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Autor: Robertson, Alastair H.F. / Woodcock, Nigel H.

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Sedimentary history of the south-western segment of the Mesozoic-Tertiary Antalya continental margin, south-western Turkey

By ALASTAIR H. F. ROBERTSON[1]) and NIGEL H. WOODCOCK[2])

ABSTRACT

We summarize the facies and geological evolution associated with the formation and destruction of the margin of a small Mesozoic ocean basin on the northern border of Gondwanaland. After Permian bioclastic limestone deposition in epicontinental seas, continental extension was initiated in early Triassic time with appearance of micritic and oolitic limestones, dolomites and gypsum. After block-faulting, acidic tuffs mark the onset of volcanism (early Ladinian); radiolarites and Ammonitico-rosso facies record later subsidence (Ladinian). Early stages of crustal extension (Anisian to Carnian) generated a complex palaeogeography. Horsts capped by carbonate build-ups were separated by grabens floored by thick alkalic mafic extrusives with hemipelagic carbonate and radiolarite cover. During the block-faulting, pre-rift basement rocks were subaerially eroded and large volumes of turbiditic quartzose clastics accumulated around the margins of both the main platform (Bey Dağları Zone) and the horsts within the rift basin (Gödene and Kemer Zones). Carbonate build-ups were initiated on shallow platforms and rifted blocks (Norian to Rhaetic), then shed large volumes of carbonate clastics ranging from detached blocks to conglomerates and peri-platform ooze (*Halobia*-limestones).

It is uncertain whether ocean-floor genesis started in latest Triassic to early Jurassic time or was delayed until latest Jurassic to early Cretaceous. During Jurassic to mid-Cretaceous, subsidence coupled with neritic carbonate deposition formed a major carbonate platform (Bey Dağları Zone) and carbonate build-ups on surviving Triassic horsts. At this time, radiolarites accumulated in deep water below the carbonate compensation depth both around the margins of the carbonate build-ups and in basinal areas floored by late Triassic mafic extrusives. During late Cretaceous time, oceanic crust was created (Gödene and Tekirova Zones), associated with submergence and onset of pelagic carbonate deposition on carbonate build-ups and platform areas.

Deformation of the Antalya area began in latest Cretaceous (Maastrichtian) time, associated with the deposition of ophiolitic clastics and olistostrome mélange. The main carbonate margin (Kumluca Zone) was tectonically imbricated. Strong uplift of the older Triassic rift areas (Gödene and Kemer Zones) was then followed by pervasive strike-slip faulting and associated deposition of subaerial ophiolite-derived clastics. Renewed east-west shortening in early Miocene time juxtaposed the already deformed Antalya margin with the parent autochthon to the west (Bey Dağları Zone). Large volumes of ophiolite-derived clastics were shed first as submarine fans and then as late Miocene prograding alluvial fans. Subsequent deposition of extensive subaerial limestone screes around carbonate massifs in the allochthon is attributed to isostatic uplift.

RÉSUMÉ

Cette note résume l'évolution géologique associée à la formation et au déclin de la bordure d'un petit bassin océanique mésozoïque, sur la paléomarge du nord de Gondwana. La sédimentation des calcaires

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[1]) Grant Institute of Geology, West Mains Road, Edinburgh EH9 3JW, U.K.

[2]) Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, U.K.

bioclastiques dans les mers épicontinentales du Permien est suivie de l'extension continentale au Trias inférieur, engendrant le dépôt de calcaires micritiques et oolitiques, de dolomies et d'évaporites. La formation de horsts et de grabens est suivie de volcanisme (Ladinien inférieur). Les radiolarites et le faciès de type ‹Ammonitico-rosso› sont le résultat d'une subsidence pendant le Ladinien. Les horsts étaient couverts par des massifs de calcaire. Les grabens avaient un substratum de roches volcaniques alkalines avec une couverture de calcaires hémipélagiques et de radiolarites. Pendant l'activité tectonique les massifs insulaires l'érosion des roches continentales anciennes produisit des siliclastiques, principalement des turbidites, sur les bordures de la plate-forme principale (zone de Bey Dağları) et des horsts entre les bassins (les zones de Gödene et de Kemer). Des massifs calcaires se formaient sur les plateformes peu profondes et sur les horsts (Norien-Rhétien), puis ils produisirent des calcaires clastiques allant de larges blocs détachés, à un faciès conglomératique et à calcaires micritiques à *Halobia*.

