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Evolution of carbonate platforms on a margin of the Neotethys ocean: Isparta angle, southwestern Turkey

By JOHN W. F. WALDRON[1])

ABSTRACT

The Isparta angle is the north-pointing cusp formed by the junction of the Hellenides and Taurides in southwestern Turkey. Numerous tectonic units in this region display shallow-water carbonate facies in the Mesozoic. Structural and sedimentary evidence from intervening basinal slices indicates that these units cannot be interpreted as fragments of a single continuous platform but must represent a number of separated carbonate banks similar to the modern Bahamas.

At the centre of the Isparta angle the margin of the major Anamas–Akseki platform is particularly well exposed. The platform was established with a reefal margin founded on Triassic rift-related volcanics, but the margin became dominated by oolite shoals in the Jurassic. Rapid subsidence of the platform margin in late Jurassic to early Cretaceous time marked the start of seafloor spreading in the adjacent Troodos ocean.

Carbonates of smaller isolated platforms are represented in the massifs Dulup Dağı, Davras Dağ, and Karacahisar. All three areas show a progressive change from low energy restricted environments in the Triassic and Jurassic to open marine conditions in the Cretaceous.

Attempted subduction of this platform mosaic occurred in latest Cretaceous time, leading to décollement and telescoping of the Mesozoic sedimentary sequences. Subsequent Tertiary thrusting gave the Isparta angle its present day geometry.

RÉSUMÉ

L'angle d'Isparta est une pointe de terre entre deux arcs créée par la jonction des Hellénides et Taurides dans le sud-ouest de la Turquie. Dans l'ère mésozoïque de cette région, plusieurs unités tectoniques exhibent des faciès carbonatés d'eau peu profonde. L'évidence apportée par la structure et la sédimentologie des écailles intermédiaires indique que ces unités ne peuvent représenter des fragments d'une seule plate-forme continue, mais plutôt un certain nombre de plate-formes carbonatées comparables aux Bahamas modernes.

La marge de la plate-forme d'Anamas–Akseki affleure au centre de l'angle d'Isparta. Cette plate-forme contient à son origine une marge récifale qui s'établit sur des laves fissurales triassiques; elle est dominée au Jurassique par un haut-fond oolitique. La subsidence rapide de cette marge de plate-forme a lieu du Jurassique supérieur au Crétacé inférieur et marque le début de l'expansion du fond océanique de la mer de Troodos.

Des roches carbonatées provenant de plate-formes plus petites et isolées sont présentes dans les massifs du Dulup-Dağı, Davras Dağ et Karacahisar. Dans ces trois régions, on observe un changement progressif depuis les environnements restreints et à basse énergie du Trias et Jurassique, aux conditions marines ouvertes du Crétacé.

La subduction partielle de cette plate-forme en mosaïque a lieu au Crétacé supérieur et provoque le décollement et sérriage des séquences sédimentaires mésozoïques. Plusieurs phases de charriage au Tertiaire donnent à l'angle d'Isparta sa configuration géométrique actuelle.

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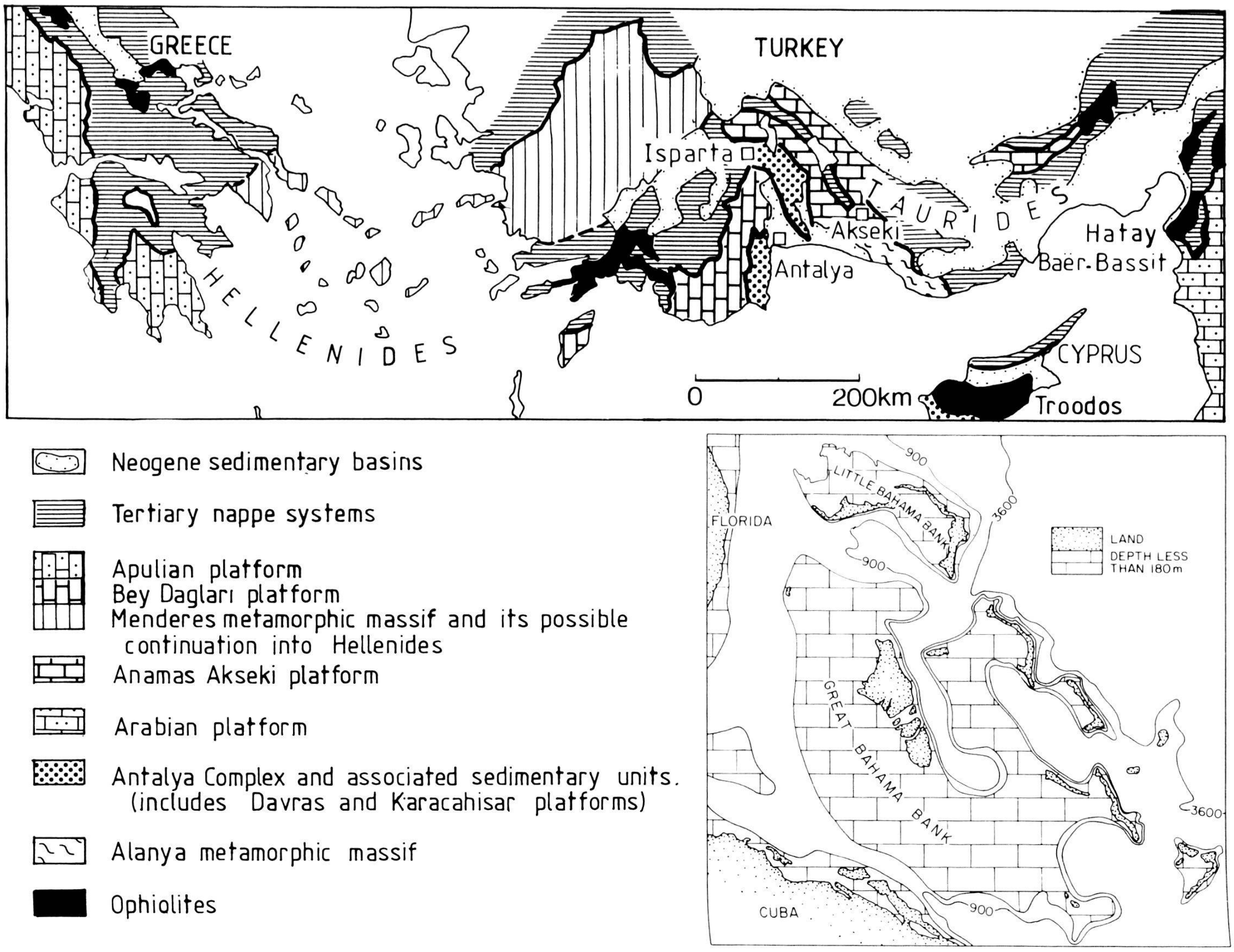


Fig. 1. Schematic tectonic map of southern Hellenides and western Taurides. Adapted from GUTNIC et al. (1979). Inset shows a modern carbonate platform terrain, the Bahama Banks, at the same scale (after READING 1978).

1. Introduction: structural framework

Many controversies in the interpretation of the Alpine–Mediterranean orogenic belts result from the uniformity of shallow-water carbonate platform facies that existed throughout much of the Mesozoic Neotethyan region, and particularly on its southern margin (BERNOULLI & JENKYNS 1974). Because of later tectonic deformations, it is often unclear whether the sedimentary platform units in a particular area are to be regarded as separate paleogeographic entities or as fragments of a single continuous platform.

The problem is particularly well illustrated in southwestern Turkey (Fig. 1), at the junction between the Hellenide and Tauride arcuate fold and thrust belts (SUESS 1901). Figure 2 shows the distribution of units with Mesozoic platform facies in this region. The largest of these units constitute the massifs here termed *Bey Dağları* and *Anamas-Akseki*. Both these platforms were deformed in Tertiary thrust events recognized throughout the Hellenides and Taurides. Figures 1 and 2 show how the traces of the Hellenide thrusts meet those of the Taurides in a north-pointing cusp, known as "Dinarisch-Taurische Schaarung", the "courbure d'Isparta" or *Isparta angle* (SUESS 1901, BRUNN et al. 1971, WALDRON 1983). Movement on the Tauride thrusts largely ended in the Eocene (MONOD 1977), whereas to the west of the Isparta angle emplacement of major nappes continued until Miocene (POISSON 1977, HAYWARD & ROBERTSON 1982). Finally, the late Miocene Aksu thrust (Fig. 2) in the centre of the Isparta angle transported the west edge of the Taurides an unknown but probably short distance over the Bey Dağları platform and adjacent units (POISSON 1977, AKBULUT 1977).

These Tertiary structures are superimposed on a late Cretaceous complex of thrust sheets, tectonic slices, mélanges, and ophiolite fragments that occupies the centre of the Isparta angle between two major platforms (Fig. 2). In this area, units characterized by basinal Mesozoic sediments (turbidites, shales, cherts), together with the ophiolite fragments and some clearly allochthonous platform carbonate sheets, have traditionally been assigned to the *Antalya nappes* (LEFÈVRE 1967, BRUNN et al. 1971, JUTEAU 1975) or *Antalya complex* (WOODCOCK & ROBERTSON 1977). Larger carbonate-dominated units occupying structurally low positions in this region (e.g. Davras Dağ and Karacahisar; Fig. 2) have generally been regarded as autochthonous. They have been grouped with the Bey Dağları and Anamas–Akseki units as parts of an originally continuous "Taurus Autochthon" (BRUNN et al. 1971, DUMONT 1976).

Clearly, the original location of these diverse units at the centre of the Isparta angle must be known before any paleogeographic reconstruction can be attempted. Some authors, notably RICOU et al. (1974, 1975, 1979), have argued that the Antalya complex and certain adjacent platform units are far-travelled tectonic klippen, transported southwards over the Anamas–Akseki and Bey Dağları platforms as nappes during the Tertiary era. In the more conservative reconstruction adopted here, these units are interpreted, following WOODCOCK & ROBERTSON (1977), not as far-travelled nappes derived from a single Tethyan basin to the north, but as fragments of a number of smaller banks and basins originally located somewhere to the southwest of the Anamas–Akseki platform, though possibly to the northeast of the Bey Dağları. The following lines of evidence support this interpretation:

