THE EAST ANATOLIAN FAULT SYSTEM; THOUGHTS ON ITS DEVELOPMENT

Esen ARPAT and Fuat ŞAROĞLU

Mineral Research and Exploration Institute of Turkey

ABSTRACT. — A fault zone consisting of left-lateral strike-slip faults extends between Karlıova and Hazar Lake, in Eastern Turkey. This major fracture zone must have been caused by the same compressional forces that formed the low-angle thrust faults belt in Southeastern Turkey. Between Hazar Lake and Genç the fault zone follows a primary zone of weakness. The segment of the fault zone between Karlıova and Bingöl was probably formed by subordinate fracturing of a tectonic plate. Bingöl-Genç segment takes place between these two main segments. Strike and slip characteristics of the fractures associated with 1971 earthquake agree with the view that the region is under north-south acting compressional forces.

INTRODUCTION

Presence of a fault zone between Karlıova and Hazar Lake has been reported by Allen (1969). Allen on small-scale schematic maps showed the fault (figures 2, 11, 12 *in* Allen, 1969) and briefly discussed its relation with the North Anatolian Fault. A part of the fault between Karlıova and Bingöl is shown on the 1:500,000-scalc geological map of the area, published by The Mineral Research and Exploration Institute of Turkey. Explanatory text of this map (Altınlı, 1963) contains adequate evidences for the fault. The same segment of the fault in Göynük Valley is also shown on the 1:2,500,000 scale tectonic map of Turkey prepared by Ketin (1966). Seismo-tectonic map of Turkey prepared by Ketin and Güçlü *(in* Ketin, 1968) has the same fault marked on it.

The severe earthquake of May 22, 1971 of Bingöl attracted attention on the fault system. We had the opportunity to investigate the main tectonic features of the region during our study[1] of the 1971 earthquake. The place of the fault in the general tectonic setting of the region is discussed in the present paper.

No name exists for this fault system. The name 'East Anatolian fault' is used in this paper.

THE BINGÖL EARTHQUAKE OF MAY 22, 1971

General data on the earthquake

The earthquake of May 22, 1971 centered near Bingöl. It occurred at 18:45 local time and had a magnitude of about 7. 755 people were killed, a large number of buildings were demolished or heavily damaged.

Some of the data on the earthquake has been published (Aytun, ed., 1972).

[1] Preliminary results of this study are given in a report dated June 10, 1971 (Arpat, 1971).

Surface fracturing which accompanied the earthquake

Numerous fractures developed during the earthquake were disclosed through various sources and means. Fractures having considerable lengths are shown in Figure 1. Fractures other than those shown might have occurred. Heavy rains which followed the earthquake might have rendered some fractures undetectable. Fractures plotted on the map (Fig- 1) are not controlled by any unstable material and they trend linearly across ridges. Three sets of fractures located in Göynük Valley have the common characters of being parallel to the general trend of the valley and of showing left-lateral strike-slip displacement. En echelon pattern is nicely exhibited by them. In Figure 1 general trends

