FORMATION OF THE GRABENS IN SOUTHWESTERN ANATOLIA

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ABSTRACT. — Tectonic compression and tensional directions at the Miocene-Quaternary interval are tried to be determined on the basis of results obtained from the evaluation of faults in Southwestern Anatolian Miocene-Quaternary sediments. Faults evaluation, one of the newest structural evaluation methods; gives more or less the same results with seismotectonic data. Studies carried out on Menderes and Burdur grabens showed a certain mechanism of graben formation in the areas under consideration. And it may thus be suggested that there is a compressive phase followed by a tensional one. Furthermore alternating tension and compression directions are normal to each other.

Through regional studies, the following phases are determined:

1. Late Miocene-Early Pliocene compression phase: compression in NW-SE direction, and compression in NE-SW direction.

2. Pliocene graben formation: Beginning in Pliocene, the graben formation continued with N-S directed tension through late Pliocene.

3. Old Quaternary Compression phase: N-S directed compression in Burdur and WNW-ESE directed compression in Sarayköy (Denizli) areas.

4. Young Quaternary graben formation: NE-SW directed tension in Menderes Graben and NW-SW directed tension in Burdur.

INTRODUCTION

Major inter-continental or intra-continental tectonic phenomena may be divided in two types. The first type is represented by thrust faults, overturned faults and strike-slip faults developed as a result of compressive tectanics. Graben formation resulting from tensional tectonics is covered under the second type.

In previous years, compressive and tensional tectonics were interpreted as processes independently occurring, since information and data on plate tectonics were limited.

The sequence of Alpine tectonic phases were established by Aubouin (1973), who considered the phases characterized by tensional tectonics and following the tectonic phases producing compression, as neotectonics. Aubouin, however, in a later work conducted in 1977, used the term «Mediterrenean period to identify the phases he has previously considered neotectonic.

Studies carried out on the Alps, have shown that the formation of grabens is closely related to compressive tectonics. McKenzie (1972) however, explains the formation of Western Anatolian grabens as relateid to the movement of Anatolia from east to west.

Tapponier (1977) claims that the grabens developed in the internal parts of the continents are formed parallel to the compressive direction.

Dewey and Şengör (1979) state that the E-W compressive direction produced resulting from the convergence of Gondwana and Euro-Asia, has led to a N-S divergence in the West.

FAULT EVALUATION

Study of faults is one of the newest methods employed in the evaluation of structural features. Anderson was the first to conduct mechanical studies on faults in 1942. Complex fault systems were studied by Arthaud in 1969. Through the studies of other workers (e.g. Carey and Brunier, 1974; Angelier and Mechler, 1977; Angelier and Goguel, 1978 and Angelier, 1979) in the following years fault evaluation method has been proved to be a reliable means to solve problems related to structure.

In the neotectonic studies also, fault evaluation may prove to be effective, in case the stratigraphy is well known. Thrust faults and tectonic activities leading to the formation of grabens, may easily be recognized since they cause considerable morphological changes, such as changes in sedimentary features, erosion, etc.

Tectonics, however, causing strike faults are hard to recognize as these may not produce distinct morphological changes.

Various workers carried out stratigraphical (Becker Platen, 1970; Bdring, 1971 and Kastelli 1972), sedimentological (Leflef, 1979, oral communications) and geomorphological (Erin?, 1955) studies on the Young Tertiary sediments of SW Turkey. Although the beginning of the graben formation is well established in these studies, compressional tectonics affecting the area prior to the formation of grabens are not considered. It should however be noted that the Upper Miocene-Lower Pliocene compression phase, is in fact a tectonic phase which can be observed in the area extending from eastern Turkey to western Greece, however locally (Mercier, 1977; Angelier 1977a; Poisson, 1977; Dewey and Şengör, 1979; Dumont *et al,* 1979; Dumont, 1979; Letouzey and Özer, 1978). Faults developed in western Turkey as a result of compressional tectonics, are characterized by lateral movement and do not produce distinct morphological changes. Some workers however, consider that the present subduction of the Aegean Arc is related to this phase (Angelier, 1977a,b; Dewey and Şengör, 1979). Results obtained from stratigraphical, sedimentological and geomorphological studies conducted on the Old Quaternary formations, also supports the same idea. It may therefore be concluded that the previous writers failed to established Old Quaternary compression phase, as it has not caused important morphological changes.