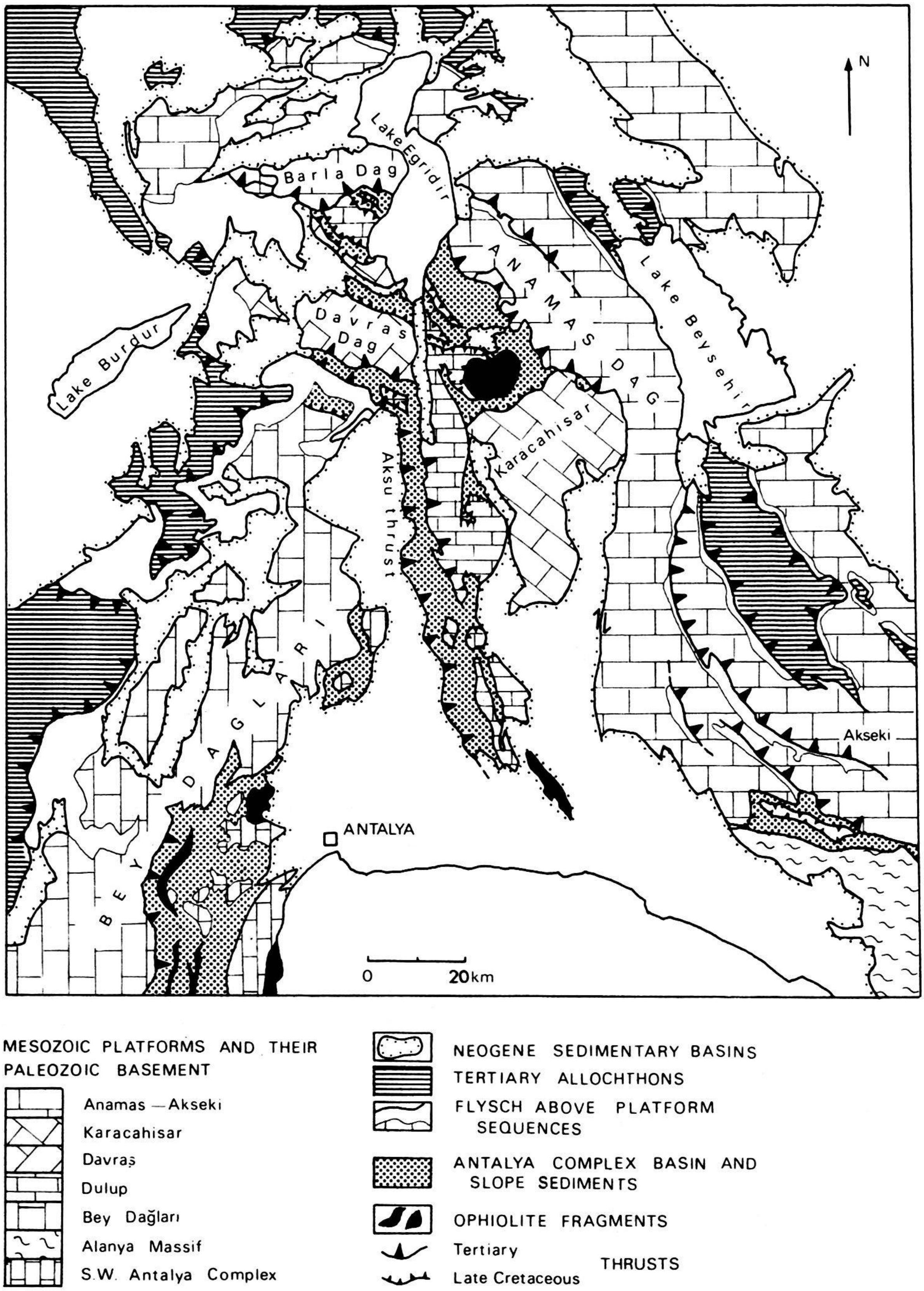


Fig. 2. Tectonic map of the central part of the Isparta angle. Compiled from Brunn et al. (1971), Gutnic et al. (1979), Dumont (1976), Woodcock & Robertson (1982), Blumenthal (1963), and mapping by the author. Figures 4, 7 and 9 are located with reference to lake Eğridir (top centre). Smaller platform units are identified in legend.

1. Structural evidence from the northeastern Antalya complex indicates an initial late Cretaceous episode of northeastward overthrusting, followed by more localized southwestward thrusting in the Tertiary era (WALDRON 1983). There is no structural evidence to suggest that the diverse platform units could have been separated and tectonically interleaved with basinal units late in their history.
2. Sedimentary facies at the southwest edge of the Anamas–Akseki platform show close analogies with certain adjacent units of the Antalya complex. In particular, distinctive lower Jurassic yellow siltstones and reddish sandy limestones (Çayır Formation) occur in both units, overlain by oolitic and oncolitic grainstones of the Yassıviran limestone, but are not found in any other platform or basin units in the area.
3. Structural studies in the southwestern segment of the Antalya complex (WOODCOCK & ROBERTSON 1977, 1982) show evidence of westward thrusting and imbrication against the margin of the Bey Dağları platform. The polarity of facies in the imbricated sediments (ROBERTSON & WOODCOCK 1981a, b, c, 1982) confirms an origin on an east-facing platform margin.
4. MONOD (1977) records that marginal parts of the Anamas–Akseki platform contain detritus derived from the Antalya complex in the late Cretaceous to Paleocene, whereas in the centre of the platform carbonate sedimentation continued until Eocene (MONOD 1977). For consistency with the hypothesis of RICOU et al. (1974, 1975, 1979) the sequences with Cretaceous and Paleocene detritus have to be regarded as allochthonous. MONOD (1977) shows that this would lead to a complicated and unlikely restoration of the pre-Tertiary geology of the area, in contrast with the more conservative hypothesis of a local origin for the Antalya complex.
5. Cretaceous to Oligocene platform limestones of the Bay Dağları massif (Fig. 2) pass up into Miocene clastic sediments derived from the Antalya complex. HAYWARD (1983), HAYWARD & ROBERTSON (1982) documents westward paleocurrents in these sediments, indicating that the Antalya complex was emplaced onto the eastern edge of the Bey Dağları. Furthermore, these sequences are continuous to upper Miocene, precluding middle Miocene transport of the Antalya complex over the Bey Dağları as required by more allochthonist hypotheses (RICOU et al. 1974, 1975, 1979).

Taken together, these data support an origin for the Antalya complex generally between the Bey Dağları and Anamas–Akseki platforms (WALDRON 1983) probably in a mosaic of smaller carbonate banks and basins. Figure 3 shows a schematic palinspastic reconstruction for part of this mosaic. Because of the uncertainties involved in unstacking the numerous thrust sheets, Figure 3 is only one of many possible reconstructions. Structural data do not place an upper limit on the distance that thrust sheets have been transported; nor do they indicate the nature of the original basement on which the platform and basement sequences were deposited. Figure 3 has been construction for *minimum shortening* consistent with the observed data; the actual dimensions of the platforms and basins were probably much greater. The direction of thrusting is also poorly constrained for some units; other arrangements of the platforms and basins can therefore be envisaged. However, the main conclusions of this paper relate to the differentiation of a number of carbonate banks, and are independent of their precise dimensions and arrangement. All directions (NE, SW, etc.) relate

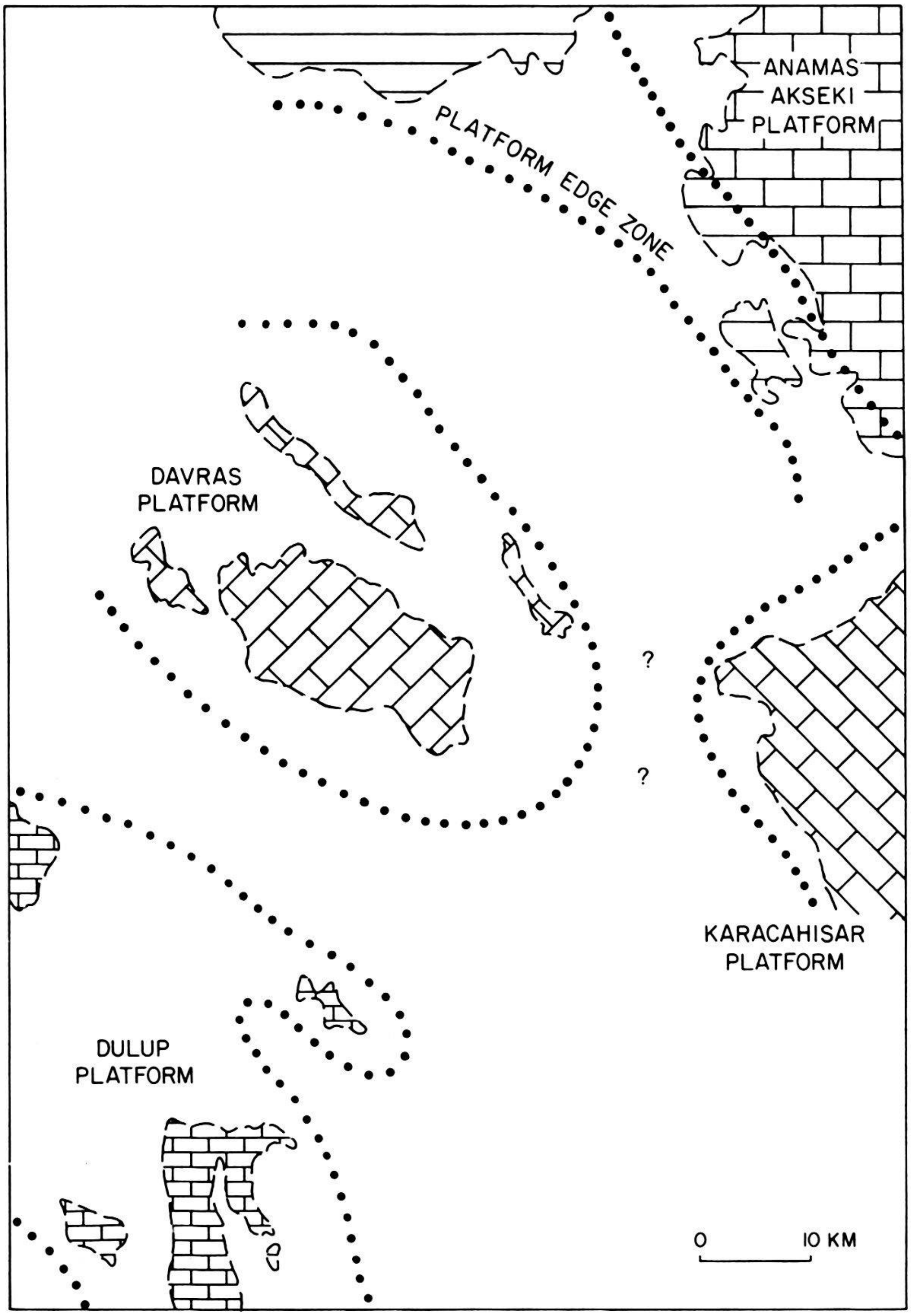


Fig. 3. Attempted palinspastic reconstruction of platform units at centre of Isparta angle, from WALDRON (1981, 1983). Preserved parts of each platform are ornamented with brick patterns corresponding to those in Figure 2. This is the most conservative reconstruction consistent with the present-day geology. The platforms were probably actually larger and more widely spaced than this.

to the present-day orientation of units, and do not therefore take into account any large rotations which the platforms may have undergone.

The following account is based mainly on the author's mapping and sampling of platforms units exposed in the area southeast of Lake Eğridir. Sediments representing *carbonate slope* and *basin* environments also occur in this area but will be described elsewhere. Correlation with adjacent areas is based on reconnaissance traverses and on compilations of published results, mostly from pioneering work of J. H. Brunn and his team at Orsay, France. The emphasis in this paper is on the margin of the major Anamas–Akseki platform and on the smaller platforms. Only brief stratigraphic reviews are given of interior parts of the Anamas–Akseki platform and the Karacahisar platform, which are described in detail by MONOD (1977) and DUMONT (1976). The reader is referred to GUTNIC et al. (1979) for the most accessible recent summary of these areas, and of the major Bey Dağları platform, which lies to the west of the Isparta angle (Fig. 2).

2. Interior of the Anamas–Akseki platform

Figure 4 (column 6–7) shows a typical sequence in the interior of the Anamas–Akseki platform, the lower part of which was described by GUTNIC (1977). The lowest unit *(Kasımlar Formation)* consists of thinly bedded turbiditic sandstones and shales, somewhat deformed and poorly exposed in the area of the section, but well-described further south (DUMONT 1976). The overlying *Menteşe dolomite* is poorly bedded and shows few primary features, though pelleted textures and large organic skeletons are locally discernable. In contrast the *Leylek limestone* shows well developed algal lamination and fenestral fabrics indicative of low-energy intertidal or supratidal environments. The *Çayır Formation* (lower Jurassic) comprises yellow siltstones and red sandstones. It is strongly deformed and may have acted as a décollement horizon during Eocene deformation (GUTNIC 1977). The *Yassıviran limestone* consists of well bedded pelletoidal, oncolitic and oolitic packstones and grainstones laid down in moderate to high energy subtidal environments. It is overlain by saccharoidal recrystallized dolomite. Higher (unnamed) parts of the sequence consist of monotonous poorly fossiliferous wackestones. The presence of "Birds-eye" cavities partially filled with vadose silt (DUNHAM 1969), and occasional algal laminites indicates predominantly intertidal to supratidal deposition. Pelagic *Globotruncana*-bearing limestone appears in the latest Cretaceous, suggesting a sudden subsidence. *Globotruncana* is also found reworked with Paleocene planktonic Foraminifera. The top of the sequence consists of Eocene calcareous sandstone turbidites, derived from nappes that were emplaced from the northeast at this time (MONOD 1977).