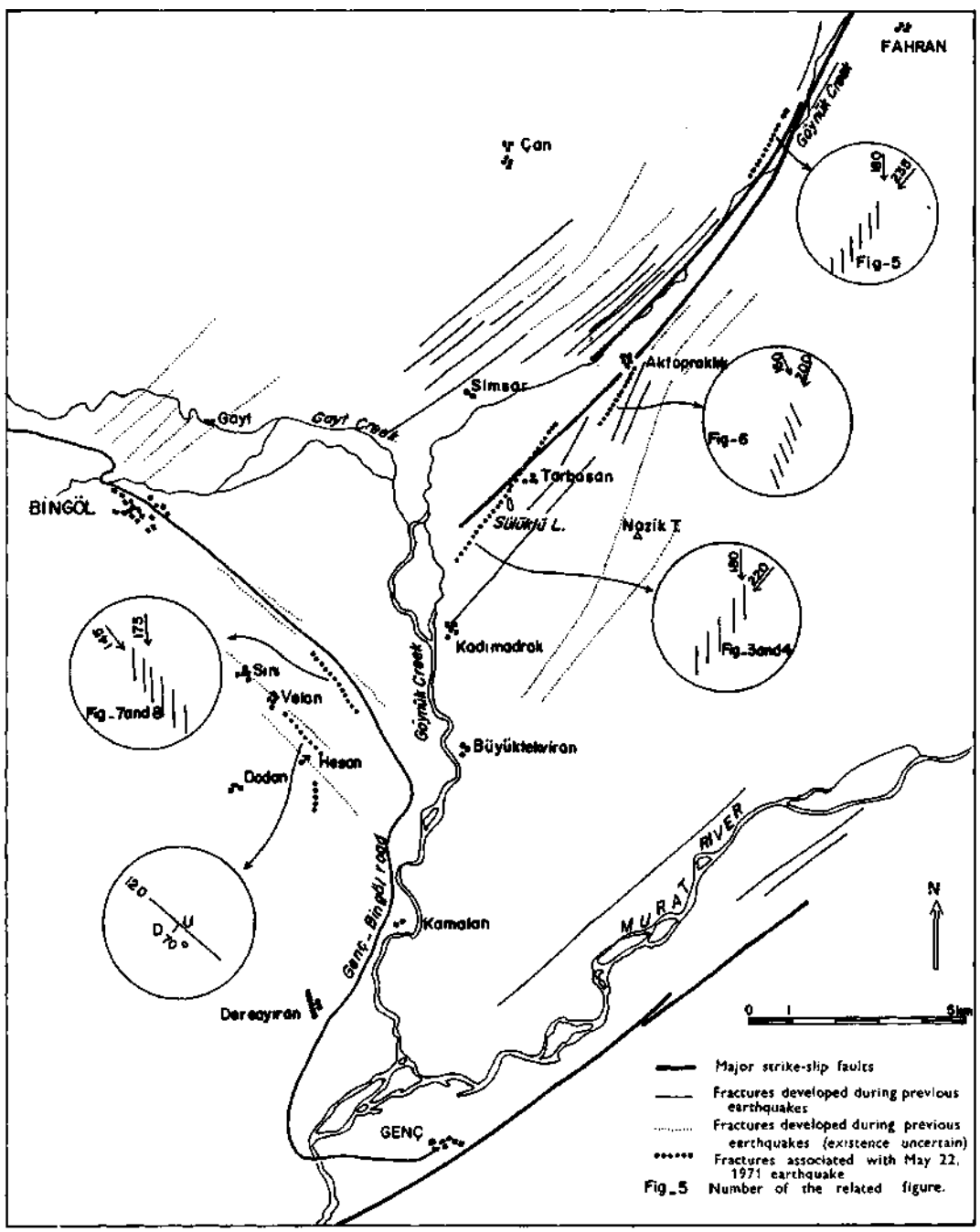

Fig. 1

of the fracture sets and strikes of en echelon units are shown by arrows with the azimuths marked on them. The walls of individual fractures of en echelon systems opened as much as 5 to 10 cm, reflecting left-lateral strike-slip displacement (Figs. 3, 4, 5, 6). Individual fractures having strikes against left-lateral displacement display thrusting. Fracture set passing across Tarbasan, branches off near Sülüklü Lake, all of its branches exhibiting left-lateral strike-slip displacement.

One of the fractures between Bingöl and Genç (the one closer to the Genç-Muş road) displays clearly an en echelon pattern that is characteristic of right-lateral strike-slip (Figs. 7 and 8). A vertical component of about 5 to 10 cm accompanied the right-lateral displacement; usually the southwest block is relatively lower. Along the fracture set extending south of Hesan, the right-lateral strike-slip displacement was detectable only in some places, the great part of the fracture zone having been almost completely destroyed by rains. The fracture situated between \ elan and Hesan extends on the northeast flank of a ridge. Northwest block subsided about 10 cm. There the dip angle of the fracture plane as determined by its trace in valleys is about 70 to the southwest. The fracture sets mentioned in this paragraph are sketched in Figure 2.