Two methods are employed presently in the evaluation of faults, i.e. graphic method and computer-based method. In the graphic method which is simpler than the latter, fields of minimum, medium and maximum force, producing faulting, are established (Angelier and Mechler, 1977), and to arrive at a reliable conclusion, faults however belonging to the same tectonic phase, differing in strike are used. Through mathematical evaluation of the results thus obtained, the details of the compression and tension directions are understood (Angelier and Goguel, 1978; Angelier, 1979). In the interpretations of earthquake epicenter mechanism in seismotectonic surveys and in the graphic method as well, the data to be evaluated are same: and it may therefore be concluded that there exists a true relationship between the seismotectonic patterns and the results obtained from older faults. The same method is employed in each case, i.e. in the evaluation of faults, basic data used is the movement of older faults, whereas in the seismotectonic evaluations, faults producing earthquakes are used. Results of measurements conducted in the Quaternary sediments of the Büyük Menderes Graben and Burdur area, show parallellism with the seismotectonic results of Ritsema (1974). Results of measurements, however, show a slight difference from seismotectonic data obtained by McKenzie in 1976 (Dumont *et al.*, 1980).

FAULT EVALUATION RESULTS

Through results obtained from regional studies, a mechanism related to the formation of grabens in the Menderes and Burdur Grabens is established.

Efes fault

Efes fault located S of Küçük Menderes Valley is on the western extension of the Büyük Menderes Graben, and has been a focus of five rhythmic movements. The first of these movements has occurred in the direction of strike and was followed by a tension nearly perpendicular to the previous compression direction (Fig. 1). The first two movements have taken place prior to late Pliocene graben formation and are capped by Plio-Quaternary slope debris. Southwestern Turkey, however, is characterized by a strong N-S or NE-SW compression, producing a nappe by the end of Miocene (Graciansky, 1972; Poisson, 1976). Direction of compression in the Efes fault, determined by the writers of the present work is conformable with the NE-SW trending Aksu phase; it however, differs from the phase described above. Efes fault, may well be considered to be related to a younger compression phase, e.g. Old Quaternary compression phase, since the age of the slope debris found in the area is not known for certain. It should however be noted that compression direction of the Old Quaternary compression phase, i.e. N-S or NW-SE, is not in conformity with the movement of the Efes fault.

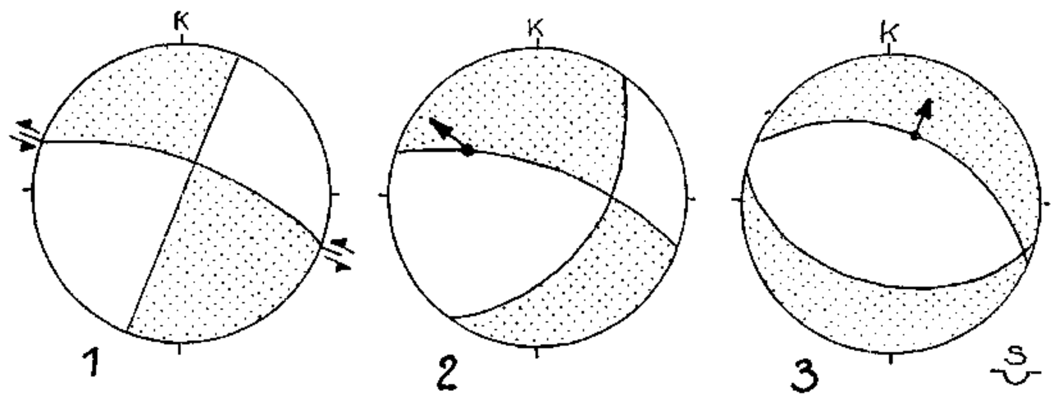

Fig. 1 - The view of the first three movements of the Efes Fault on the lower hemisphere of Smith net. Arrows are showing fault line and movement (1 - Left lateral; 2 - Normal left; 3 - Normal). Dotted areas contain tension, and white areas compression directions. 1 and 2 - indicating movements following each other at the end of Miocene - beginning of Pliocene; 3 - Pliocene movement.

Sarayköy

Pliocene limestones occurring on the western margin of the Denizli plain, were affected by three rhythmic movements. The first of these movements has resulted from N-S tension and may be correlated with the Late Pliocene graben formation. The second movement is represented by a WNW-ESE compression intersecting the normal faults of the first phase. The compression phase described here is reflected by nearly oblique or lateral fault lines (Fig. 2). In the third phase, faults developed during the second phase as a result of NNE-SSW tension, are intersected by normal faults. Faults developed in this phase are covered by" Early Quaternary travertines in the Pamukkale area. Although detailed stratigrafical data and information are lacking, it may presumed that the tectonic compression predominating in the second phase, has been effective in the Pliocene-Pleistocene interval.