La formation de croûte océanique date du Trias supérieur au Jurassique inférieur, ou du Jurassique supérieur au Crétacé inférieur. Pendant la période du Jurassique au Crétacé moyen une subsidence accompagnée de dépôts de calcaires néritiques une grande plate-forme carbonatée est formée (la zone de Bey Dağları) ainsi que des massifs de calcaire mineurs sur les horsts survivant du Trias. A cette époque des radiolarites furent déposées en grande profondeur autour des massifs insulaires et sur la croûte volcanique mafique du Trias. Pendant le Crétacé supérieur la croûte océanique fut formée (les zones de Gödene et de Tekirova), la submersion engendrant le dépôt de calcaires pélagiques sur les massifs et la plate-forme carbonatée.

Pendant le Crétacé supérieur la déformation de la région d'Antalya commence, produisant des sédiments clastiques ophiolitiques et un mélange de type olistostrome. La principale bordure carbonatée (la zone de Kumluca) est affectée par des failles renversées. Une surélévation des grabens du Trias (les zones de Gödene et de Kemer) est suivie d'une phase tectonique avec de nombreux accidents décrochants et la sédimentation de débris ophiolitiques continentaux. Pendant le Miocène la bordure déjà déformée d'Antalya est juxtaposé à l'autochtone à l'ouest (zone de Bey Dağları) par un autre raccourcissement. L'apport de débris ophiolitiques devient encore plus important d'abord en forme de cônes sousmarins plus tard formant des cônes alluviaux d'âge Miocène. Les éboulis carbonatés autour des massifs de calcaire sont le résultat d'un surélèvement ultérieur.

CONTENTS

1. Introduction

We have recently described various aspects of the structural and sedimentary history of the south-western segment of the Antalya Complex, south-western Turkey (Fig. 1, Woodcock & Robertson 1977, 1981, 1982; Robertson & Woodcock 1980a, 1981a, b, c; Robertson 1981; Hayward & Robertson 1982). When combined with other available data, mostly of Turkish and French geologists (e.g. Marcoux 1976; 1978; Kalafatçioğlu 1973; Juteau 1975; Delaune-Mayere et al. 1977; Şenel 1980), it is now clear that the Antalya Complex documents the evolution of the margin of a Mesozoic ocean basin located along the northern edge