OUTLINE OF THE GEOLOGY OF THE AREA BETWEEN KARLIOVA AND HAZAR LAKE

The area between Karlıova and Bingöl is underlain predommatly by volcanic rocks, mostly andesite and basalt. The stratigraphy and the age of this volcanic cover have not been made subject of detailed studies. But personal observations of the writers lead to the following generalizations. Basalts wherever present overlay andesitic rocks. In the vicinity of Göynük village marine sediments of Miocene age crop out, volcanic cover lying unconformably on them. Thus an age younger than Miocene has to be assigned to a great majority of the basalts and andesites. Tuffs which take place mostly in the lower parts of the volcanic cover have been identified on air photos in places. They occur as the dominant lithology between Bingöl and Palu (Fig. 9). As can be seen in Figure 10, volcanic rocks between Karlıova and Bingöl are only moderately deformed. But to the west of Bingöl, volcanic rocks are sharply folded.

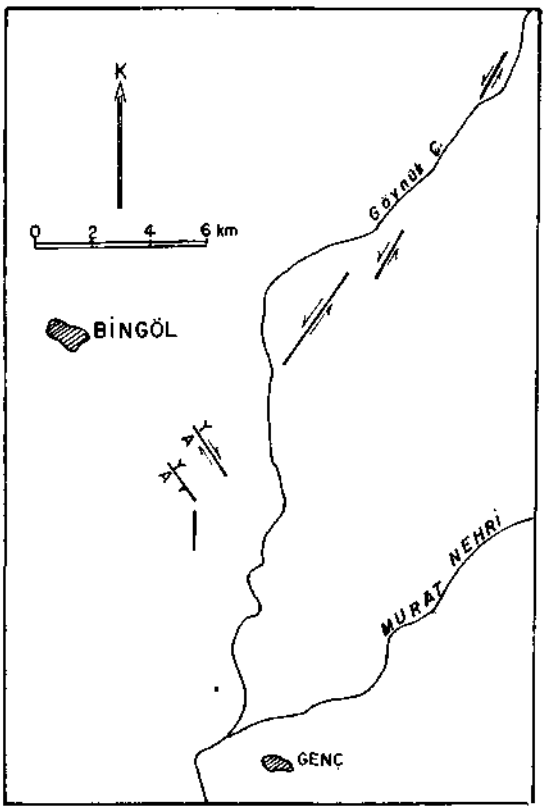

Fig. 2 - Displacements along fractures associated with May 22, 1971 earthquake.

A fracture pattern nicely displayed by the drainage system has been developed in volcanic terrane. Air photo investigations have led to the conclusion that these fractures are not related to jointing. They must have developed under the forces which affected the whole region. Fracture pattern of this type is not detectable in folded area.

Marine Miocene limestones crop out in the vicinity of Göynük village and at about 15 km

northeast of Bingöl.[2] Both outcrops are bounded by the Göynük Valley and a very wide zone of tectonic breccia takes place at their valley side. Metamorphic-rocks consist mostly of marbles and phyllites. The lithological characteristics of the two metamorphic bodies are alike. Light yellow - white-colored limestone from both outcrop assemblages has been determined as Burdigalian in age by E. Sirel, Paleontologist in M.T.A.

East of Bingöl rocks of Eocene, Oligocene, Miocene ages crop out under the volcanic cover consisting of tuffs. These outcrops become larger toward east. Upper Cretaceous terrane is dominant between Palu and Hazar Lake. In the vicinity of Gen9, the area south of Murat River is underlain by metamorphic rocks. Serpentinites and Upper Cretaceous sediments mixed with ophiolites crop out south of Palu and extend toward Hazar Lake.