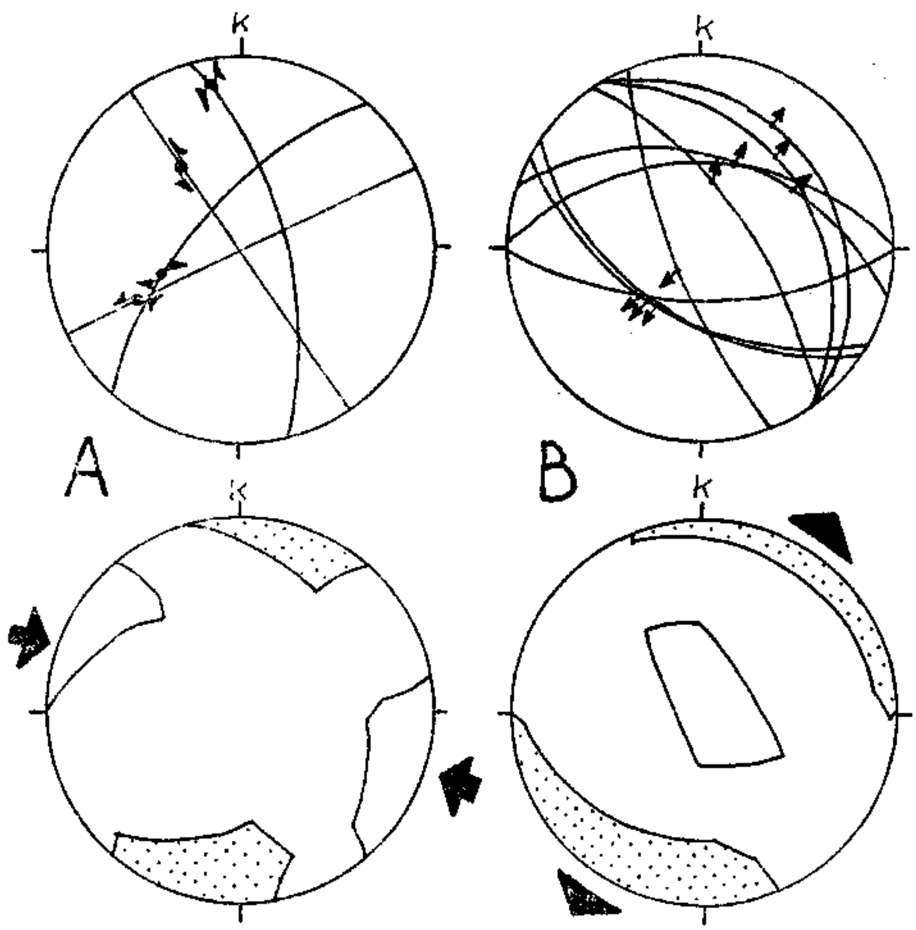

Fig. 2 - Faults formed at Sarayköy Sazak village in Upper Pliocene (upper part) and their solution by right-angle method. Dotted areas contain tension, and white areas compression directions. WNW - ESE compression at A, and NNE-SSW tension at B can be seen (Smith net, lower hemisphere).

Burdur

A lacustrine sequence, ranging in age from Pliocene to Pleistocene occurs on the eastern flanks of the Burdur graben (Bering, 1971). NE-SW trending left-strike faults have been observed in the Pleistocene sediments occurring in the vicinity of Günalan village (Dumont *et al.,* 1979). Results of measurements indicate that these faults have developed due to a N-S compression (Fig. 3). In another locality, the slickenside of the strike fault, developed as a result of the same movement, is intersected by a normal fault. Study of the slickenside described here, suggests the effects of a E-W tension. Evaluation of the fault developed within the Young Quaternary slope debris unconformably overlying the Pliocene, also suggests the effects of a NW-SE tension. These results are in conformity with the seismotectonic results obtained by Ritsema (1974) and McKenzie (1976). Since it is clear that an entirely different tension must have been in effect in the Young Quaternary-Actual interval, the graben formation phase resulting from E-W tension, following a compression phase, should have taken place by Late Pleistocene or Early Holocene.

