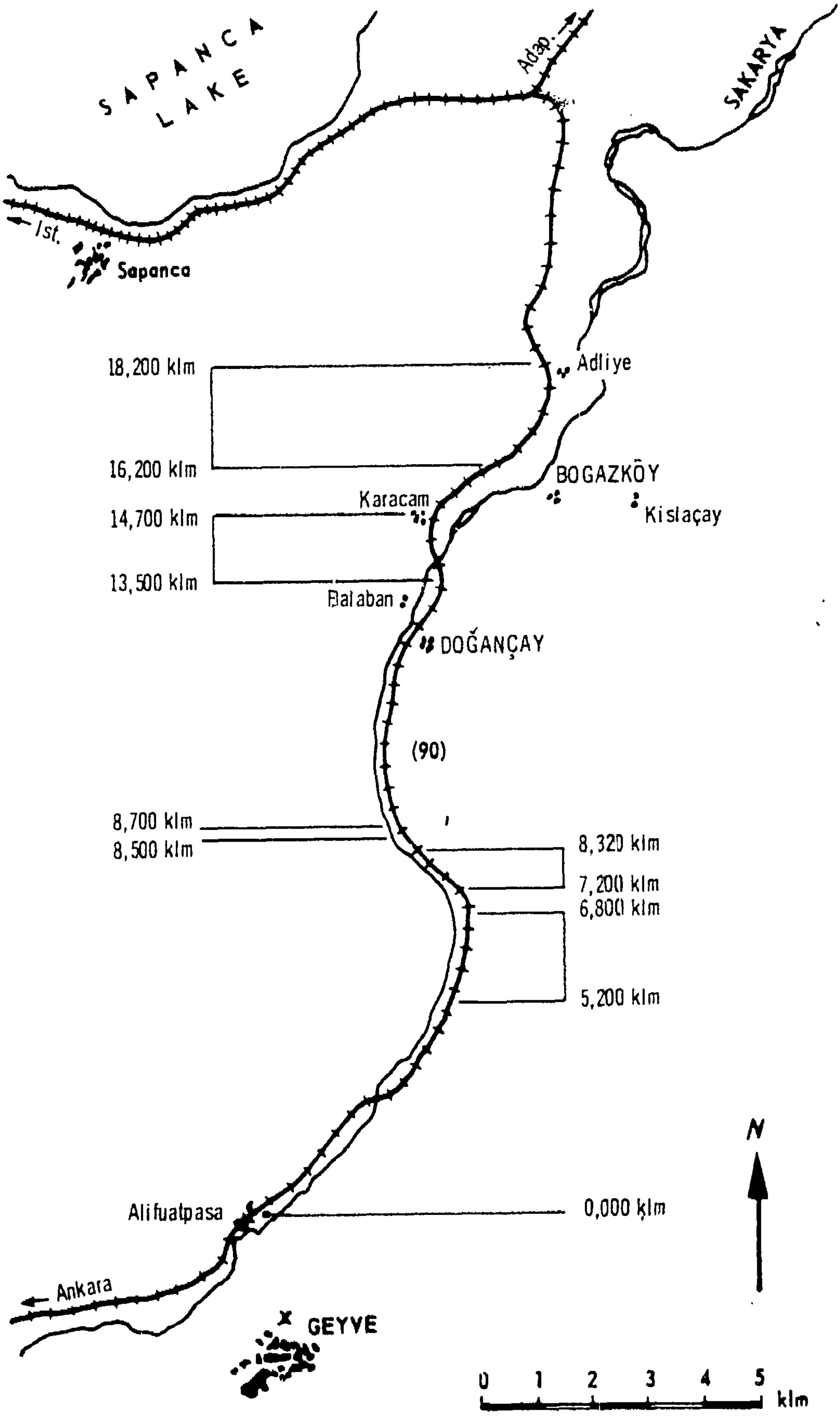
130

131