To the south and east various authors have documented lateral variations within the Anamas–Akseki platform. BRUNN et al. (1971) report onlap of the lower part of the sequence against Paleozoic metamorphic basement north and south of Lake Beyşehir (Fig. 2), which was not finally covered by marine transgression until Middle Jurassic. The lower Jurassic Çayır sands were probably derived from this land area. Further south, MONOD (1977) has recorded a variety of Paleozoic and Triassic units lying unconformably beneath Jurassic limestone. MONOD also records an upper Jurassic to lower Cretaceous pelagic interval (Akkuyu Formation) representing an intra-platform basin, and an extensive mid-Cretaceous bauxite horizon indicating temporary emergence of the central part of the platform. In these areas, platform sedimentation continued uninterrupted to Eocene, without late Cretaceous pelagic facies (BRUNN et al. 1971).

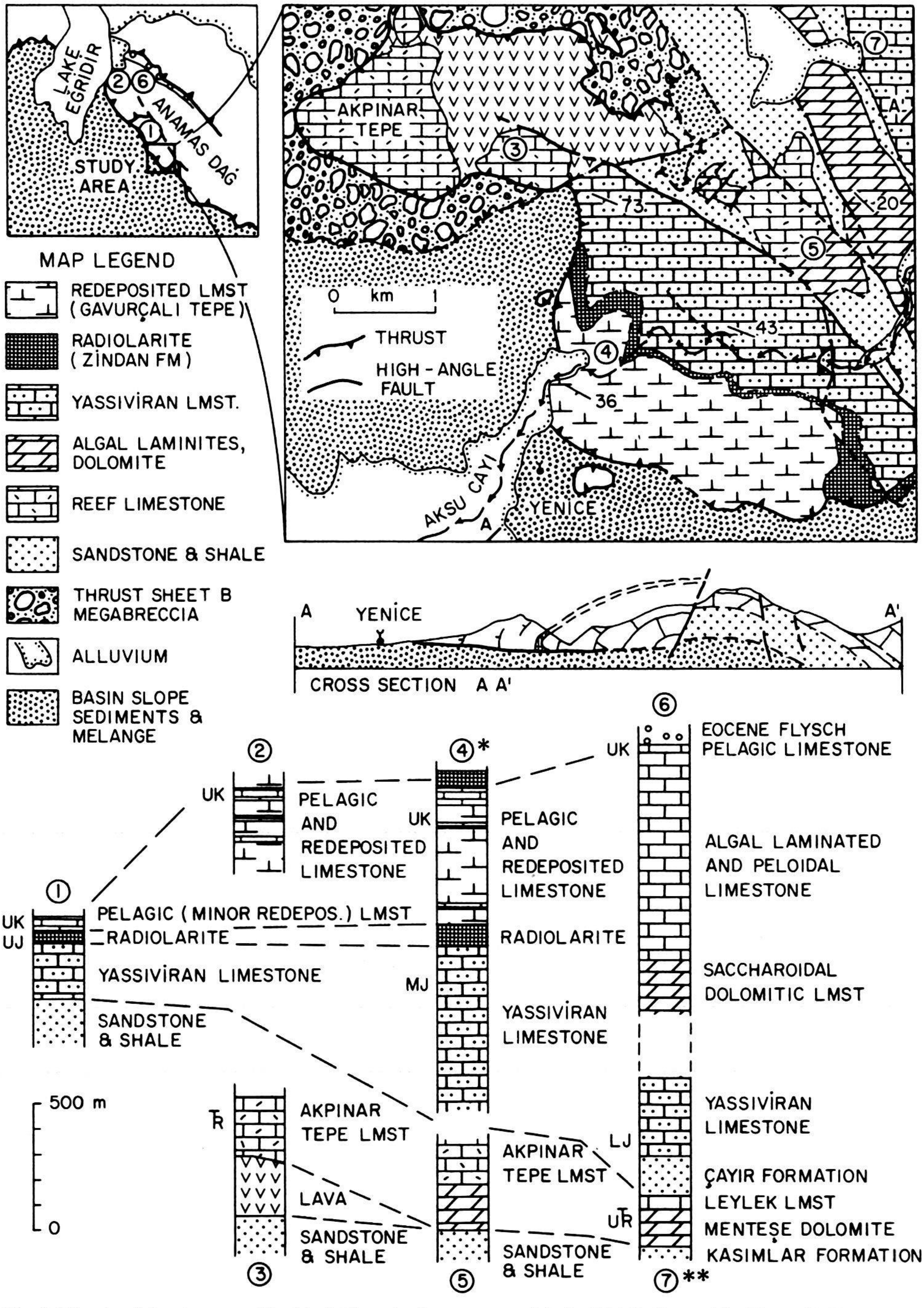


Fig. 4. Margin of the Anamas–Akseki platform in the area east of Lake Eğridir (located in Figure 2). Top: Map and cross section of thrust sheet A (map shows structure and location of stratigraphic sections). Bottom: Stratigraphic sections. *Section 4 in part after DUMONT et al. (1980). **Section 7: thicknesses after GUTNIC (1977).

3. Margin of the Anamas–Akseki platform

Platform-edge sequences are uniquely exposed along the southwest edge of the Anamas Dağ (Fig. 4), and in the Barla Dağ (Fig. 2) to the west of Lake Eğridir (GUTNIC et al. 1979). In the Anamas Dağ area two thrust sheets of Tertiary age are present. The upper sheet (sheet A) is largely intact and shows evidence for only one major episode of thrusting (towards the southwest). The lower sheet (sheet B) consists partly of a jumble of blocks (a megabreccia); it is thought to have suffered late Cretaceous thrusting towards the northeast prior to the Tertiary event, accounting for its more chaotic structure (WALDRON 1983).

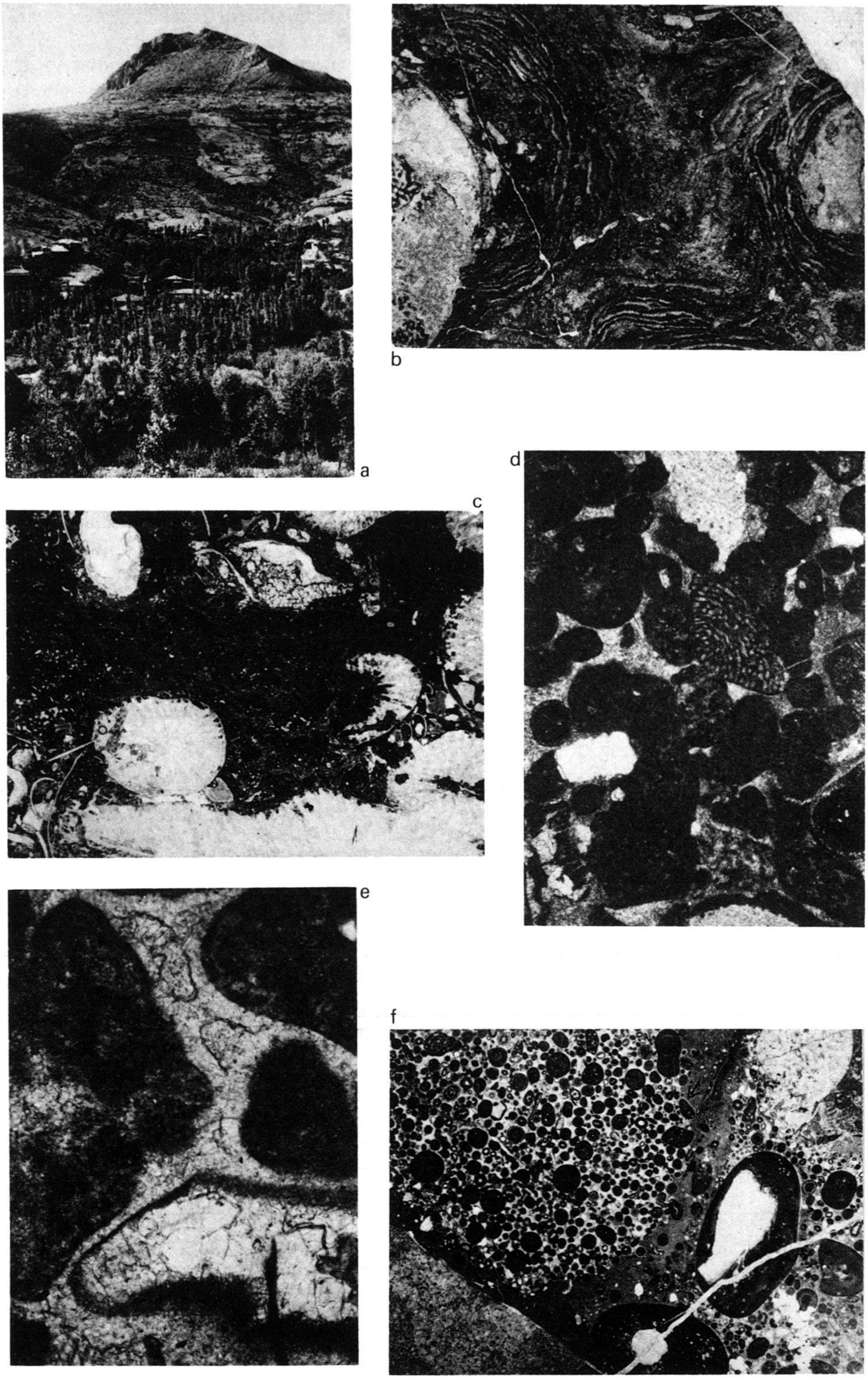
Triassic sequence

Columns 3 to 5 in Figure 4 illustrate the stratigraphy of sheet A. The three partial sequences are separated partly by high angle faults whose major movement probably predates formation of the thrust sheet. The oldest rocks seen are shales and turbiditic sandstones (Sofular Formation) of probable Triassic age. These are overlain by 200–400 m of pillowed and massive mafic lava flows, ranging from porphyritic ankaramite through alkali basalt to mugearite (JUTEAU 1975, WALDRON 1981). The Akpınar Tepe limestone, dated as Triassic by JUTEAU (1975) overlies the lavas with apparently normal contact. Pinkish micritic limestones occur locally at the contact. Elsewhere, the lava is overlain directly by a variety of white saccharoidal reef limestones in which large recrystallized corals and other skeletons up to 1 m in diameter are occasionally visible. Better preserved though unidentifiable colonial corals occur 4 km to the east (locality 5 in Figure 4). Here, however, the coral-bearing limestones pass down into well-bedded peloidal and dolomitic limestone, and massive dolomites. These can be traced eastward into the Menteşe dolomite of the Anamas–Akseki platform, as indicated in Figure 4.

Sheet B (column 1 in Figure 4) lacks these reef and platform facies; instead the Triassic is represented by a thick sequence of sandstone and limestone turbidites (calciturbidites) with interbedded shale (Sofular Formation). Lenses and beds of rubbly carbonate conglomerate in the lower part of the formation contain abundant coral, bryozoan and algal debris. Occasional large (up to 5 m) rounded blocks of well preserved reef limestone are found immersed in Sofular Formation mudstones. The Triassic coral *Thecosmilia* has been identified from these blocks (C. Kiragli, personal communication, 1979), which also contains large thick-shelled molluscs and echinoderm fragments (Fig. 5c). All the fossils have exceptionally well-preserved shell microstructures, in contrast to the in situ reef limestones of Akpınar Tepe. The rounded shape of the blocks and the truncation of skeletons at their edges indicate that they fell or rolled into the mudstones from an adjacent reef. POISSON (1977) records similar blocks in the Tilkideliği Formation (also Triassic) to the west of Antalya. The contact with the overlying Yassıviran limestone is poorly exposed but appears conformable.