About 15 km south of Genç-Palu line a low-angle thrust faults zone runs in general east-west direction. In this fault zone fault planes dip to the north. Metamorphic rocks overlie a group of rocks including Miocene sediments. The movements of allochthonous bodies containing Mesozoic and Tertiary sediments continued at least until the end of Pliocene; for sediments in Pliocene age are also affected by the movement (Rigo de Righi and Cortesini, 1964).

The plains between Bingöl and Genç and the area in the vicinity of Palu consist of terraces made of loose gravels and sands derived from volcanic rocks. These terraces of Murat River system are deeply dissected by the actual drainage net.

THE EAST ANATOLIAN FAULT

General aspects

Through study of air photos and verifying some critical points on the ground an evaluation of the general tectonic setting of the area has been attempted. For this purpose tectonic features decided important were first drawn on 1:35,000-scale air photos, data were then transferred on 1:100,000-scale topographic maps and finally from 1:100,000-scale maps to 1:500,000-scale map. Lineations (displayed by drainage pattern, vegetation cover, slopes etc.), attitudes of beddings and of fold axes, and strike-slip faults, low angle reverse faults have been plotted and Figure 10 has been obtained.

Left-lateral strike-slip character of the faults between Karlıova-Bingöl and between Palu-Hazar Lake is exhibited by abundant features of Quaternary faulting. Fractures showing left-lateral displacement, associated with the 1971 earthquake support the view that left-lateral character is dominant along the fault.

Data imply that the two metamorphic terranes in Göynük Valley, shown on 1:500,000-scale Geologic Map of Turkey, were forming a single body under the volcanic cover prior to faulting. Lithology of these two bodies is very similar. Marine Miocene sediments crop out at these two areas and nowhere else in a large area which includes Göynük Valley and its surroundings. Both bodies contain large tectonic breccia zones at their valley side. Miocene outcrops are shown in Figure 10 by *X*. According to these data, not investigated in detail, left-lateral displacement along the fault is about 22 km in Göynük Valley. If dark red-colored mudstones of Mesozoic age between Palu and Hazar Lake are used for the same purpose, 27 km left-lateral movement can be calculated for this part of the fault zone. These mudstone outcrops are shown by *Y* in Figure 10.

Southwest extension of the fault is displayed by the presence of prominent lineations on the topographic maps. Locations of epicenters on the Epicenter Map for Turkish Earthquakes, given in the Catalog of Earthquakes for Turkey and Surrounding Area (Ergin *et. al.*, 1967) also reflect the southwest continuation of the fault. Branching out of the fault near Hatay and its connection with Dead Sea fault system through some of its branches seems quite possible. It is generally accepted that Dead Sea fault system shows left-lateral movement, its mechanism is explained by the opening of the Red Sea and the fault system extends toward Turkey (Freund, 1965 and several articles in The World Rift System, report of symposium, 1965).

Along the investigated portion of the fault zone left-lateral character is neatly exhibited between Karlıova-Bingöl and between Palu-Hazar Lake. The fault can not be easily followed between Bingöl and Palu. In this region the fault deviates from the Göynük Valley direction and beginning from Genç roughly follows Murat River Valley, but it is not as distinct as in Göynük Valley. Landsliding and intensive erosion by Murat River might have rendered difficult the conservation of fault traces. The area between Bingöl-Genç-Palu is highly folded in contrast to the Göynük Valley region. The movement along the fault in this part might have been absorbed by folding. But trends of fold axes do not clearly and simply support this possibility.

The place of the fault in the general tectonic setting of the region

The most important tectonic element of the region seems to be the low-angle reverse faults zone at the south. This zone crosses uninterruptedly over the whole Southeast Turkey, passes through Iraq and in Iran runs parallel to the Persian Gulf under the name of Zagros Fault Zone. Along all its length it shows the character of a zone developed between the folded miogeosynclinal area of the Arabian platform and the ophiolitic belt at the north. If the fact that some deep-focus earthquake epicenters are located on this zone is also taken into consideration, this zone can be evaluated as a contact zone between two large plates. As could be inferred from the presence of young folded areas and of great low-angle reverse faults, this zone is under influences of compressive forces. In the region discussed compressive forces act in south-north direction as inferred from the trends of fold axes and from the geometry of the low-angle reverse faults.