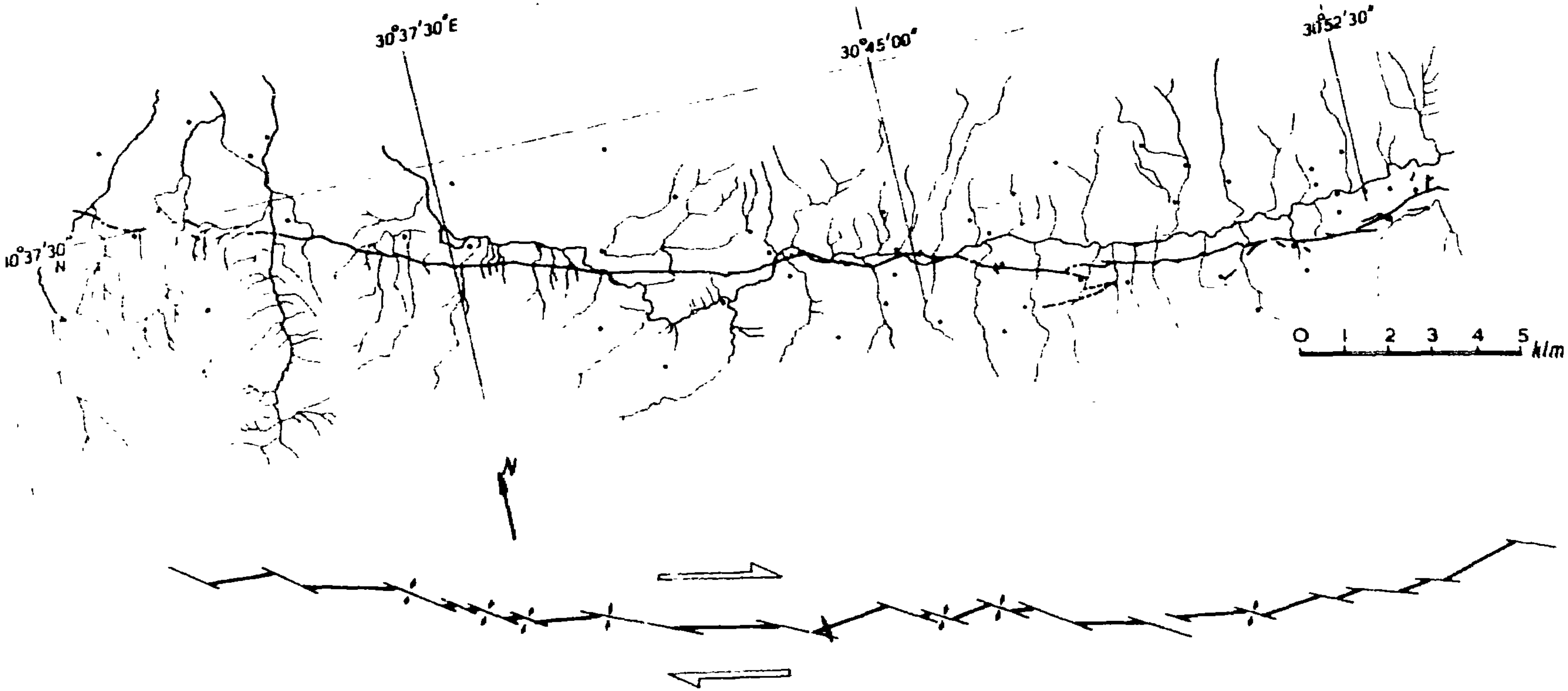
129 Detail of destroyed column; no stirrups.