Lower to middle Jurassic; Yassıviran limestone

The Jurassic and Cretaceous history of the platform edge zone is recorded in the "Zindan sequence" of sheet A and its equivalents in sheet B. The Zindan sequence is


a
b
c
d
e
f

spectacularly exposed in the gorge of Aksu Çay, northeast of Yenice (Fig. 4), where its stratigraphy has been described by DUMONT et al. (1980).

The Yassıviran limestone is the lowest unit in this sequence (Fig. 4). The limestone is mostly evenly bedded in units 10 cm to 1 m thick, but contains occasional thick lenticular bodies of intra-formational conglomerate. These have strongly eroded bases, indicating removal of up to 10 m of well-bedded limestone.

Most of the limestone is dark grey packstone (Fig. 5), containing abundant peloids, and generally lesser quantities of ooids, intraclasts, grapestone, oncolites, echinoderm fragments, molluscs, benthonic Foraminifera, calcareous Algae, etc. Much quartz sand is present near the base of the Formation. Rarer grainstones consist mainly of ooids or grapestone. Intergranular space is sometimes partially filled by isopachous fringes (Fig. 5e) of cloudy cement with palisade fabric. This probably pseudomorphs an early marine Mg-calcite or aragonite cement of the type described by SCHROEDER (1972), JAMES & GINSBERG (1979), and others, in recent carbonates. The conglomeratic limestones contain a much greater variety of material, including large (50 cm) coral-bearing lithoclasts, intraclasts, sponges, and oncolites (Fig. 5f). The matrix is sandy oolitic grainstone and packstone.

In contrast to sheet A, the Yassıviran limestone of thrust sheet B is thin (2–300 m) and is exposed in numerous small tectonic slices. It is generally lighter in colour and thinner bedded than the limestone of sheet A, and shows frequent cross-stratification. The dominant lithology is oolitic grainstone mixed with abundant terrigenous sand. Near the base, thin (5–10 cm) horizons of yellow siltstone occur, associated with pink-weathering sandy calcarenites. These facies may be correlated with Çayır Formation of the Anamas–Akseki platform to the northeast (Fig. 4).

The Yassıviran limestones of sheet A were deposited in high-energy oolite shoals (grainstones) and more sheltered areas behind shoals (packstones), whereas the cross-bedded grainstones of sheet B indicate a continuously current-swept environment. Deposition on a slight structural and topographic high at the platform edge would explain both the predominance of high-energy conditions and the relative thinness of the sequence in sheet B. Conglomeratic facies of the Yassıviran limestone were deposited in large channels of uncertain origin. The channels may have been cut either by tidal currents draining the platform or by headward erosion of slope canyons.

Fig. 5. Margin of the Anamas–Akseki platform. a: View of Akpınar Tepe (see Fig. 4) from south. Hill is capped by Akpınar Tepe reef limestone (Triassic) thrust over poorly exposed melange/megabreccia. b: Akpınar Tepe limestone; algal binding surrounds recrystallized spongiomorph hydrozoa. Thin section; width of field 2 cm approx. c: Reef limestone from block in Sofular Formation shales (Triassic). Coral and mollusk skeletons bound by dark micrite, rich in organic matter. Thin section; width of field 2 cm approx. d: Typical Yassıviran limestone of sheet A. Peloid packstone with orbitoline (centre), echinoderm fragment (bright grain at top), and quartz sand (upper centre). Thin section; field 3.5 mm high. e: Yassıviran limestone. Grainstone showing early isopachous palisade cement with meniscus form. Remaining interparticle space is filled by blocky cloudy cement. Clear cement fills void left by solution of skeletal fragment (bottom). Thin section; field 1.4 mm high. f: Yassıviran limestone. Oncolitic limestone conglomerate. The whole upper left part of the photograph is an intraclast of oolitic grainstone, coated by a layer of weakly laminated micrite to form a large oncolite. The grainstone was only weakly cemented when coated, as shown by the very thin fringe of clear cement beneath the micrite (arrow). Two smaller oncolites, nucleated on now-replaced skeletal fragments, are cut by vein at lower right. They are partially embedded in the large oncolite. The matrix of the conglomerate is oolitic packstone and grainstone. Line cutting off bottom right corner may be a later microfault. Thin section; field 3.2 cm wide.

Upper Jurassic to Cretaceous

The Yassıviran limestone is abruptly overlain (Figure 4, columns 1, 4) by upper Jurassic (to lower Cretaceous?) black radiolarian cherts (Zindan and Yılanlı Formations). The cherts show "ribbon" interbeds of vitreous chert and siliceous shale, and contain abundant Radiolaria. Black cherts pass upwards in both sequences into variegated green and red cherts, and cherty calcilulites interbedded with graded beds of redeposited calcirudite and calcarenite. In sheet A these carbonates (Gavurçalı Tepe Formation) are coarse and very thickly bedded; they contain a variety of reefal debris as well as assorted platform-derived material. The carbonates of sheet B are thinner bedded and finer grained, forming a much smaller total percentage of the sequence than in the corresponding part of sheet A. The sheet B cherts pass up into pink coccolith-bearing pelagic limestones (Kocakent Tepe Fm) dated as upper Cretaceous by the presence of *Globotruncana* sp. Occasional beds of calcarenite continue to occur; these are composed mainly of rudist and echinoderm fragments. An equivalent upwards passage from chert to pink pelagic limestone is seen within the Gavurçalı Tepe limestone of sheet A, but massive graded channelized calcirudites and calcarenites continue to dominate in this sequence.

The upper parts of these platform edge sequences were clearly deposited in deeper water than the underlying platform and reef carbonates. The abundance of Radiolaria and scarcity of carbonate material in the cherts suggests that they were deposited below the local calcite compensation depth (CCD), though clearly still within reach of carbonate material introduced by turbidity currents. The CCD need not have been particularly deep; WINTERER & JENKYNS (1982) suggest comparison of Tethyan radiolarites with siliceous sediments of the present day Gulf of California, rather than with siliceous oozes deposited below the CCD in the deep ocean basins. Nevertheless, the rapidity of the late Jurassic transition from limestone to chert is remarkable. Only a few meters of turbiditic calcarenite mark the transition zone in sheet B, while the change from packstones to radiolarite in sheet A seems abrupt, though poorly exposed. Possibly an interval of slow deposition coincided with the rapid subsidence of the platform edge zone at this time.

The subsequent change from chert to pelagic limestone in the mid Cretaceous is more easily explained. GARRISON & FISCHER (1969) and BOSELLINI & WINTERER (1975) have suggested a rapid Cretaceous depression of the Tethyan CCD resulting from the rise of calcareous nannoplankton as major sediment contributors. Rapid depression of the CCD would produce an upward change from radiolarite to pelagic limestone over a range of depths.

The highest stratigraphic levels (upper Cretaceous–?Paleocene) in the platform edge zone show an incoming of chalky marls and ophiolite-derived sand in some areas. However sheet A shows only a return to radiolarian chert deposition presumably reflecting renewed subsidence, but no direct evidence of the late Cretaceous thrust event.

Geometry and evolution of the platform edge

Figure 6 represents a model for these facies relationships at the present southwest edge of the Anamas–Akseki platform.

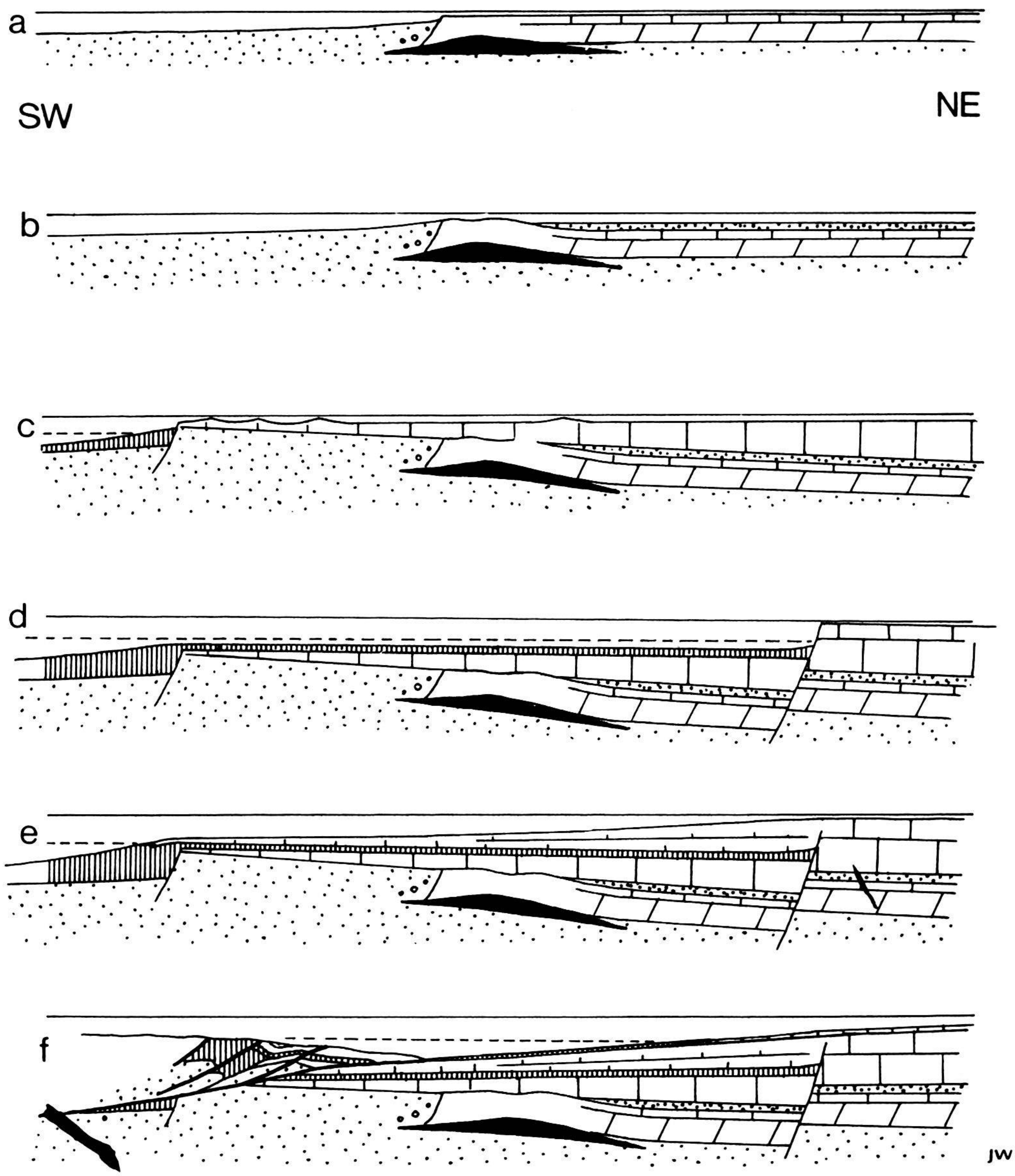


Fig. 6. Evolution of the Anamas–Akseki platform margin. Not to scale. a: *late Triassic*. Establishment of reefal platform margin (Akpınar Tepe limestone) over lava (black). Dolomite and algal laminites form in platform interior. Reef blocks roll into clastic sediments (Sofular Formation) in deeper water. b: *early Jurassic*. Temporary swamping of platform by clastic sediments (Çayır Formation). c: *early to middle Jurassic*. Yassıviran limestone deposited in environments ranging from low-energy subtidal shelf to high energy oolite shoals. Radiolarian cherts in basin to southwest. d: *late Jurassic to early Cretaceous*. Rapid subsidence of shelf edge zone below CCD (dashed). Deposition of radiolarite in former shelf edge zone. e: *late Cretaceous*. CCD falls leading to pelagic limestone deposition in former shelf edge zone. Thick redeposited calcarenites derived from shelf to northeast. f: *latest Cretaceous*. Deformation and emplacement of Antalya complex thrust sheets. Subsidence of margin caused by weight of allochthon.