The trend and the left-lateral character of the East Anatolian fault in Göynük Valley are in accordance with a south-north shortening. Fractures which are responsible of the lineations in volcanic terrane in both sides of the valley could also be interpreted as shear fractures developed as a result of south-north shortening. Of the folds between Bingöl and Palu those closer to Palu have axis trending in accordance with south-north shortening. Near Bingöl fold axes bend towards northeast. This area falls into the region where fault traces are not detectable. Northeast-southwest direction could be the initial one as well as it could be reached by rotation of initially east-west trending axes.

South-north compression appears to be the primary force acting in the region.

The part of the fault between Hazar Lake and Genç could be thought as being developed in the zone constituting contact between two major plates. Left-lateral movement between Palu and Hazar Lake agrees very well with the suggested dominant south-north compression. Between Gen9 and Palu, where the fault trends perpendicular to the axis of shortening, folding and thrusting are expected instead of faults with lateral displacement. This region exhibits these expected characteristics.

The segment of the fault between Karlıova and Bingöl seems to trend in complete accordance with the regionally acting forces. Evidences for this are the following: fault runs in a narrow zone without showing any deviation from its general trend; the lineations reflecting shear fractures in both sides of the fault zone have the same trend, implying no rotational movement of the blocks took

place; folded areas which would reflect local compression did not develop in the vicinity of this segment of the East Anatolian Fault. The bending of the fault trace near its juncture point with the North Anatolian Fault zone may he explained by the drag along the North Anatolian Fault.

No sign is seen about a preexisting zone of weakness along Göynük Valley wich would have been used later by the East Anatolian Fault. The thick volcanic cover might be sealing such a zone. But the observations mentioned in the preceeding paragraph might be evaluated adequate to conclude that the East Anatolian fault there developed in an originally unbroken plate.

In the frame of this general scheme the segment between Bingöl and Genç lies between a segment in a newly developed zone and another one following an older zone of weakness between two major plates.

Evaluation of the fracture pattern associated with May 22, 1971 earthquake

Geometry of the fracture pattern associated with May 22, 1971 earthquake is not conflicting with the above-discussed general conclusions on the tectonic setting of the region. North-south compression should cause left-lateral movement along Göynük Valley and right-lateral movement in the Bingöl-Genç: direction. Fractures developed during the 1971 earthquake have these characteristics.

Shifting toward northeast of the block northeast of Bingöl can give explanation for the tension associated with the right-lateral movement in fractures between Bingöl and Genç. On the other hand, underthrusting of the southernmost block might have caused its lowering; but no sign of thrusting associated with the earthquake has been seen in the mountainous area southwest of Bingöl. Fault plane solution might throw light on this problem.

Age of faulting

East Anatolian Fault is one of the major active faults of Turkey. The faulting is post-Miocene in Göynük Valley where Miocene marine sediments were displaced by the fault after their deposition. Other segments of the East Anatolian Fault appear to be closely related to the great low-angle reverse fault zone which is beleived to be post-Miocene in age. Thus in this region at least left-lateral character of the fault is post-Miocene.

Manuscript received April 25, 1972

BIBLIOGRAPHY

ALLEN, C.R. (1969) : Active faulting in northern Turkey: Contribution no. 1577. *Division of Geological Sciences, California Institute of Technology,* U.S.A.

ALTINLI, İ.E. (1963) : Explanatory text of the Geological Map of Turkey of 1:500 000 scale; Erzurum sheet. *Publ. M.T.A. Inst.,* Ankara.

ARPAT, E. (1971) : 22 Mayıs 1971 Bingöl depremi; Ölü Deniz fay sisteminin Karhova ilçesi ile Hazar Gölü arasındaki bölümü (ön rapor): *M.T.A. Rep.* (unpublished), Ankara.

