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Observations on the complexity of the East Anatolian Fault, Turkey

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Abstract—That the East Anatolian fault is made up of discrete segments of different strike and diverse structural style is well illustrated by oblique hand-held photographs taken from the Space Shuttle. Linear and curvilinear faults plus major folds show the variable deformability of the collage of material that constitutes the Anatolian Plate, now undergoing the early stages of collision tectonics.

THE EAST ANATOLIAN FAULT is shown as a straight line on most schematic tectonic maps that show Turkey being pinched westward toward the Aegean Sea (e.g. Hempton 1982, Jackson & McKenzie 1984, Fig. 1). It actually consists of several distinct segments (Arpat & Saroglu 1972, Hempton *et al.* 1981, Sengor *et al.* 1985) of different strike separated by 'knots' of diverse structural origin (Fig. 2). This note uses photographs taken by astronauts aboard the Space Shuttle to illustrate the complexity of the fault. For an up-to-date and thorough discussion of this zone and its role in the recent tectonic evolution of Anatolia see Sengor *et al.* (1985).

Arpat & Saroglu (1972) commented on the difficulty of mapping continuous fault traces and in a later paper (Arpat & Saroglu 1975) they showed detailed fracture trace maps of the segments of the fault and the 'knots' that separate them. Hempton *et al.* (1981) defined the five segments of the fault, here numbered from north to south for use in this note (Fig. 2).

Figure 3(a), a hand-held photograph taken from the Space Shuttle, shows the northern segments. Because the view is oblique, it emphasizes the different strike directions of the segments, and thus more easily demonstrates that the simple straight-line diagrams drawn for regional discussions are gross simplifications. The brief discussion below will describe the segments from north, where it intersects the North Anatolian Fault, to south, where the present fault trace curves into the western branch of the Dead Sea Fault zone.

Arpat & Saroglu (1972) named the East Anatolian Fault during their study of the visible fault traces along it, the impetus for this being the M7 left-slip Bingol earthquake on the Goynuk segment (Segment 1, Fig. 2) in 1971. They showed that marine Miocene sediments are offset 22 km in the Goynuk Valley and Mesozoic sediments northeast of Lake Hazar are offset by 27 km. Seymen & Aydin (1972) in their study of this segment showed a 15 km offset of a basalt–metamorphic rock contact. Arpat & Saroglu further concluded that the fault is post-Miocene in origin. Recent studies (Sengor *et al.* 1985) show its initiation as Pliocene. Hempton (1985) showed that the Middle Eocene Maden Melange is displaced 21 km immediately southwest of Lake Hazar. The Euphrates River is displaced only 13 km as is clearly visible on the photograph. Arpat & Saroglu also showed that the fault continues to the southwest and turns to become the western branch of the Dead Sea Fault zone.

Segment 1, through Goynuk, is clearly visible as a NNE-trending narrow, linear, 65 km-long valley. South of Bingol, segment 2 is a 65 km-long 'knot' that is a left-step that showed right-slip normal displacement along NW-trending faults during the 1971 earthquake (Arpat & Saroglu 1972). This knot also marks a major change in strike in the segments on either side (segments 1 and 3). Arpat & Saroglu (1972) also mapped a major strike–slip fault that extends northeast from Genc along the Murat River, visible as the linear reach on the photo. Dewey *et al.* (1986) suggest that the compressional bend near Bingol is being cut off by a straighter fault to the NW (not observable in Fig. 2).

In their comprehensive paper on the North and East Anatolian Fault zones, Sengor *et al.* (1985) describe a model to explain the variation in strike along a fault by the intersection of the fault with a 'zone of higher convergent strain'. Segments 2 and 4 are the results of intersections of this type. The fault in the zone will rotate toward the strike of the zone and generate restraining bends with their associated thrusts and/or folds. This