The late Triassic platform had a steep, reef-dominated margin, though localized escape of debris from the interior must have occurred to produce calcareous turbidites on contemporary basin slopes (WALDRON 1981). The platform was temporarily swamped by terrigenous detritus (Çayır Formation) in the earliest Jurassic. Platform conditions returned over a wider area (Yassıviran limestone) but the reef rim was not re-established, although occasional coral fragments in the Yassıviran limestone may be derived from localized patch reefs. Instead, the platform edge was formed by a structural high covered by a thin sequence of oolite shoals.

The sudden incoming of radiolarites throughout the marginal zone in the latest Jurassic must indicate a relatively sudden subsidence of the shelf edge to below what was probably a fairly shallow carbonate compensation depth (CCD). Later in the Cretaceous the CCD probably became deeper, leading to deposition of pink pelagic limestones in the former shelf-edge zone. The margin of the Cretaceous platform lay further to the northeast, and is not preserved. Its nature can only be inferred from redeposited material in the slope sediments, which suggests a generally open platform margin with local sponge and rudist bioherms.

Renewed subsidence at the end of the Cretaceous immediately preceded the northeastward emplacement of thrust sheets onto the edge of the former platform area, but in the interior of the platform, carbonate sedimentation survived into the early Tertiary era.

4. Davras platform

A group of isolated smaller carbonate massifs (Davras Dağ, Eğridir, Çayköy, and Barla; Fig. 7) occupies the central region of the Isparta angle. The carbonates of all four massifs are overlain tectonically by thrust sheets of basinal sediments, ophiolite fragments, and mélanges. These massifs were accordingly mapped as tectonic windows by BRUNN et al. (1971). However, the carbonates at Barla (GUTNIC et al. 1979) and at Çayköy (WALDRON 1983) appear also to be thrust *over* other basinal units, and thus represent an allochthonous sheet intercalated *between* slices of basinal origin. They are therefore interpreted here as parts of a second carbonate platform, named after the Davras Dağ massif.

The most complete sequence is exposed on the slopes of Davras Dağ itself, where GUTNIC et al. (1979) map ?Triassic–Jurassic dolomites overlain by Jurassic to Cretaceous neritic limestones. More accessible sections are exposed in the Çayköy massif (Fig. 7). The lowermost part of the sequence there is dominated by lower to middle Jurassic subtidal peloid-foram packstones and foram wackestones with large in situ thick-shelled bivalves. Subordinate fenestral packstones (Fig. 8a) indicate temporary exposure, probably in the intertidal zone. Beds of peloid grainstone become more common up-section, indicating increasingly high-energy conditions. The upper part of the unit is dominated by well bedded packstones, in which echinoderm and rudist debris becomes increasingly abundant at the expense of peloidal and intraclastic material. Some beds are conglomeratic, with rudist, sponge, and rare coral fragments. Large bodies of apparently homogeneous lime mud in this part of the sequence are seen in thin section to consist almost entirely of large sponge skeletons, which probably acted as important sediment traps. The highest 5 to 40 m of the limestones consist of bedded,

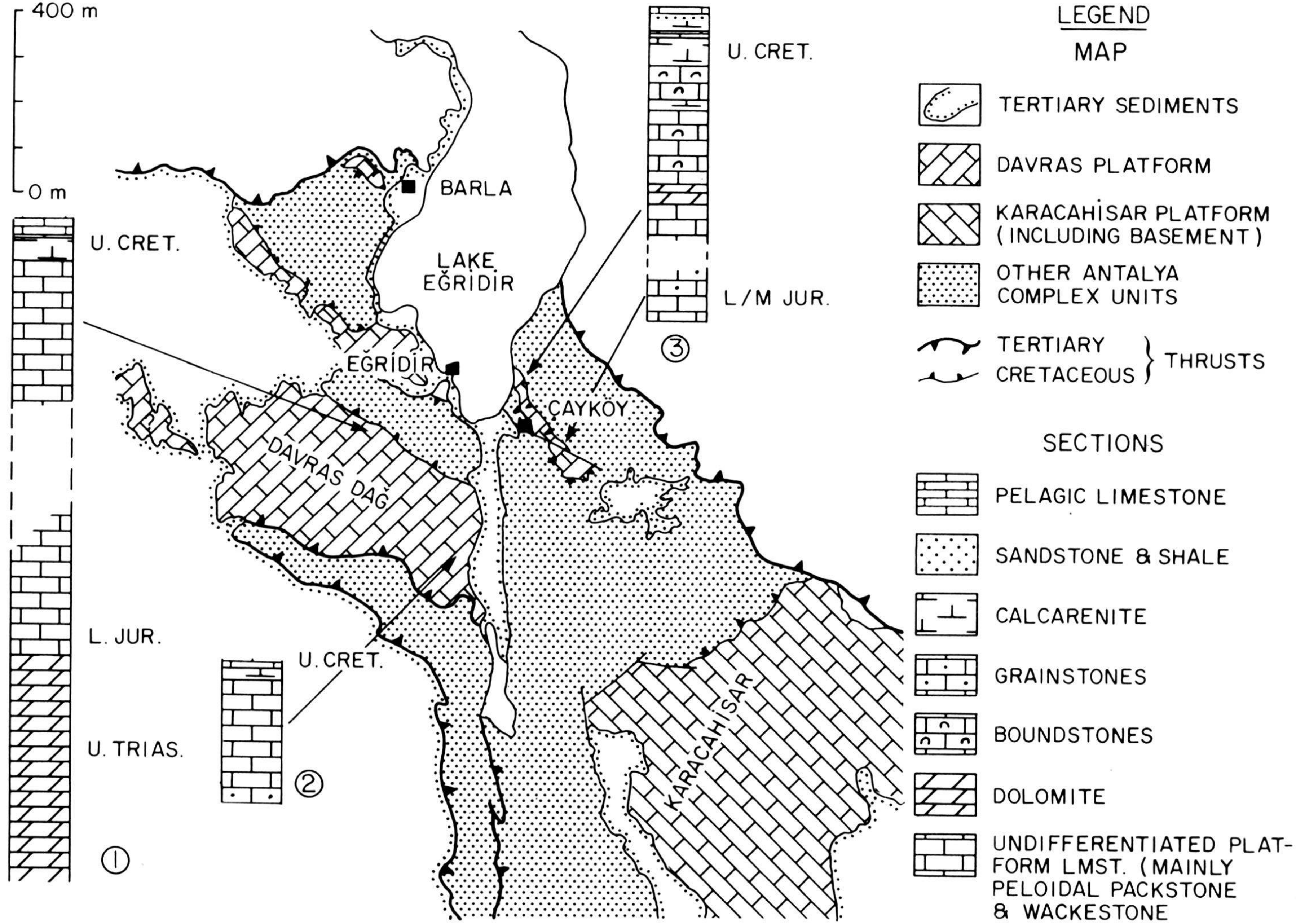


Fig. 7. Davras platform; map and stratigraphic sections. Section 1 is constructed from map and descriptions of Gutnic et al. (1979). Section 2 after Akbulut (1977). Section 3 measured by the author. Map compiled from Gutnic et al. (1979), Dumont (1976) and the author's field maps. Location of Lake Eğridir is shown in Figure 2.

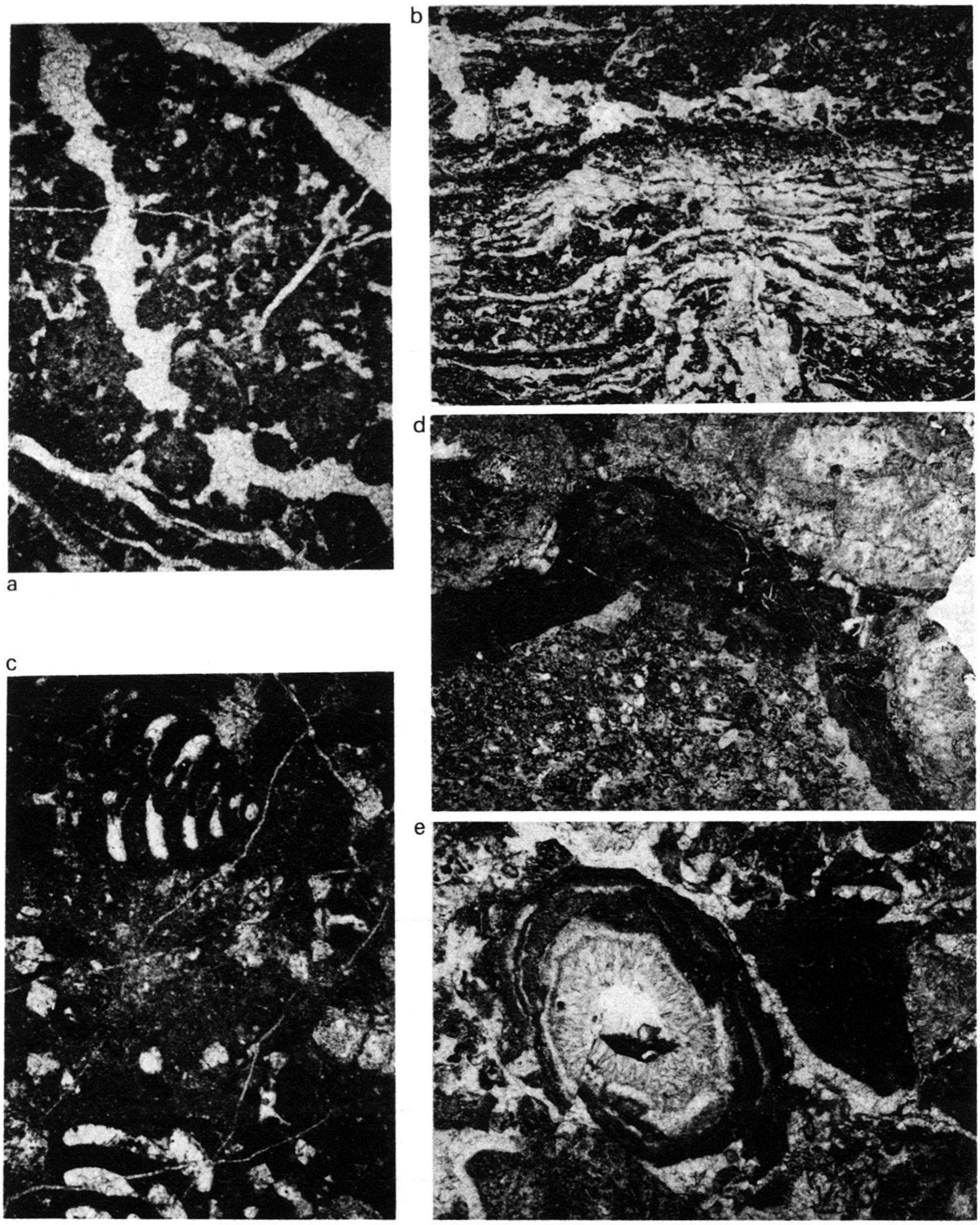


Fig. 8. Davras and Dulup platforms. a: Packstone of Davras platform with cement-filled sheet-cracks of irregular outline, and later veins. Thin section; field 3.5 mm high. b: Kovada dolomite of Dulup platform; algal laminated dolomitic limestone with (?) stromatolitic mound. Acetate peel; field 2 cm wide. c: Dulup limestone; packstone–wackestone with Foraminifera (*Valvulina* sp.). Thin section. Field 3.5 mm high. d: Dulup limestone; isolated platform slice; boundstone. Heavily recrystallized frame-building sponges or spongiomorph hydrozoa (top left, top right, bottom right) are coated by micritic binding. Lower part of field is complex reef sediment including encrusting ?Foraminifera. Geopetal at top left is filled by isopachous cloudy cement fringe followed by clear blocky spar. Thin section. Field 3 cm wide. e: Dulup limestone; isolated platform slice; conglomeratic limestone. Oval structure left of centre is algal coating which must originally have surrounded a large organic skeleton. Skeleton was dissolved leaving void now partially filled with radiaxial fibrous mosaic (Bathurst 1959). The remaining central cavity was filled by geopetal internal sediment, followed by cloudy, then clear cement.

calcarenites interbedded with white to grey micritic limestones containing upper Cretaceous planktonic Foraminifera. These are interbedded at the top of the sequence with mudstones and calcareous sandstones containing radiolarite and ophiolite fragments. Dip discordances suggest a local unconformity between these pelagic and redeposited sediments and the underlying more uniform limestones. The platform is cut by a number of minor N–S and NE–SW faults which do not affect the overlying thrust sheet. These faults possibly predate the latest pelagic and redeposited layer of limestone, and would account for the apparent unconformable relationship.