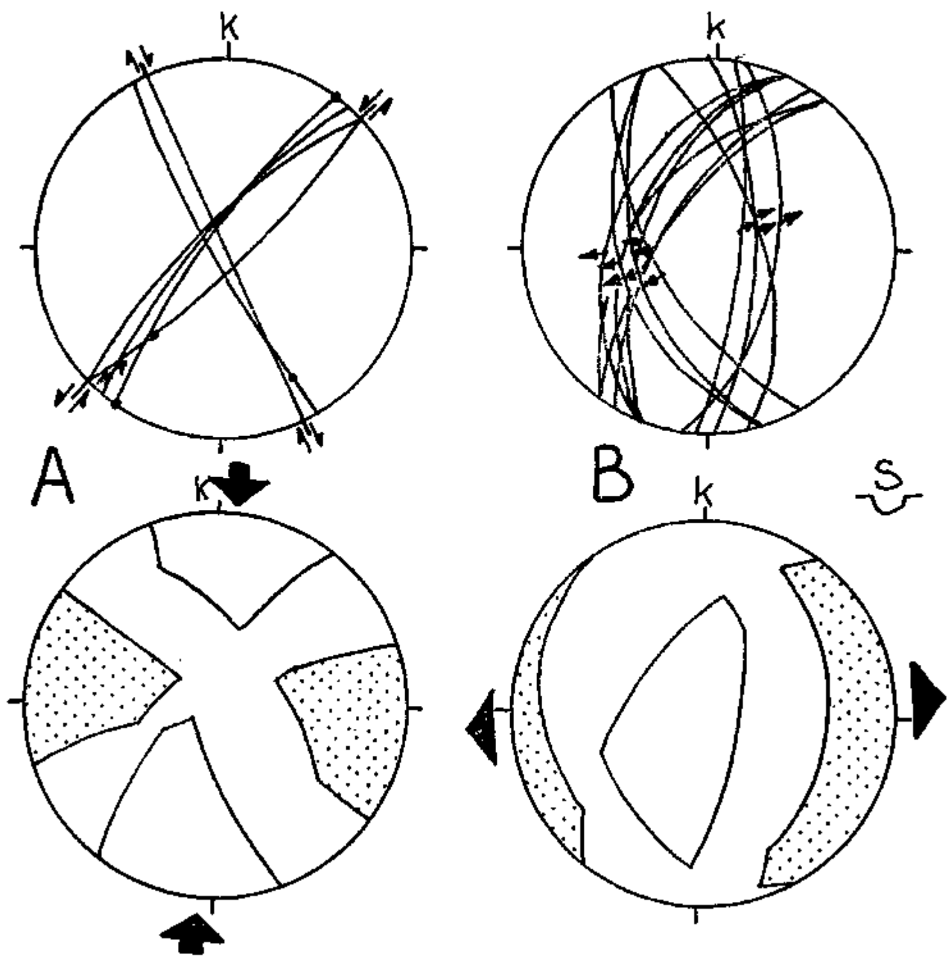

Fig. 3 - Faults formed at Burdur in Pliocene-Pleistocene (upper part) and their solution by right-angle method. Dotted areas contain tension and white areas compression directions. N-S compression at A and E-W tension directions at B can be seen.

ALTERNATING PHASES AND GRABEN FORMATION

Evaluation of results

On the basis of results obtained, it has been presumed that a compression phase must have prevailed prior to graben formation tectonics Previous studies on stratigraphy indicate that two major graben formation periods prevailed in Southwestern Turkey. The first period affecting SW Turkey has occurred during Uppermost Miocene (Becker Platen, 1970; Lüttig and Steffens, 1976) or

Lower Pliocene (Kastelli, 1972) and is followed by the second period, which mainly affected the Denizli and Burdur regions in Old Quaternary. Although other graben formation phases must have also occurred in SW Turkey, these shall not be covered here as it has been assumed that such phases were in fact a continuation of the previous periods or were produced by a totally different tectonic phenomenon, e.g. subduction mechanism (Le Pichon and Angelier, 1979). Furthermore, prior to the graben formation phases, compression tectonics must have prevailed in the region.

Conclusions to be drawn from the compression and tension directions observed in the area are as follows:

1. A compression phase, followed by a graben formation phase (tension) can be distinguished.

2. Directions of compression and tension phases are nearly perpendicular.

3. Compression tectonics are characteristically reflected by strikeslip faults; and since the effects produced by this phase are not strong, morphology of the area don not show substantial changes.

Mechanical explanation

Figure 4A shows maximum, medium and minimum compression directions in the case of compression tectonics. Figure 4B on the other hand, reflects a case where the tension tectonics are dominating. Here the maximum compression is reduced to medium compression, which in turn becomes the greatest compression observed. The effects of the tension phase (Graben formation) continue, even after the effects of the horizontal greatest compression do reach a termination point. It should however be noted that the region continues to undergo a homogenous movement, taking place on a regional scale, regardless the termination of the effects of the compression. Should this be the case, there shall be a conformity with the explanation given by McKenzie (1976) for grabens and the pattern suggested by the writers of the present paper.