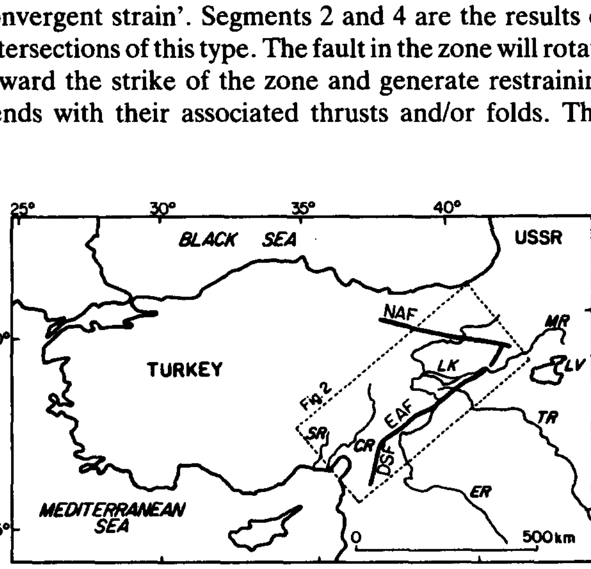


Fig. 1. Location map of Anatolia and environs, showing part of the Dead Sea Fault (DSF) and the East Anatolian Fault (NAF). Area of Fig. 2 also outlined. Abbreviations: CR, Ceyhan River; ER, Euphrates River; LK, Lake Keban; LV, Lake Van; MR, Murat River; SR, Seyhan River; TR, Tigris River.