Fig. 3 - Fracture ar southwest of Tarbasan (east of Bingöl); looking east. Fracture extends in southwest direction. Left-lateral displacement is certain. Western block usually lowered 1 or 2 cm.

[illegible] ind

Fig. 5 - A part of the fracture zone at about 4 km southwest of Fahran; looking southwest. En echelon pattern characteristic of left-lateral strike-slip is well developed.

Fig. 6 - Fractures at the south of Aktopraklık in Göynük Valley; looking south. Left-lateral movement is about 10 cm.

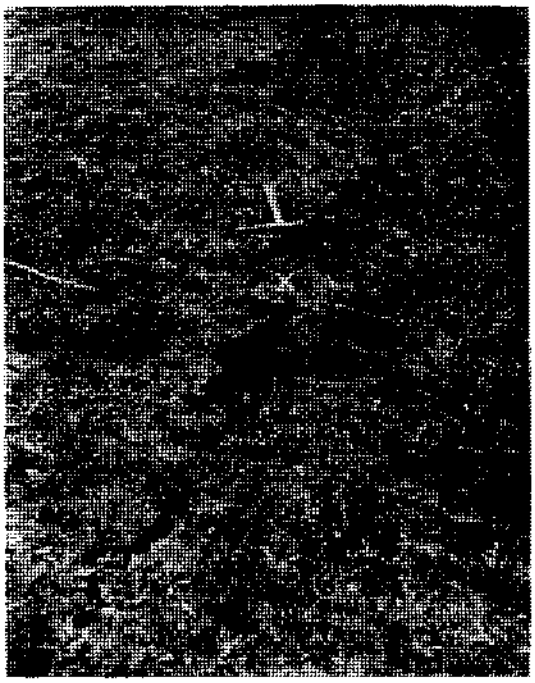

Fig. 7 - Fracture at the east of Sini (southeast of Bingöl); looking southeast. Handle of the hammer points 145. Displacement is right-lateral. The movement to the north of the western block (marked with *X*) is seen clearly. A few centimeters' lowering of the western block is frequently observed.

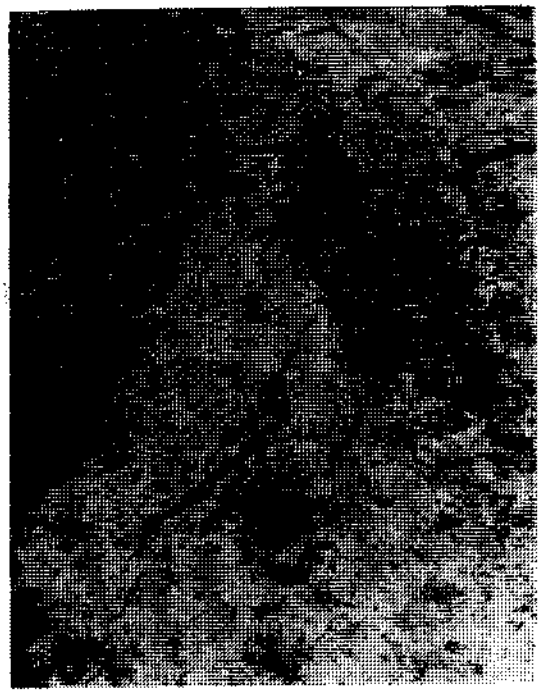

Fig. 8 - Southern continuation of the fracture shown in Fig. 7, characteristics are the same.