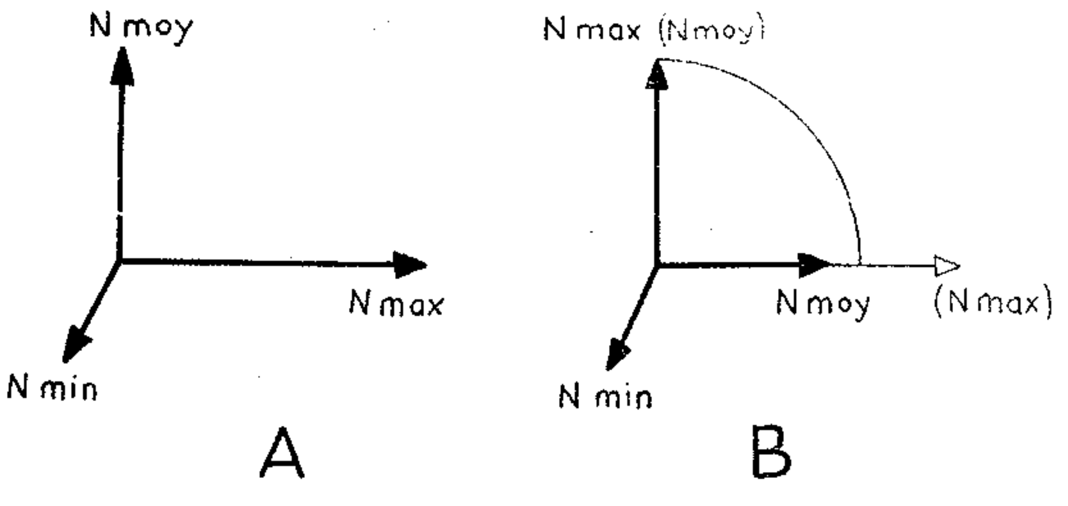

Fig. 4 - A - The figure indicates maximum, medium and minimum compression directions during the state at which compression tectonics is dominant; B - State at which tension tectonics is dominant: Maximum compression is decreased and turned to medium and medium compression of state A is maximum *now*. The effect of horizontal compression is then finished and tension effect (graben formation) is continued with an increasing importance.

DISCUSSION ON GRABENS - WESTERN TURKEY

McKenzie (1972) in a previous work on the plate tectonics, suggests that the grabens located in western Turkey, represent a transition zone between the Anatolian and Aegean plates. The same idea is further supported by Dewey and Şengör (1979). McKenzie in a later work (1976) suggests that complex tectonic features observed in the region are related to an ancient structure, since he does not consider the area located between the Anatolian arid Aegean plates a simple plate boundary. Workers such as Mercier (1977, p. 668), Angelier (1977b, p. 657), Lemeille *et al.,* (1977, p. 674) proved the presence ofa number offaults in Anatolia and Greece as well, undergoing repeated movement. According to these workers, movement in some faults continue since Miocene.

Based on the results obtained it may be concluded that the oldest movement in the fault zones developed on the margins of the grabens, has occurred in the direction of strike (in case the basement rocks are observable). The writers further believe that such movements have occurred in Miocene or before (Efes, Muğla, Kovada Grabens). It is also observed that the grabens formed in the present region, follow previously developed fractures and may therefore be found throughout the area.

Taponnier (1977) considers graben formation as an equivalent of tension fractures developed parallel to the direction of compression in the metallurgical tests. Taponnier further claims that the grabens are surface indications oftension fractures developed parallel to the direction ofcompression in intracontinental regions.

It should however be noted that the region or continent to be affected from such a phenomenon, should be homogenous and unfractured. The writers of the present paper believe that the development of tension fractures in continents previously fractured and broken is impossible since movements will occur along the present fractures. Furthermore according to the pattern suggested, traces of compression, however locally, must have been left during graben formation. In fact no regional compression has been observed in the area. The area is characterized by the presence of a compression phase, followed by tectonics producing grabens.

IMPORTANT TECTONIC PHENOMENA TAKING PLACE IN THE UPPER MIOCENE-QUATERNARY INTERVAL

Late Miocene-Early Pliocene compression phase (Fig. 5A)

During the Late Miocene-Early Pliocene compression phase, the entire Aegean and Anatolian region is affected. Late Miocene-Early Pliocene compression tectonics taking place following the N-S to NW-SE trending Taurus compression phases have led to the development of an entirely new structural pattern (Poisson, 1977; Letouzey and Özer, 1978; Dumont, 1979). Some workers consider that the subduction of Aegean Arc during Plio-Quaternary is closely related to the compression phase referred above (Mercier, .1977; Angelier, 1977*a,b;* Dewey and Şengör 1979). In contrast to the northward movement of the Arabian plate due to left-lateral mdvement of the Levantin Fault and the divergence of the Red Sea, the compressional effects of the African plate were substantially subdued as a result of the left-lateral movement described above.