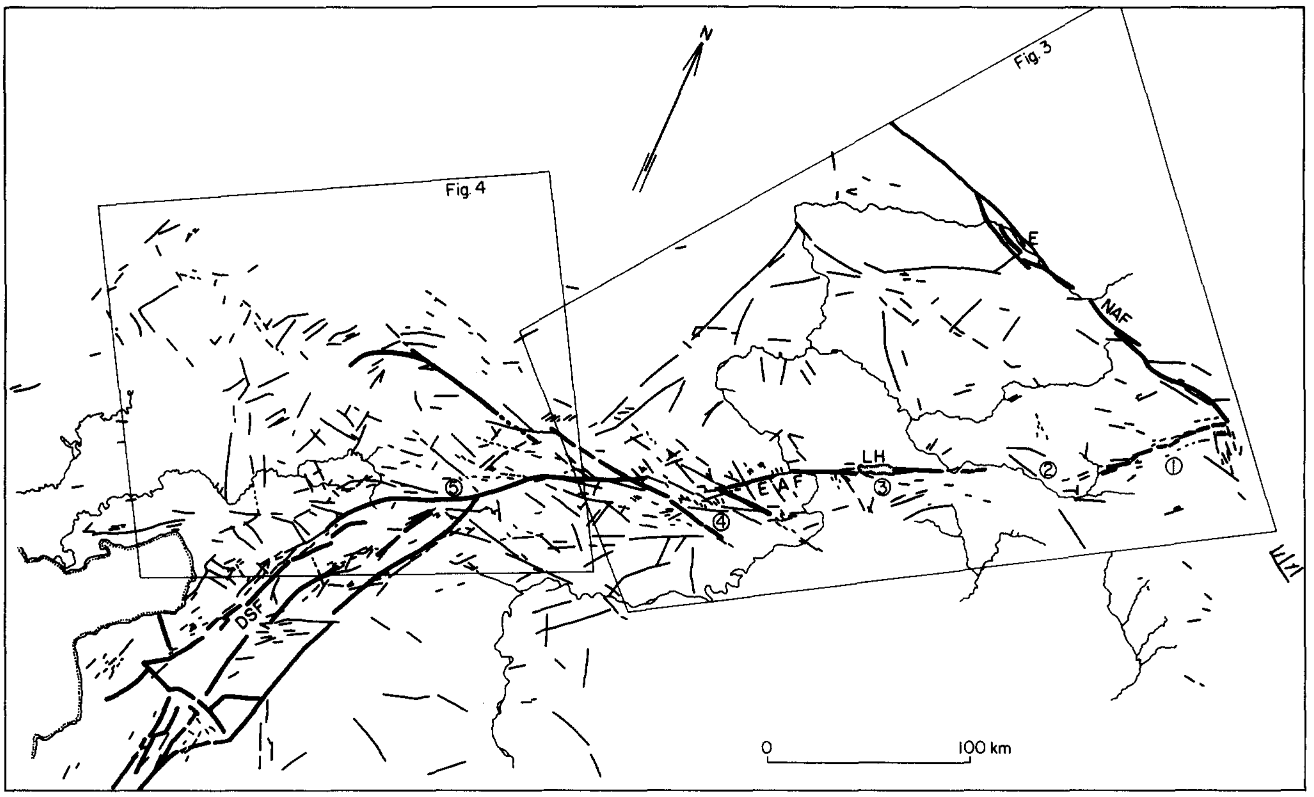


Fig. 2. Map of main traces of the East Anatolian Fault and principal adjacent linears (mostly faults) visible on 1:500000 LANDSAT with additional data from Arpat & Saroglu (1972, 1975), Muehlberger (1981). Also shown are areas of Figs. 3 and 4. Abbreviations: DSF, Dead Sea Fault; E, Erzincan; EAF, East Anatolian Fault; LH, Lake Hazar; NAF, North Anatolian Fault. Numbers are fault segments described in text and shown on Figs. 3 and 4.

model is also appropriate to explain as zones of higher convergent strain the Lebanon segment of the Dead Sea Fault zone where it traverses the Bekaa Valley and the Palmyra aulacogen (Syrian fold belt) or the 'Big Bend' of the San Andreas Fault where it traverses the Transverse Ranges of Southern California.

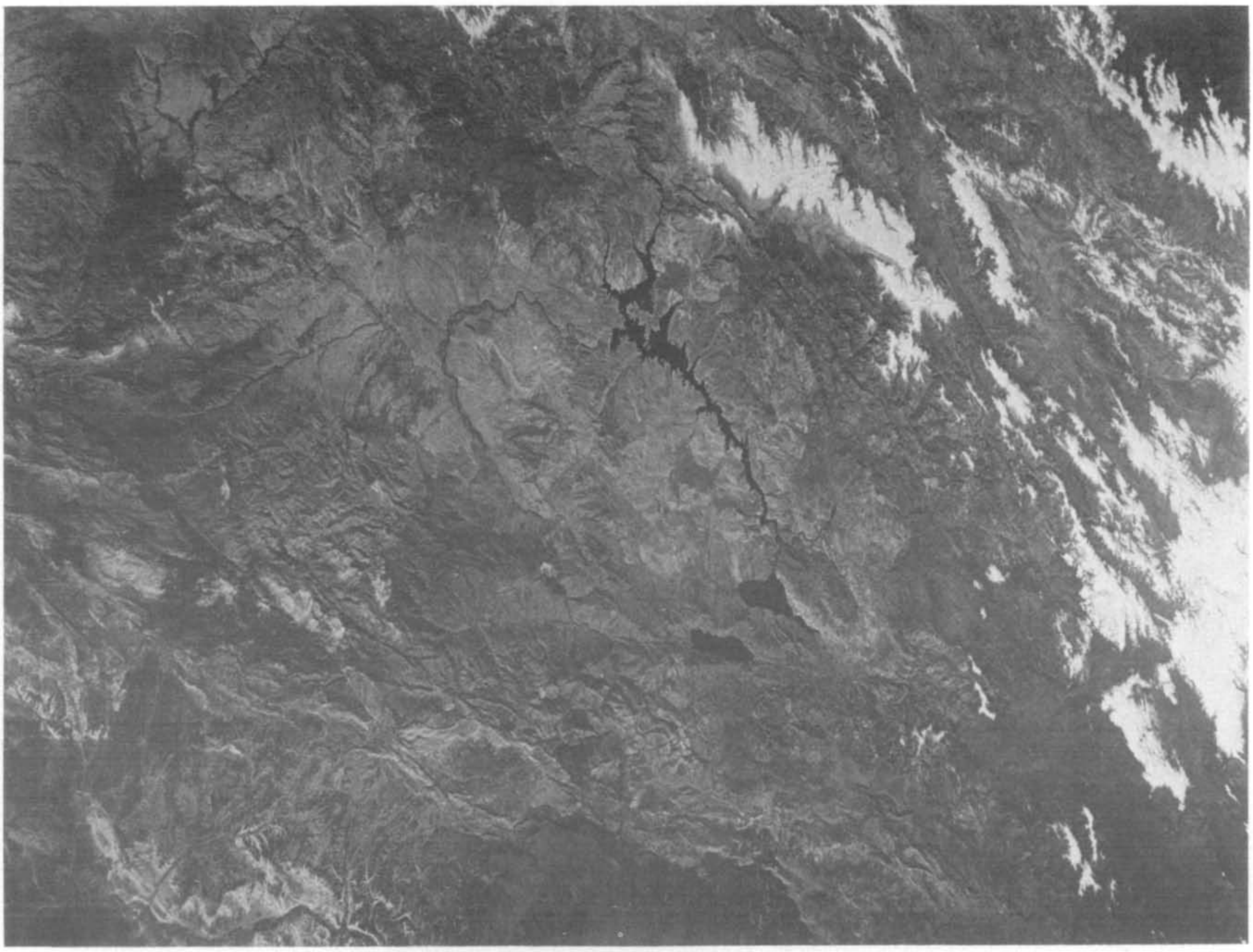
Lake Hazar, centered on segment 3, occupies a part of a well-defined, relatively straight, narrow, 110 km-long valley. Note that the drainage area into Lake Hazar is indeed small, the Euphrates River and its tributaries drain most of the area of the photograph.