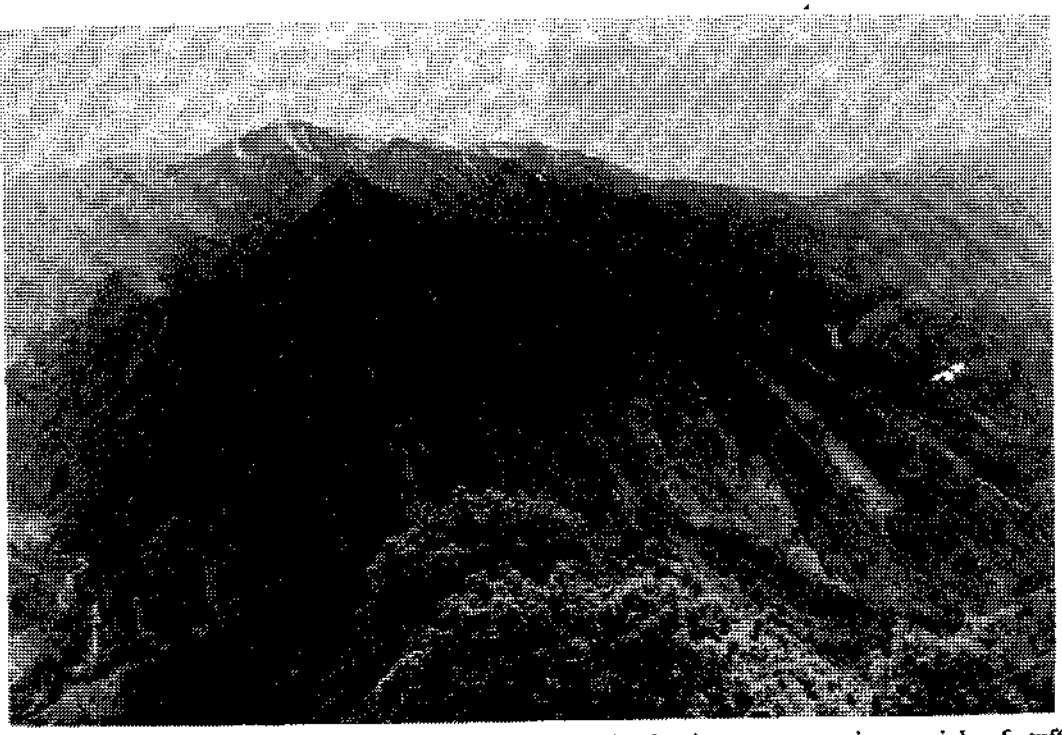

Fig. 9 - East of Balpınar village (west of Bingöl). Folded volcanic terrane consists mainly of tuffs and lava flows.