Little is known of the distribution of facies within the Davras platform, and its original extent cannot be accurately determined; Figure 3 shows only the minimum size compatible with the present distribution of outcrops.

5. Dulup platform

Platform carbonates form the structurally highest tectonic unit in the centre of the Isparta angle, which includes the peaks of Kaymaz Dağ and Dulup Dağı (Fig. 9), and a structurally complex terrain to the south (Fig. 2) described by AKBULUT (1977). These units are believed to represent an originally continuous thrust sheet or complex of sheets, although continuity cannot be proved in the case of the Kaymaz Dağ and other isolated klippen. The original dimensions of the Dulup platform are unknown; the boundary shown in Figure 3 is sufficient to encompass the various klippen but the platform may originally have been much larger. Figure 9 shows a compilation of stratigraphic sequences from the Dulup platform and related units.

Carbonates of Dulup Dağı

The oldest rocks in the Dulup platform sequence are dark grey recrystallized limestones of Permian age (DUMONT & KEREY 1975, WALDRON 1981), immediately above the base of the sheet. These are overlain with probable unconformity by dolomites and dolomitic limestones assigned to the Kovada Dolomite by DUMONT & KEREY (1975) and presumed to be of Triassic or lower Jurassic age. Primary fabrics are preserved only in the less dolomitic parts of this formation. The most abundant primary microfacies is algal laminated boundstone (Fig. 8b) similar to the loferite of FISCHER (1964). Small bulbous stromatolites and desiccation cracks indicate an intertidal to supratidal environment of deposition for much of the dolomite. Rarer unlaminated limestone containing micritized bioclastic fragments probably represent locally higher energy conditions associated with storms or tidal channels. Bioturbated lime mudstones and ostracod-bearing wackestones without desiccation features were probably deposited in ponds of abnormal salinity within the intertidal to supratidal zone. Large organic remains are very rare in the Kovada dolomite. However one sample from the north edge of Dulup Dağı contains heavily recrystallized sponges and possible corals, encrusted and bound by laminated algal micrite indicating at least localized development of fully marine, reefal conditions.

The base of the overlying Dulup limestone is marked by pinkish grey peloidal packstones, contrasting with the underlying white dolomites. The limestone includes middle to upper Jurassic and middle Cretaceous fossils in the type area (DUMONT &

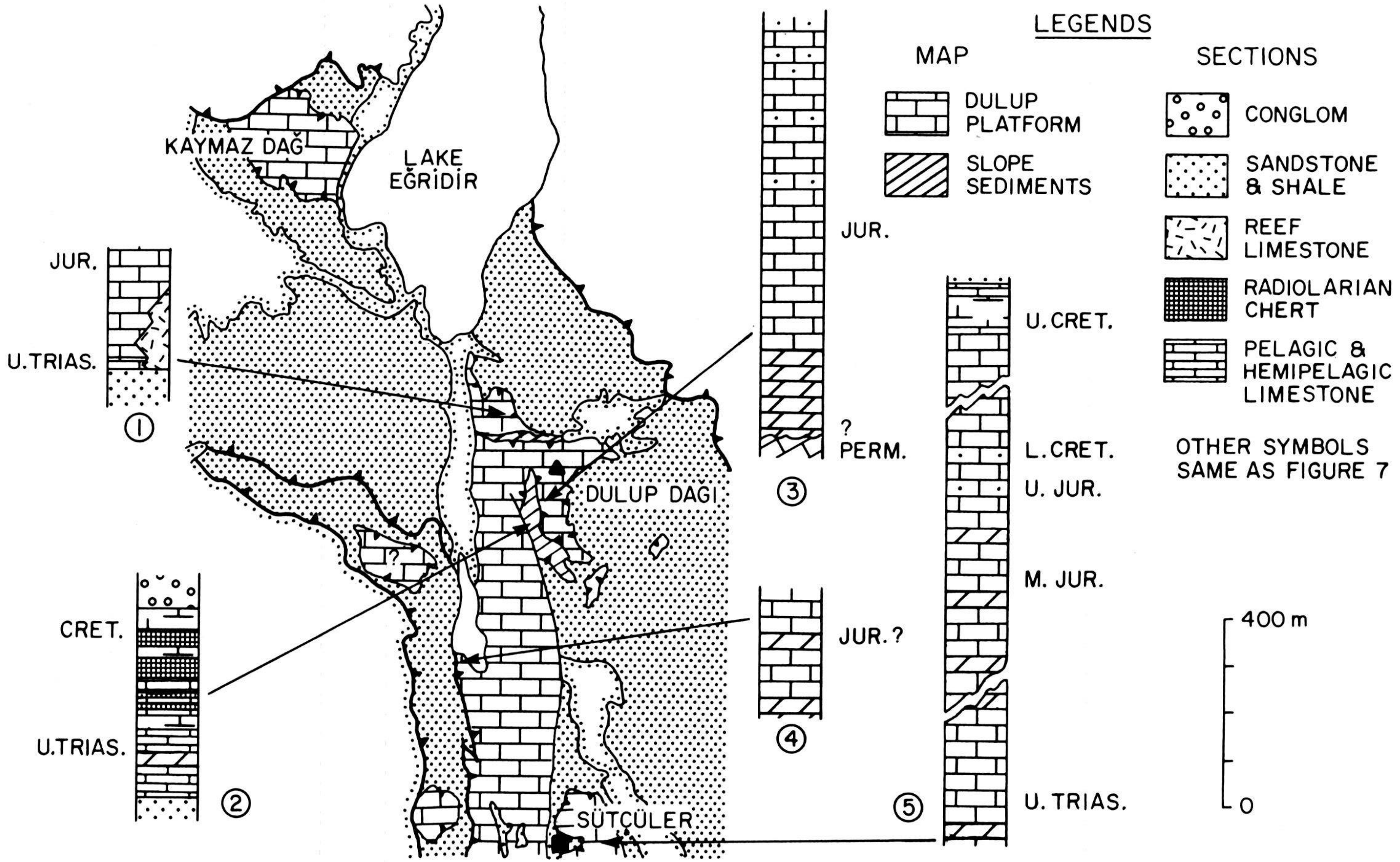


Fig. 9. Dulup platform: map and stratigraphic sections. Column 1 represents isolated platform slice to north of Dulup Dağı. Column 2 is a carbonate slope sequence now preserved as a thrust sheet beneath the Dulup sheet. Column 3 represents sequence on Dulup Dağı. Columns 4 and 5 are compiled from AKBULUT (1977). Column 5 is a composite section; amount of overlap at breaks in section may be less than shown. "Lake Eğridir" may be located with reference to Figure 2.

KEREY 1975). Most of the Dulup limestone consists of well bedded peloid-foram-bioclastic packstones (Fig. 8c) which represent a predominantly subtidal marine shelf. Local occurrences of irregular spar-filled cavities and sheet cracks indicate intertidal conditions. Ostracod-bearing lime mudstones similar to those of the Kovada dolomite also occur locally. Occasional higher energy subtidal conditions are indicated by peloidal grainstones. In contrast with the Kovada dolomite, fully marine subtidal carbonates are much more abundant than the restricted and intertidal facies.

Isolated platform slices north of Dulup Dağı

Isolated tectonic slices of Dulup limestone occur immediately north of Dulup Dağı (Fig. 9) and separated from it by slices characterized by basin-slope sediments. The isolated platform slices contain a much wider range of facies than the main massif. At the base, thinly bedded micritic limestones containing Radiolaria and thin-shelled bivalves overlie sandstones of probably Triassic age. The thinly bedded limestones, which probably represent hemipelagic "peri-platform oozes" pass up into sponge-hydrozoan boundstones (Fig. 8d) and coarse conglomerates containing large sponges, hydrozoa, corals, intraclasts and lithoclasts of peloidal limestone, small oncolites, dasycladacean Algae, peloids, and grapestone. Both conglomerates and boundstones show complex histories of cementation and sediment fill (Fig. 8d, e) and are interpreted as reef limestones. The tectonic position of these massifs suggest at least partial separation from the main Dulup platform, as suggested in Figure 3.

Correlation with adjacent areas

West of Lake Eğridir, the Kaymaz Dağ klippe (Fig. 9) is reported by GUTNIC et al. (1979) to display a sequence of lower to middle Triassic sandstones containing clasts of Permian limestone, overlain by thick poorly stratified Triassic dolomites and limestones including reefal facies.

South of Dulup Dağı, AKBULUT (1977) traced platform carbonates (assigned by him to the "Sütçüler Unit") for 40–50 km. The more northerly sections measured by AKBULUT (Fig. 9) display a sequence of dolomites overlain by limestones similar to those of Dulup Dağı. Further south, however, the basal dolomite disappears. Its place is taken by upper Triassic to lower Jurassic platform limestones overlying upper Triassic hemipelagic limestones containing Radiolaria and thin-shelled bivalves. AKBULUT also describes the upper Cretaceous part of the platform sequence, which has been removed by erosion in the type area. This includes calcarenites containing orbitolines and debris of rudist bivalves, resting with local unconformity on the Jurassic limestones. The sequence passes up into pelagic *Globotruncana* limestones. The onset of deformation is recorded in these limestones by the appearance of radiolarian chert fragments derived from uplifted basinal areas.

Triassic "Ammonitico Rosso" facies are described by AKBULUT (1977) and GUTNIC et al. (1979) in several isolated tectonic slices. These pink, condensed, hemipelagic limestones apparently pass up into Jurassic to Cretaceous platform facies. The original position of these fragments is poorly constrained; it is not known whether these too represent parts of the Dulup platform.

Tectonically beneath the main Dulup Dağı massif are slices of basin-slope sediments believed to represent the margin of the Dulup platform (Fig. 9). These include periplatform micrites, peloidal grainstones, redeposited limestone conglomerates, and, in the upper part of the sequence, rudist-echinoderm bioclastic calcarenites.

Evolution of the Dulup platform

Figure 10 illustrates schematically the evolution of the Dulup platform. The date of establishment of the platform is poorly controlled, but probably coincides with the late Triassic appearance of hemipelagic limestones in adjacent slope-basin sequences. The platform was probably founded on an uplifted horst of Permian limestone in the type area, and was initially surrounded by a broad apron of periplatform ooze, which was progressively colonized by reef and platform carbonates during the late Triassic and early Jurassic. The platform was dominated by algal mat and restricted facies (Kovada dolomite) until early or middle Jurassic time. Reefs may have rimmed the platform, maintaining low energy conditions and preventing the escape of sand-sized carbonate detritus into the basin-slope environment. In the absence of evaporites dolomitization of the carbonates can most reasonably be attributed to mixing of marine pore waters with meteoric water which soaked into temporarily exposed parts of the platform (Badiozamani 1973).