The southern knot, segment 4 (light-colored oval mountain range in the lower left of Fig. 3) appears as a restraining bend on Arpat & Saroglu's map (1975). The major linear that extends to the west can be traced past the restraining bend at the edge of the photograph into the west-striking fault near Goksun (better shown on Fig. 4) that curves southwest at its western end. This fault has the appearance of an early effect of indentation tectonics (cf. indentation model of India and Asia by Tapponnier & Molnar 1976) as the full thickness of the Arabian Plate entered into the collision zone smashing the collage that constitutes the Anatolian Plate. The Shuttle photographs show the en échelon pattern of east-trending linears that appear to offset the southern segments from the Lake Hazar segment. The linears extending east from the EAF are faults of the Bitlis suture, a zone of higher compressive strain at the boundary of the Arabian Plate and the accretionary collage of Anatolia.

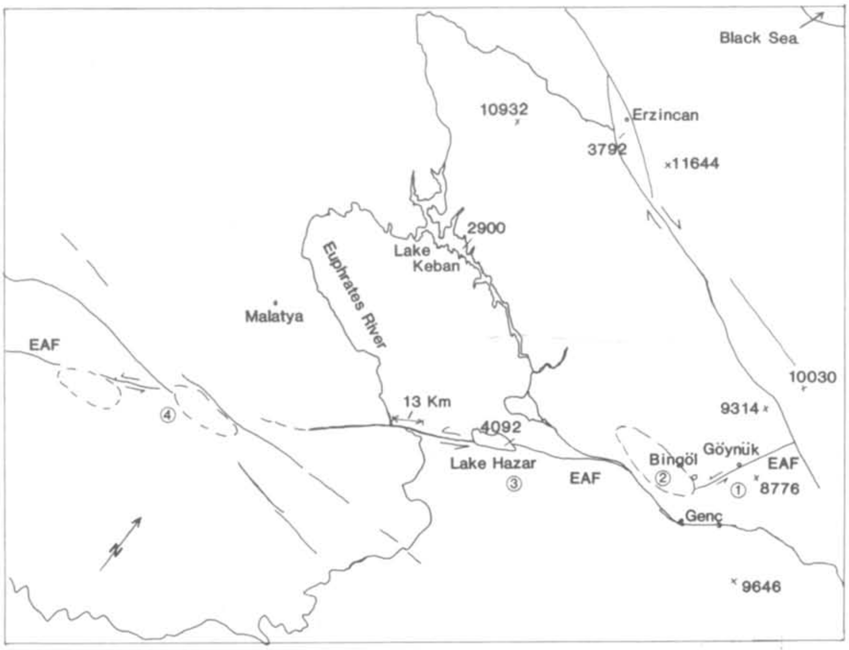
Figure 4 shows, from south to north: (1) the curving trace of the Dead Sea Fault where it crosses the Aksu River and becomes the East Anatolian Fault (segment 5); (2) two prominent splays of the Dead Sea Fault farther east (Muehlberger 1981) that deflect the East Anatolian Fault into more northerly-striking segments; (3) a large doubly-plunging anticlinal mountain north of Maras, as well as smaller ones farther north; (4) the curved fault past Goksun that is an element of indentation tectonics; and (5) fainter curved traces farther north that mimic the Goksun Fault. Note the absence in the photograph of through-going structures southwest of the East Anatolian Fault that would continue west of the Gulf of Iskenderun to join a postulated plate boundary off Cyprus. The Amanos Range, southwest of the Aksu River, is shown on the Adana Geological map sheet (Erentoz & Ternek 1962), however, to have a band of ophiolite on the south side of the major arcuate drainage with Lower Paleozoic age rocks mapped on the north.