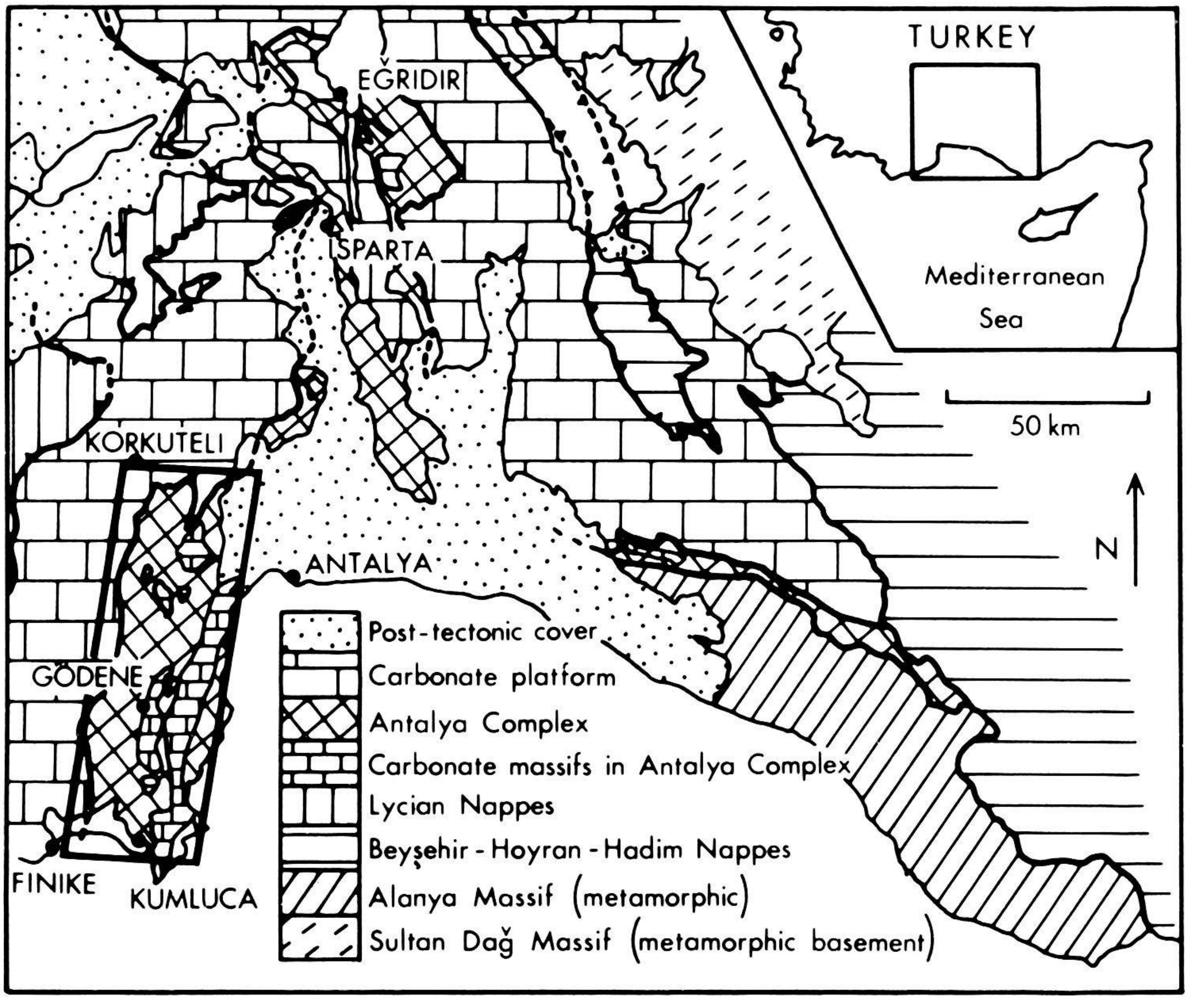


Fig. 1. Outline geological map of southern Turkey to show the Antalya Complex in relation to other tectonic units. South-western segment of the Antalya Complex is shown in box.

of Gondwanaland. To date, the continental margins of the Eastern Tethys have been studied much less than those of the Western Tethys which are now fairly well understood (e.g. BERNOULLI et al. 1979). The Antalya Complex lies in a critical area close to the junction between the Hellenides and the Taurides, areas of contrasting geological history (BRUNN 1974; MONOD 1976). Detailed sedimentological work can identify depositional environments related to continental margin development. Here it is shown that the sedimentary rocks of the Antalya Complex record phases of mid to late Triassic rifting, later Mesozoic passive margin development, and subsequent tectonic emplacement dominated by strike-slip tectonics.

1.1 *Tectonic zonation*

A key point is whether the various ophiolitic and related rocks formed in a single major oceanic basin of Atlantic type or as several smaller basins separated by micro-continental slivers (BRUNN 1974). Much published work on the Antalya area has assumed a unique origin in a major basin located in central or northern Turkey