130. Detailed of destroyed column- no stirrups.

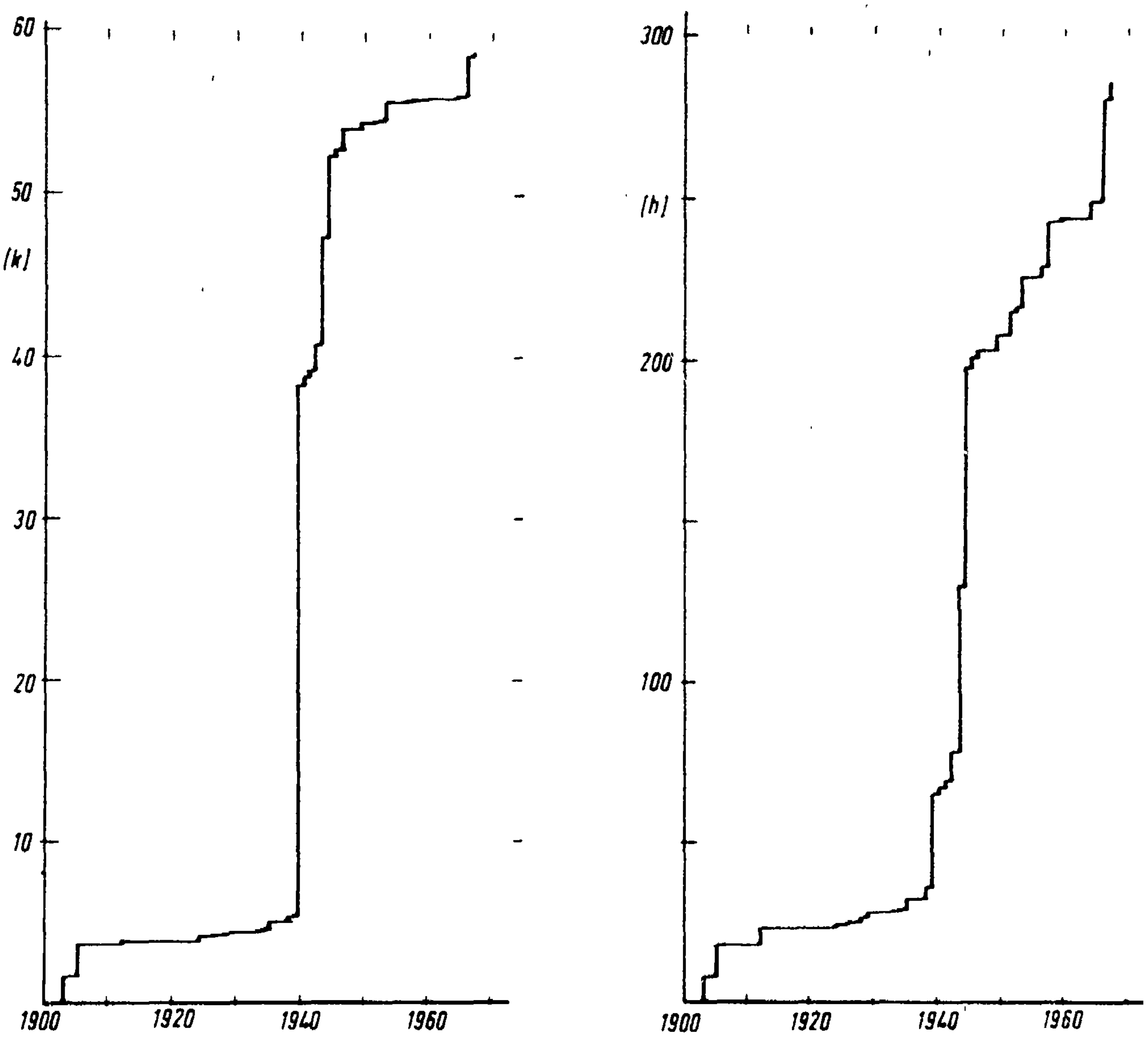
131. External column at foundation level; no stirrups.



132. Damage to Istanbul and Ankara railway line in the Baladan defile.



133. Map of main fractures in central part of fault zone and generalized en echelon pattern of main fractures.



134. Accumulative graphs of fatalities and number of houses destroyed in the Anatolian fault zone during the last 60 years. k = number of people killed, in thousands; h = number of houses destroyed or damaged beyond repair, in thousands.

Drafted by E.M. Fournier d'Albe, AVS

Visas: Director, AVS)
BMS/Reports)
BMS/Europe) on Draft
ADG/SC)
ODG/CAB)

[illegible]

20 November 1968

Sir,

I have the honour to send you, under separate cover by air mail, three copies of the report of the earthquake reconnaissance mission sent to Turkey at the request of your Government, following the destructive earthquake of 22 July 1967 in western Anatolia. Twenty additional copies are being sent by surface mail and further copies may be obtained upon request, should you need them.

I am happy to note that this report is the result of close collaboration between the two experts sent to Turkey by UNESCO and two members of the staff of the Ministry of Housing and Reconstruction. The report has been carefully studied within the Secretariat and I should like to draw your attention particularly to the fact that it contains, on pp. 17 to 40, a very detailed description of the geological effects and damage in the fault zone. As you are aware, I have proposed to the present session of the General Conference, in paragraph [illegible]37 of document 15 C/5, that UNESCO should assist research on the mechanism of earthquakes in the Anatolian fault system, during the coming biennium. The present report is thus immediately relevant to such research.

The authors point out that although this earthquake was of greater magnitude than the Varto earthquake of 19 August 1966, the damage and casualties were fortunately much less, due in large measure to the better quality of construction in western Turkey.

H. E. Mr Ilhami Ertem
Minister of National Education
(Maarif Vekâleti)
Direction of External Relations,
Dis Münasebetler Müdürlügü
ANKARA
Turkey

The contents of this report will be of considerable interest to other international agencies [illegible] United Nations Development Programme, as well as to scientific and [illegible] organisations, both national and international. It will also be of value to scientists and engineers concerned with the [illegible] of earthquakes and of the means of protection against them. If you are in agreement, I therefore propose to make copies of this report available to such organisations and institutions. If I do not hear from you to the contrary before the end of this year I shall assume that you have no objection to this procedure.

May I take this opportunity to express once again my appreciation of the effective collaboration [illegible] Turkish specialists in this earthquake reconnaissance mission and of the assistance that was rendered to members of the mission, during their [illegible] work, by many individuals and institutions in Turkey, and particularly by the Department of Reconstruction of the Ministry of Housing and Reconstruction.

Please accept, Sir, the assurances of my highest consideration.

René Maheu