Thus the evidence shown suggests that the EAF is not moving as a single entity but instead is moving in several discrete segments, each with a different amount of slip that is a function of the strike of the fault relative to the strike of the Dead Sea Transform. A strike–slip fault oblique to a convergent zone will rotate into a position more parallel to the strike of the zone by pure shear (a zone of higher compressive strain of Sengor *et al.* 1985) and may develop into an oblique–slip reverse fault (Jackson & McKenzie 1984).

Thus the East Anatolian Fault can be seen to have two

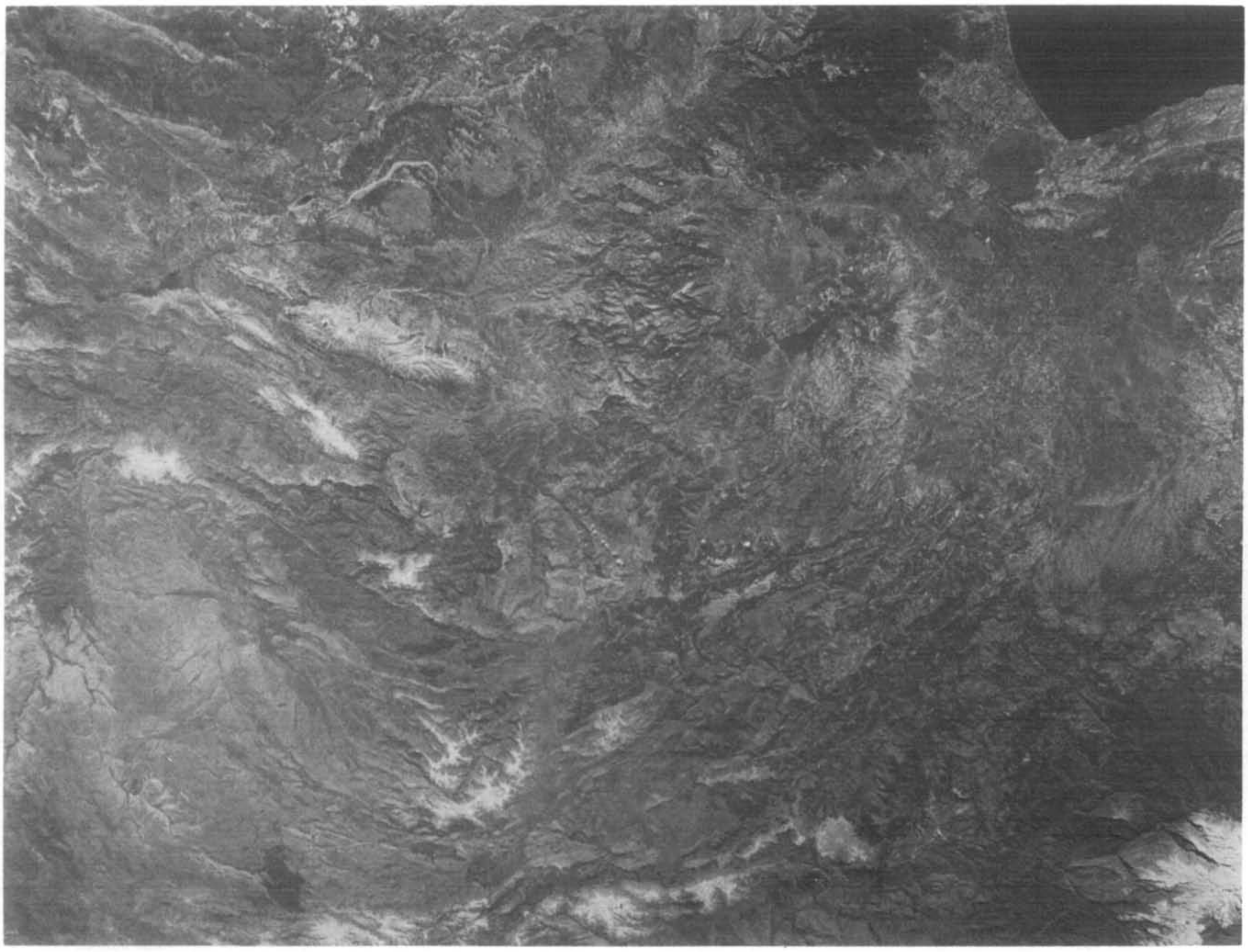


(a)