The change in the early or mid-Jurassic to predominantly open platform conditions (Dulup limestone) is marked by a roughly contemporary change in adjacent basin-slopes from hemipelagic limestones to coarse calcarenites (Fig. 9). The complete absence of frame-building organisms both from the Dulup limestone and its redeposited basin-slope equivalents indicates that the platform was no longer rimmed by a reef

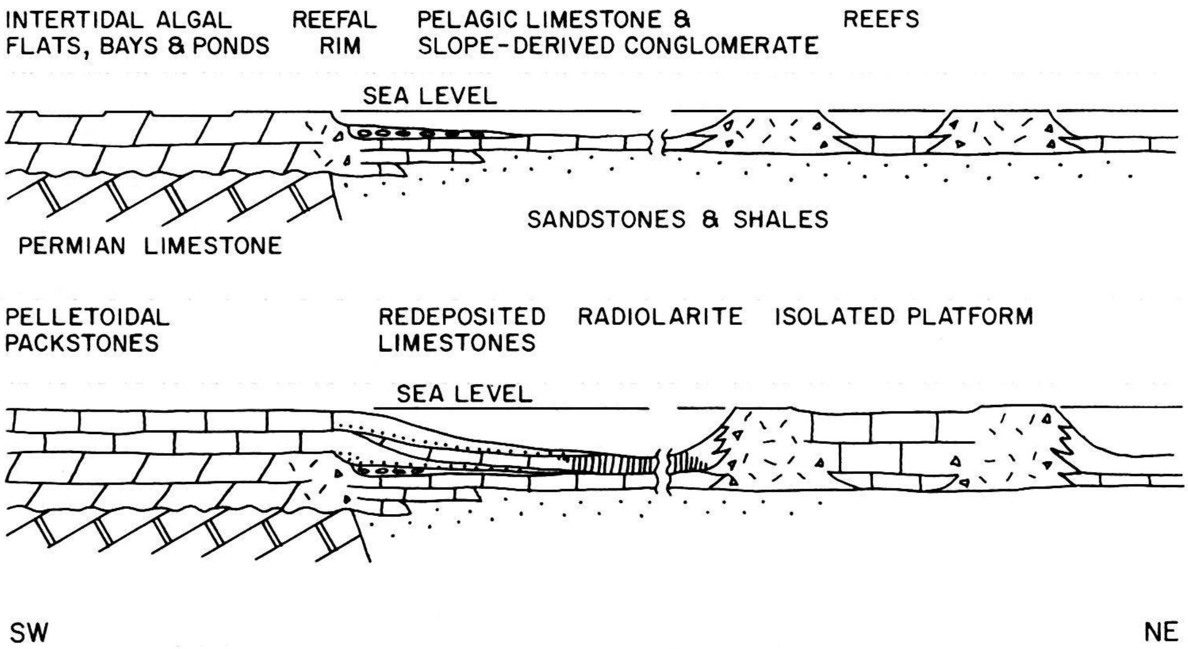


Fig. 10. Evolution of the Dulup platform (not to scale). Top: ?upper Triassic–lower Jurassic. Deposition of Kovada dolomite in main platform. Establishment of reefs to north, above sandstone and shale, and surrounded by hemipelagic limestone. Bottom: lower Jurassic–lower Cretaceous. Dulup limestone deposited on open platform. Establishment of new restricted platform above reefs to north.

barrier, although reefs apparently persisted in the isolated massifs to the north of Dulup Dağı.

Parts of the platform may have been emergent in the lower Cretaceous. Where preserved, the Cretaceous sequence shows a further transition from peloidal packstones to grainstones and rudist-echinoderm calcarenites. The Dulup platform in the late Cretaceous was probably dominated by poorly bound rudist mounds and crinoidal "meadows". Platform sedimentation was terminated by rapid subsidence at the end of the Cretaceous, at the time of the onset of deformation.

The history of the Dulup platform broadly resembles that deduced for the Davras platform. Both platforms show evolution from generally restricted intertidal or supratidal dolomitic facies in the Triassic to mainly open marine conditions by the late Cretaceous.

6. Karacahisar platform

The Karacahisar carbonate massif lies adjacent to the Anamas platform on the east limb of the Isparta angle (Fig. 7). The carbonates of this area were thoroughly investigated by DUMONT (1976), who described a central core of Paleozoic and Precambrian basement rocks upon which was founded the thick (1 km) middle Triassic reef complex of the Dipoyraz Dağ, today uplifted to form one of the highest peaks in the region. The reef complex was inundated with clastic sediments (Kasımlar shales) in the late Triassic, but the overlying Menteşe dolomite records the establishment of an extensive and relatively uniform carbonate platform in Norian time. Platform conditions prevailed throughout the Jurassic and much of Cretaceous time, with deposition of a 1 km sequence predominantly of packstones deposited on a subtidal shelf. The Karacahisar platform was tilted and uplifted in the late Cretaceous. Maastrichtian pelagic limestones deposited unconformably on the older limestones are overlain by a thin layer of ophiolite-derived and radiolarite-derived clastic sediments, and then by thrust sheets of basinal sediments (DUMONT 1976).

DUMONT regarded the Karacahisar unit as part of a single "Tauride platform", and therefore as continuous with the Anamas–Akseki platform. Nevertheless, a small slice of redeposited and cherty limestone (Série de Camova) is described by DUMONT tectonically between the Karacahisar and Anamas–Akseki units. This raises the possibility that the two platforms were separated by a basinal area, which would neatly explain the absence of early Jurassic sandy facies (Çayır Formation) from Karacahisar, the stratigraphy of which is otherwise comparable to the Anamas–Akseki platform.

The history of the Karacahisar platform is more closely similar to that of the Davras platform, and it is possible that the two massifs are continuous beneath the thrust sheets of basinal sediments that lie to the northwest of Karacahisar. This possibility is indicated by question marks in Figure 3.

7. Comparison with adjoining areas

The mosaic of small carbonate units which occupies the centre of the Isparta angle separates two much larger platform areas. One of these, the Anamas–Akseki platform, has been traced eastwards into central Anatolia (ÖZGÜL 1976). The other is the Bey

Dağları platform, which extends from the west limb of the Isparta angle to the Aegean Sea, and is inferred by many authors (e.g. ÖZGÜL & ARPAT 1973, BRUNN et al. 1976, ŞENGÖR & YILMAZ 1981) to be continuous with the Apulian platform in the external zones of the Hellenides and Italian Apennines (Figure 1).

The Bey Dağları platform has not been as deeply eroded as the Anamas–Akseki region. Its post-Triassic history is documented by POISSON (1977) but its Paleozoic basement is unknown. Southeast of the Bey Dağları, ROBERTSON & WOODCOCK (1981a, b, c, 1982) have reconstructed a region of basins, localized carbonate build-ups, and more extensive carbonate platforms, somewhat analogous to that here described. The region is distinguished, however, by a thick Triassic lava pile (JUTEAU 1975, ROBERTSON & WOODCOCK 1981c) in which WOODCOCK & ROBERTSON (1982) report a predominance of strike-slip tectonics during late Cretaceous to Tertiary deformation.

Southeast of the Isparta angle, a Mesozoic platform sequence occurs in the Alanya massif (Fig. 2), thrust northwards against the Anamas–Akseki platform, but separated from it by basinal sedimentary sheets. The Alanya massif differs from other platform units in being strongly deformed and metamorphosed. OKAY & ÖZGÜL (1982) record blueschist within the massif, implying that the Alanya platform was at least partially subducted before being thrust into its present position as a stack of nappes (ŞENGÖR & YILMAZ 1981, A.M.C. Şengör, personal communication, 1984).

8. Discussion: tectonic evolution of the platform mosaic

Figure 11 shows schematic lithofacies maps for platforms in the Isparta angle during the Mesozoic. The maps are subject to the same uncertainties as Figure 3 (see introduction) and therefore illustrate only the general character of the platforms and not their precise geometry. Diagrammatic cross sections for the Dulup and marginal Anamas–Akseki platforms are shown in Figures 6 and 10.

In early late Triassic (Carnian) time the distinction between future platform and basin areas was poorly developed. The establishment of most of the major platforms seems to have occurred in the succeeding Norian stage. The location of platforms was almost certainly tectonically controlled. The Dulup platform was founded on an uplifted block of Permian basement, while the Anamas–Akseki platform initially fringed on uplifted land area that remained exposed until mid-Jurassic time. Rapid deposition of mixed clastic and platform-derived sediment in interplatform areas probably indicates a high rate of subsidence of these areas. The alkali basalt and ankaramite lavas extruded at the platform edge are similar to lavas from areas of continental rifting such as the Kenya Rift (KING 1970, LIPPARD & TRUCKLE 1977) and Oslo Graben (SEGALSTAD 1977). Similar lavas are much more thickly developed in the southeast margin of the Bey Dağları platform (ROBERTSON & WOODCOCK 1981c), in a zone of known Triassic fault movement (DELAUNE-MAYÈRE et al. 1976).

All these observations indicate that the platform mosaic was established as a result of a Triassic episode of rifting and crustal extension. Broadly analogous facies and paleogeographical development is seen in the Triassic of many parts of the Alpine–Mediterranean system. Most notable are the carbonates of the Italian Dolomites (BOSELLINI & ROSSI 1974) and the Northern Calcareous Alps of Austria (ZANKL 1967). In both areas a complex geography of platforms separated by basinal areas was estab-