Eastern Turkey

Results obtained by Letouzey and Özer (1978) from micro-tectonic studies, show that in the Late-Miocene-Early Pliocene interval the compression directions in the Adana, Tarsus and Erzincan areas and Hatay and Mut had been NW-SE and E-W, respectively.

Southwest Turkey

Upper Miocene horizons of the Söke area (Becker Platen, 1970) are affected by a ENE-WSW trending compression phase, which resulted in the development of strikeslip faults. Efes and Muğla (Düğrek) faults are, believed to have been affected from this compression phase. To the N of Antalya ENE-WSW trending compression tectonics, leading to Late Tortonian-Early Pliocene thrusting, had prevailed (Poisson, 1977; Dumont *et al.*, 1979; Dumont, 1979).

Aegean Region

In various parts of the region, compression tectonics represented by Late Miocene-Pliocene overturned faults and strikeslip faults have been observed. A strong tectonic phase leading to the development of major overturned faults and thrusting has prevailed in the following localities- Istankoy (Kos) island (Jarrige *et al.,* 1976), Sakız (Chios) island and Nykoria (Lemeille *et al.*, 1977); Sisam (Samos) island (Angelier, 1976); Eube (Guernet, 1971);Zanti and Sefeloni islands W of Corinth Gulf (Sorel, 1976).

Lower Pliocene sediments occurring in the present region are believed to have been affected from this phase.

GRABEN FORMATION IN PLIOCENE (Fig. 5B)

Results obtained from stratigrafic and paleogeographic studies indicate that the graben formation in Southwest Turkey started in the interval between Late Miocene and Early Pliocene (Becker Platen, 1970; Bering, 1971; Kastelli, 1972). According to Leflef (1979, oral communications), sedimentological studies further support this conclusion. In the Efes and Söke areas, fault lines developed as a result of Late Miocene-Early Pliocene compression tectonics, are intersected by normal faults belonging to the graben formation phase. The formation of grabens in Western Turkey, had continued throughout Pliocene (Becker Platen, 1970; Mercier, 1977; Angelier, 1977); in Burdur and Söke areas however, this phase has not been so strong, the areas in question being rather characterized by paleogeographic changes (Bering, 1971). Mercier (1977) on the other hand notes that compression tectonics are absent in the Pliocene sediments occurring on the Sefaloni and Zanti islands (Western Greece) located on the western extension of the Aegean Arc.

OLD QUATERNARY COMPRESSION PHASE (Fig. 5C)

Old Quaternary compression tectonics, which differ from Upper Miocene-Lower Pliocene compression tectonics, can be observed in the region extending from Central Anatolia to Western Greece. The convergence of Arabian and Euro-Asian plates and African and Euroasian plates has produced considerable compressional effects.

Aegean Region and Greece

The region as a whole may be divided in two areas-Area I : In this area, comprising of the outskirts of the Aegean Arc (Preapulien zone, Rhodes and Crete islands) the compression direction is nearly perpendicular to the Aegean Arc (Angelier, 1977a and *b)* In the internal parts of the Aegean Arc, however, to the N of volcanic arc, the compression directions developed are diverse (Mercier, 1977).