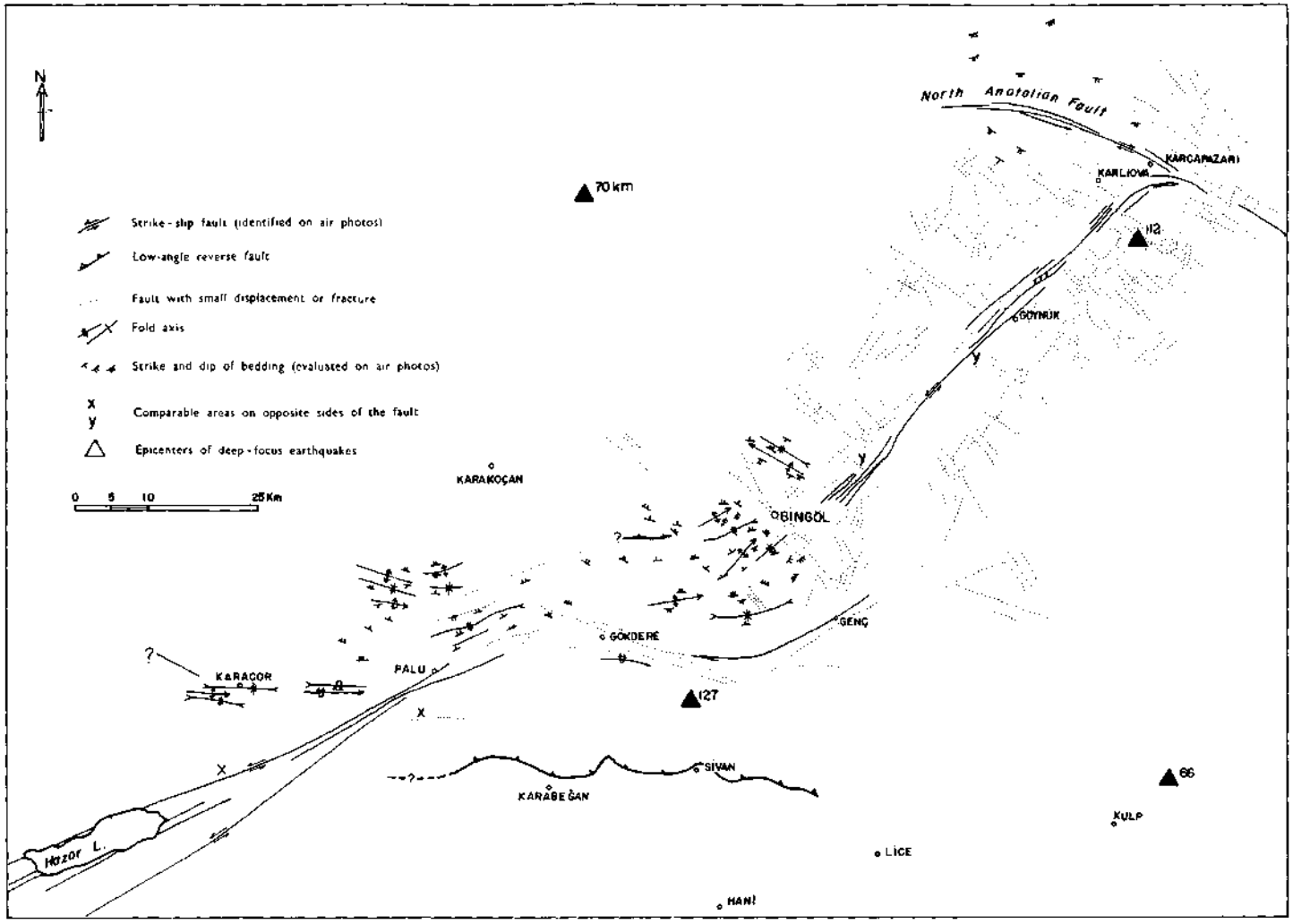

Fig. 10 - Main tectonic features of the area between Karlıova and Hazar Lake.

AYTUN, A., ed. (1972) : 22-5-1971 Bingöl Depremi Raporu. *Deprem Araştırma Enstitüsü, İmar ve İskan Bakanlığı Yaynıl.*

ERGİN, K.; GÜÇLÜ, U. & UZ, Z. (1967) : A catalog of earthquakes for Turkey and surrounding area (11 A.D. to 1964 A.D.) *Tech. Univ. İstanbul, Faculty of Mm. Eng.,* Istanbul.

FREUND, R. (1965) : A model of the structural development of Israel and adjacent areas since Upper Cretaceous times. *Geol. Mag.,* \. 102, pp. 189-203.

KETIN, İ. (1966) : Tectonic units of Anatolia (Asia Minor). *Bull. Mm. Res. Expl. lust. Turkey,* no. 66, pp. 23-34, Ankara.

———(1968) : Relations between general tectonic features and the main earthquake regions of Turkey. *Bull. Min. Res. Expl. Inst. Turkey,* no. 71, pp. 63-67, Ankara.

PINAR, N. & LAHN, E. (1952) : Türkiye depremleri izahlı kataloğu. *Bayındırlık Bak. Yapı ve İmar İşleri Reisliği Yayınl.,* seri 6, sayı 36.

RIGO de RIGHI, M. & CORTESINI, A. (1964) : Gravity tectonics in foothills structure belt of southeast Turkey. *Bull. Amer. Assoc. Petrol. Geologists,* v. 48, pp. 1911-1937.

The World Rift System, report of symposium, 1965, *Geological Survey of Canada,* paper 66-14, *Queen's printer* Ottawa, Canada.

1:500.000-scale Geological Map of Turkey, Erzurum sheet. *Min. Res. Expl. Inst. Turkey.*