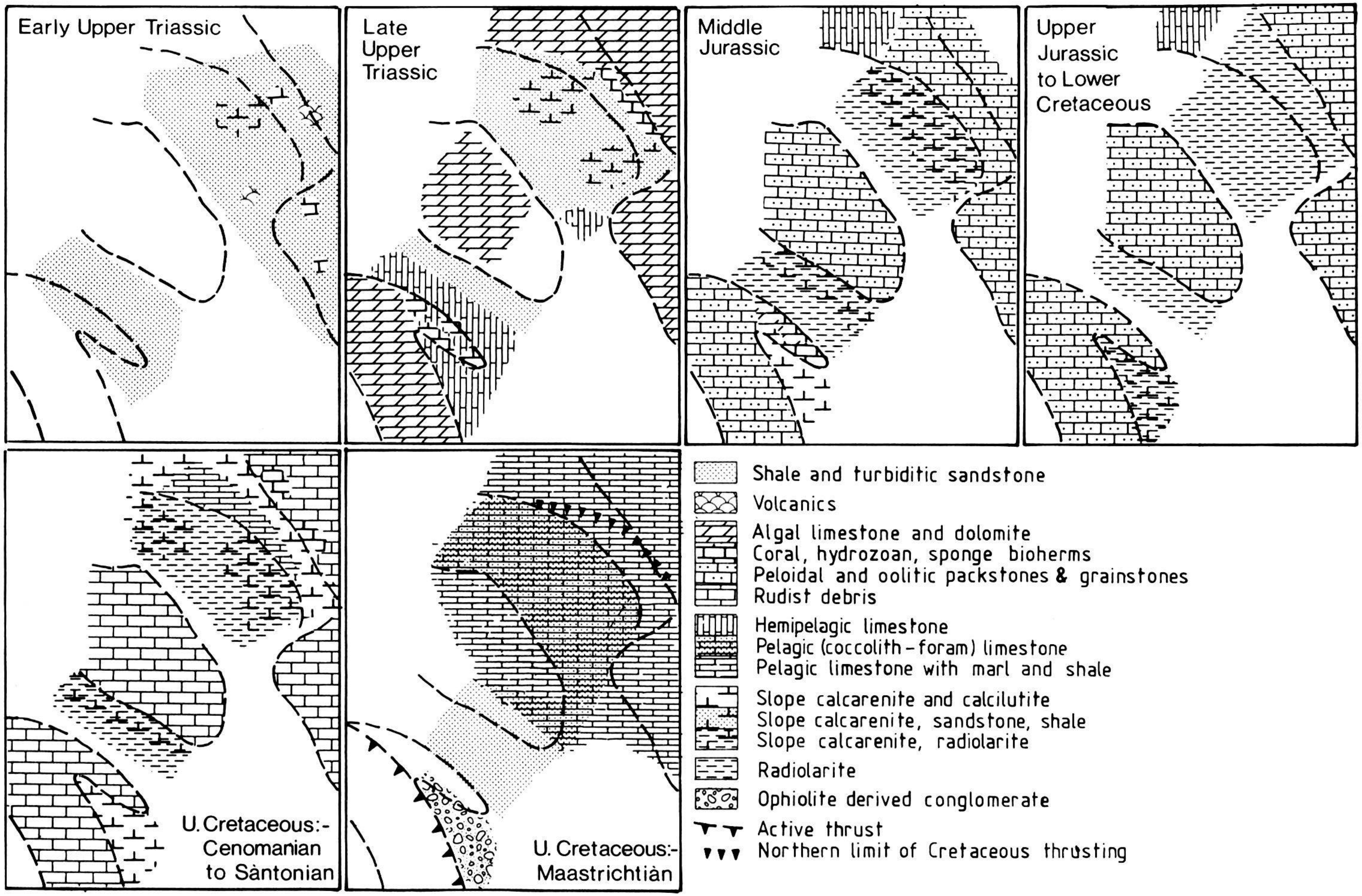


Fig. 11. Schematic lithofacies maps indicating the main facies present and general features of their distribution in one possible palinspastic reconstruction (see Fig. 3). Blank areas represent no data. Time intervals are broad owing to poor paleontological control in some sections.

lished in the late Triassic. Platform establishment is known to have been initiated by Triassic rifting in many such areas (e.g. Austria: LAUBSCHER & BERNOULLI 1977; Greece: SMITH et al. 1975; Oman: GLENNIE et al. 1976, GRAHAM 1980).

There is no direct evidence that any oceanic crust existed in the rift system at this stage, as all known ophiolites in the region are younger. ŞENGÖR & YILMAZ (1981), in their comprehensive review of Turkish tectonics, argue strongly for the existence of a southern branch of the Neotethys ocean to the south of the Anatolian platform from the late Triassic onwards. However, stratigraphic relationships along the margin of the Anamas–Akseki platform (Fig. 6) attest to continued differential vertical movements in Jurassic time, while Jurassic volcanic activity is recorded further northeast within this

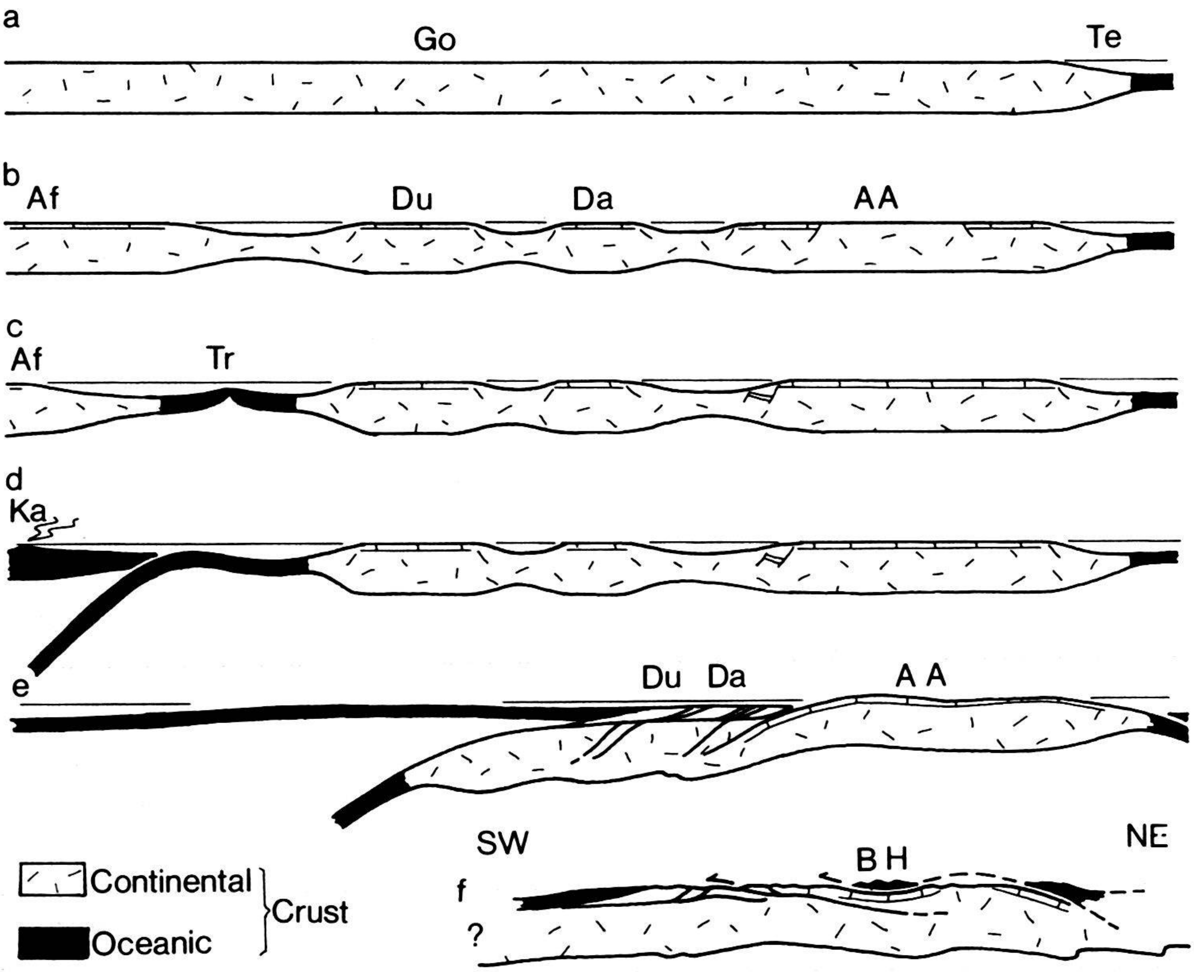


Fig. 12. Model for the evolution of the continental margin. Diagrams represent a roughly SW–NE section through Anamas–Akseki, Davras and Dulup platforms (Fig. 2). Not to scale. a: Permian passive margin of Gondwanaland (Go), with Tethys ocean (Te) to north. b: Triassic rifting initiates evolution of Dulup (Du), Davras (Da) and Anamas–Akseki (AA) platforms, separated from Africa (Af) by deeper water area. c: early to middle Cretaceous. Spreading of Troodos ocean (Tr) separates platform mosaic from Africa. d: late Cretaceous. Subduction of Troodos ocean; volcaniclastics (Ka) in Cyprus. e: latest Cretaceous. Attempted subduction of platform mosaic telescopes the sedimentary sequences. Alanya massif (strictly speaking not on this profile) partially subducted and undergoes blueschist metamorphism. f: Tertiary. Southward emplacement of nappes (BH) over Sultan Dağ massif. To the southwest, interaction of the telescoped platform mosaic with the Bey Dağları platform probably involved strike-slip or oblique thrust movements in the region marked "?", producing the present configuration of the Isparta angle.

platform (GUTNIC 1977, GUTNIC & JUTEAU 1973). The platforms described here are therefore assumed to have lain on the attenuated and rifted northern margin of Gondwanaland throughout much of the Jurassic (Fig. 12b). The pattern of banks and basins at this time must have resembled the modern Bahamas in scale and sedimentary environments. Preserved parts of the Anamas–Akseki and Bey Dağları platforms are comparable in area to the Great and Little Bahama Banks, whereas the Davras, Karacahisar and Dulup platforms were closer in dimensions to the smaller banks in the Bahamas area (Fig. 1).

Renewed vertical movements – principally a rapid subsidence of the Anamas platform margin and the Bey Dağları (GUTNIC et al. 1979) occurred around the end of the Jurassic period (Fig. 6). In southwestern Turkey, these events were probably associated with the start of seafloor spreading in the ocean from which the Antalya and Troodos ophiolites (Fig. 1) were later expelled. This oceanic area developed south of the Anamas–Akseki, Davras, Dulup, Karacahisar and Alanya platforms, separating them from the African or Arabian shelf (Figure 12c), and probably also from the Bey Dağları platform.

The Troodos ocean began to close in late Cretaceous time. This closing is recorded by calc-alkaline volcaniclastics in Cyprus (Kannaviou Formation; ROBERTSON 1977). The absence of such volcanics in Turkey indicates that the subduction zone probably dipped southwards (Figure 12d and ŞENGÖR & YILMAZ 1981). Eventually the subduction zone attempted to consume the Alanya platform, which underwent blueschist facies metamorphism. The more northerly platforms in the Isparta angle mosaic were not subducted to any great extent, but underwent décollement and were thrust northwards towards the Anamas–Akseki platform (Fig. 12e).

Each of the platform units shows local evidence of uplift and erosion followed by rapid subsidence immediately prior to the arrival of thrust sheets. This sequence of events probably resulted from bending of the relatively rigid lithosphere (Fig. 12d and e) ahead of the advancing allochthon (WATTS & TALWANI 1974; DUBOIS et al. 1974, 1975; JACOBI 1981; COHEN 1982; ŞENGÖR & YILMAZ 1981).

The Bey Dağları and interior parts of the Anamas–Akseki platform largely escaped effects of deformation in the latest Cretaceous. Thrust sheets arrived on the north edge of the Bey Dağları platform in the Paleocene (GUTNIC et al. 1979) but most of the deformation along its eastern margin appears to have been concentrated along north–south strike slip faults (WOODCOCK & ROBERTSON 1981, 1982). In the central Anamas–Akseki platform, carbonate sedimentation continued until the arrival in the Eocene of clastic sediments derived from the southward advancing Tertiary nappes (Fig. 2). The Bey Dağları platform survived until Miocene, when it too was swamped by nappe-derived flysch. Subsequent movement along the Aksu thrust (Fig. 2) transported the entire Anamas–Akseki platform, with the thrust sheets that had previously been emplaced onto it, over the northeast edge of the Bey Dağları, to produce the present-day configuration of the Isparta angle.

9. Conclusions

The Isparta angle probably represents a mosaic of carbonate platforms located between the Mesozoic Apulian and Anatolian "microcontinents" which may even have been separated by a small oceanic region during the Cretaceous period. The platforms originated in a Triassic rift system but did not become fully separated from Gondwanaland until the birth of the Troodos ocean in the late Jurassic or early Cretaceous. During the Mesozoic the smaller platforms expanded and evolved from reef-rimmed "atolls" with restricted lagoonal interiors, to open mainly subtidal plateaux. Minor uplift and then rapid subsidence preceded décollement and thrusting of the smaller, more southerly platforms in latest Cretaceous time; the large Anamas–Akseki and Bey Dağları platforms survived into the Tertiary.

The modern Bahama Banks provide a model for carbonate platform sedimentation in the Tethys which predicts that platforms will show complex paleogeographic configurations, in contrast to the somewhat linear facies belts shown in many palinspastic reconstructions. The complex tectonic configuration of the Isparta angle is in part inherited from such a complex pretectonic paleogeography, and provides a unique opportunity to study the three-dimensional evolution of carbonate platforms.

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