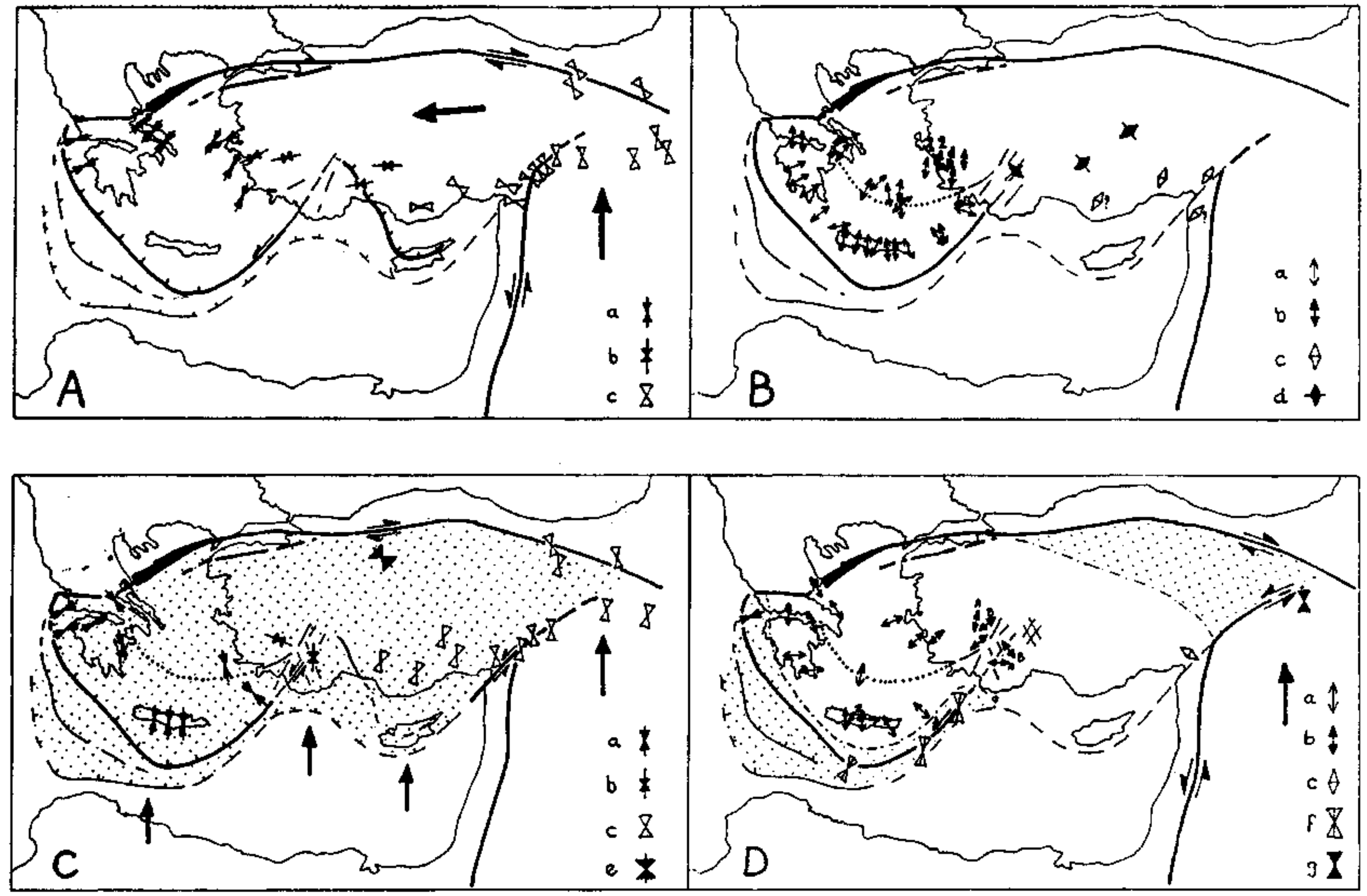

Fig. 5 - Tectonic compression and tension directions seen in Turkey from the end of Miocene until today;

a - Angelier, 1977a,b and Mercier, 1977; b - Dumont, 1979; Dumont *et al*., 1979; Dumont *et* al., 1980; c - Letouzey and Özer, 1978; d - Tectonic directions according to general geological data; e - Nebert, 1958; f - Ritsema, 1979; McKenzie, 1978; g - Personal communication on Lice earthquake (with Arpat, E., 1976).

A - Compression tectonics phase of the end of Miocene-early Pliocene; large arrows show the movements directions of Arabian and Anatolian plates. B - Tension tectonics of the end of Pliocene; 1 - Tension direction at the beginning, 2 - Tension direction at Efes during the end of Pliocene is shown. Northern Anatolian Fault movements of Levantine and Southern Anatolian Faults and the subduction form couldn't be shown because of the unsufficiency of data. C - Old Quaternary (End of Pleistocene-Early Holocene); Compression tectonics. Whole of Aegean and Anatolian are under the effect of a N-S compression. D - Holocene and Today; Aegean subduction zone which is under a compression effect (Ritsema, 1974) and Eastern Anatolia which is effected by the compression of Arabian plate are the dotted regions. Tension tectonics is dominant at Aegean and Western Anatolia. There may be an alternation of compression and tension tectonics at the western cordon of the Northern Anatolian Fault.

Southwest Turkey

Old Quaternary compression tectonics are observed in the Burdur and Sarayköy areas. In contrast to the N-S striking compression in Burdur, Sarayköy area is characterized by a WNW-ESE compression. These two areas, located on the extension of the Aegean volcanic arc are divided from each other by a line extending from Gökova gulf to Çivril. The line mentioned here, is also referred to by Çağlayan *et al.*, (1980). Burdur area, like the outskirts of the Aegean Arc, is subject to the effects of the African and Euro-Asian plates converging in N-S direction. Compression in the Sarayköy area, shows a change of direction as shown in Figure 6, due to Gökova-Çivril line.