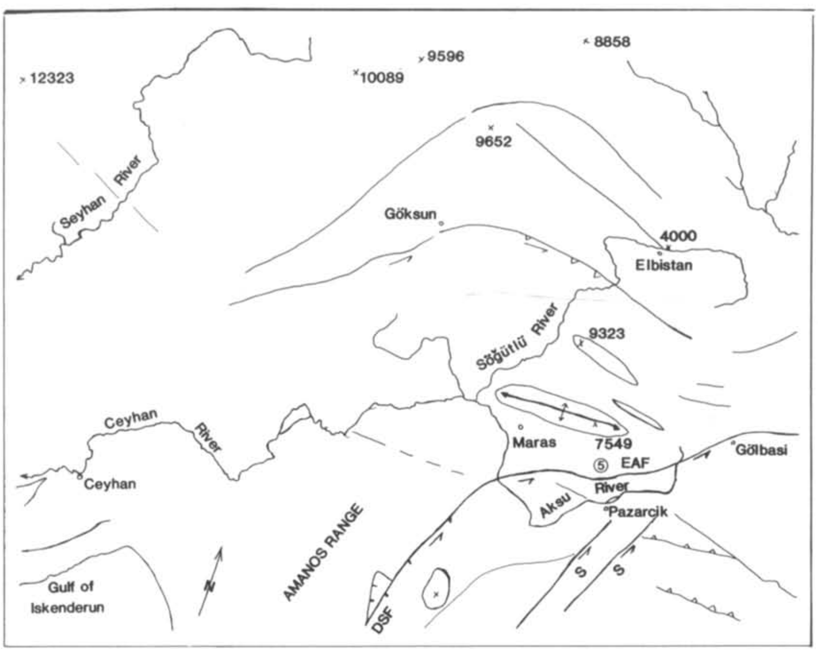


(b)

Fig. 3. Part of (a) hand-held Space Shuttle Photograph 61A-43-068 and (b) sketch map of main features. Northward-looking oblique of central Turkey showing most of the East Anatolian Fault (EAF) and the eastern part of the North Anatolian Fault (NAF) showing the Lake Hazar and Erzincan pull-apart basins. Elevations in feet. Black-and-white copy of part of a color transparency. Photographs 069, 070, and 071 of this series are an excellent mosaic of the WNW-trending part of the North Anatolian Fault and its three right-stepping segments between latitudes 35° and 40°E.



(a)



(b)

Fig. 4. Part of (a) hand-held Space Shuttle Photograph 61A-43-067 and (b) sketch map of main features. Northward-looking oblique across south-central Turkey showing area where Dead Sea Fault (DSF) and its splinters (S) interact with the East Anatolian Fault (EAF). Elevations in feet. Black-and-white copy of part of a color transparency.

segments (2 and 4) that are involved in north–south compression and are acting as restraining bends, whereas the alternate strands are nearly linear strike–slip zones, but of differing style: segment 1, a nearly linear zone; segment 3 with the Lake Hazar pull-apart basin along the fault; and segment 5 with the Hatay graben, a pull-apart basin aligned along the Dead Sea Fault zone.

We speculate that the reason for the segmentation is that Turkey consists of blocks of varying rigidity that flatten to different amounts as the 'rigid' Arabian continental block indents this region. The amount of indentation is small and has been occurring for a lesser length of time relative to that invoked for the India–Asia collision (Molnar & Tapponnier 1975) and thus is a useful model of an early stage in collision-indentation tectonics.

Acknowledgements—Our thanks to the crew of Shuttle Mission 61A for taking these photographs. The United States National Aeronautics and Space Administration furnished the color transparencies. David Stephens, photographer of our department, made the black-and-white copies.

NOTE: All Shuttle photography is available from EROS Data Center, Sioux Falls, S.D. The numbers given in this paper are the unique numbers for the photographs described.

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