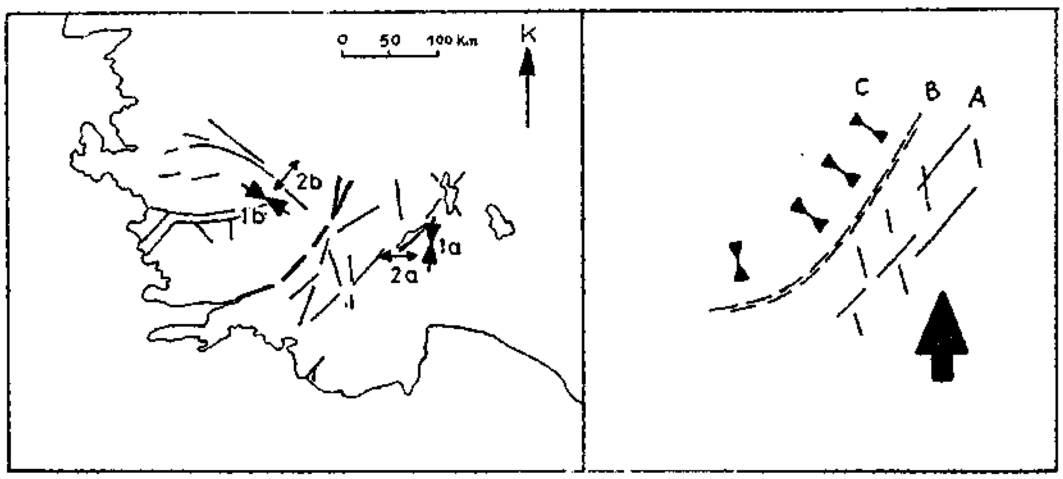

Fig. 6 - Compression tectonics (1) and following tension tectonics (2) at (a) Burdur and (b) Sarayköy-Sazak at left. Schematic drowing at right shows A: Burdur area which is under the influence of compression of African continent, B: Gökova-Acıgöl line which is on the continuation of Aegean volcanic arch and C: Inner Aegean region; compression direction changes because of line B, and it turns to a perpendicular direction to that line.

Central and Eastern Turkey

Compression direction in the Plio-Quaternary sediments occurring N of Alanya, in the İskenderun Gulf and Eastern Turkey is NNE-SSW. Compression tectonics in the surroundings of Ankara has produced thrusting (Nebert, 1958). NW-SE compression direction observed in this area, is conformable with the trend of the North Anatolian Fault.

QUATERNARY GRABEN FORMATION (Fig. 5D)

A new tectonic phase producing grabens has taken place in Young Quaternary. In Burdur area, the major tectonic phenomena, i.e. graben-formation, has occurred in Late Pleistocene or Early Holocene (Bering, ,1970), resulting from E-W trending tensional effects. In Sarayköy area however, NNE-SSW trending tension and graben formation phase have occurred synchronously. Graben formation which started in Young Quaternary is known to continue to actual times (Arpat and Şaroğlu, 1975; Arpat and Bingöl, 1969). Faults affecting Young Quaternary sediments have diverse trends, i.e. NE-SW in Pamukkale and Kuşadası, NW-SE in Burdur (Dumont *et al.,* 1980). Based on the results obtained from seismotectonic studies, the direction of tension in the Menderes

Massive is determined to be NE-SW (Ritsema, 1974; Papazachos and Komnihakis, 1977). McKenzie (1976) however, states that the area discussed, here, is subject to the effects of a NNE-SSW trending tension. The same writers have further established the presence of a NW-SE trending tension in the Burdur area. Results of the seismotectonic studies covering Menderes and Burdur areas, are in conformity with the tension directions determined in Young Quaternary sediments. .

According to Nebert (1958) Old Quaternary compression phase was followed by tectonics producing grabens in Central Anatolia. In the İskenderun area as well the Old Quaternary compression tectonics are followed by a NW-SE tension (Letouzey and Özer, 1978) direction, which is perpendicular to the previous tension direction.

CONCLUSIONS

Evaluation of the results obtained from regional studies show that the entire Aegean region and Anatolia is affected from Miocene-Pliocene compression phase followed by Pliocene graben formation and Old Quaternary compression phase followed by Quaternary graben formation. It is thus evident that grabens are formed within an alternating compression and tension pattern. The region indicated with dots in Figure 5C, shows areas subject to compression. During Old Quaternary, the entire Aegean region and Anatolia has been subject to compressional effects. At present however, only the Aegean Subduction Zone (Fig. 5D) (Ritsema, 1974) and S9me parts of Eastern Turkey, which are directly affected by the movement of the Arabian plate, are continuously subject to the effects of compression. In regions such as Aegean, Western and Central Turkey, tension tectonics prevail, with compression tectonics being taking place only very locally.

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