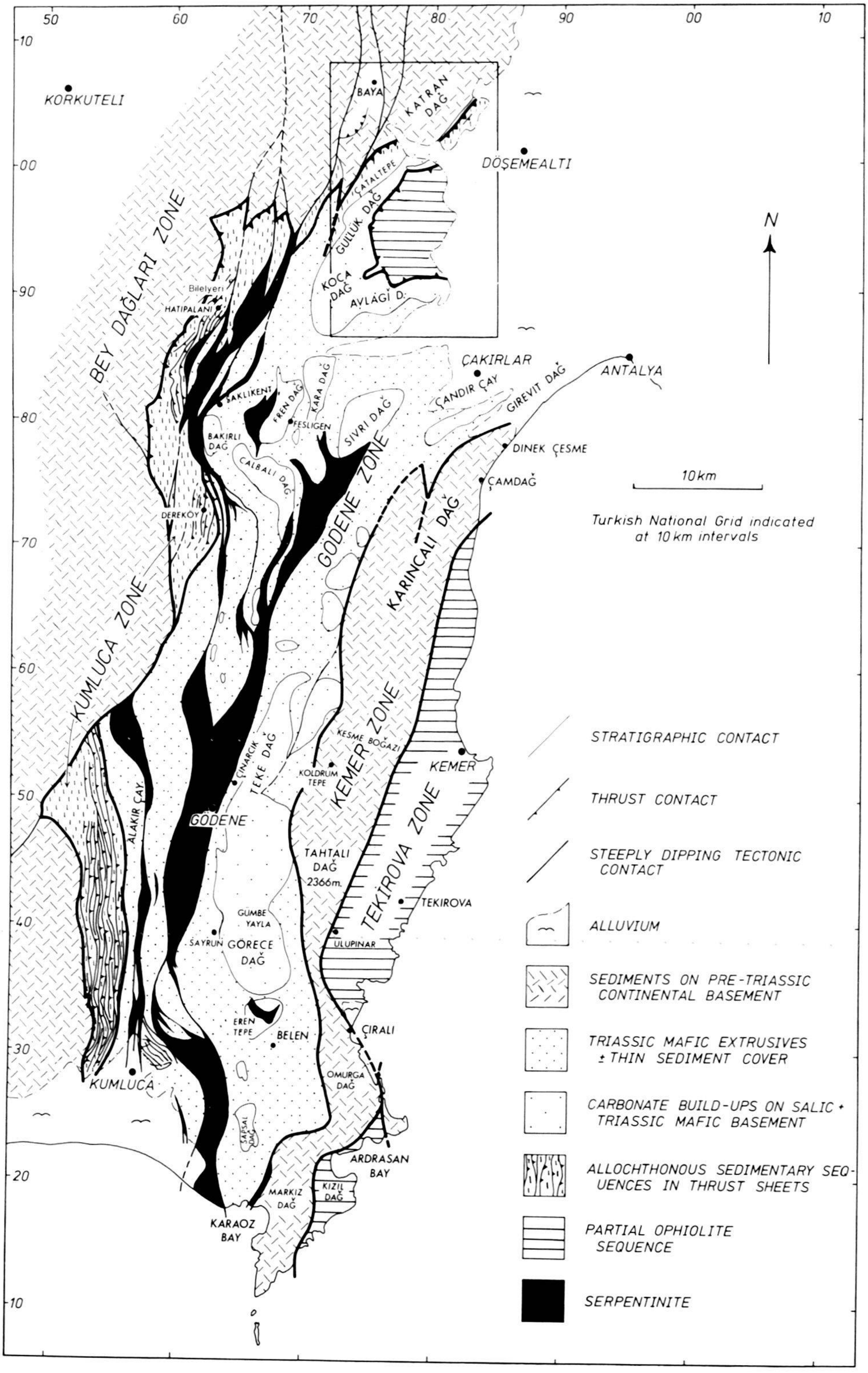
(RICOU et al. 1974; MONOD 1976; MARCOUX & RICOU 1979; RICOU & MARCOUX 1980). When considering the possibility of substantial allochthoneity, the scale of fieldwork must be kept in mind. The whole Antalya area, for example, could fit into a small part of an Atlantic continent-ocean transition. Nevertheless, our detailed field studies oppose the earlier interpretations of the Antalya rocks as a stack of three major nappes (e.g. BRUNN 1974; MONOD 1976; RICOU et al. 1974, 1975), the "Lower", "Middle" and "Upper Antalya Nappes". Key points in our argument (ROBERTSON & WOODCOCK 1981a, b, c; WOODCOCK & ROBERTSON 1981, 1982) are that a) sedimentological data show that the "Lower" and "Middle" Nappes are laterally equivalent facies variants, b) the "Upper" Nappe commonly rests with normal stratigraphical contact on the "Middle" Nappe, c) internal deformation is typically dominated by originally high-angle rather than low-angle structure, d) the "Upper" Nappe sequence is strikingly similar to that of the locally adjacent Bey Dağları platform, e) regional studies appear to preclude long distance transport of the "Nappes" from either the west (HAYWARD & ROBERTSON 1982), or from the north (WALDRON 1981). We have instead concluded from structural and sedimentological analysis that the Antalya Complex records the margins of a small Mesozoic ocean basin originally located to the south of Turkey in the present East Mediterranean area, distinct from oceanic basins further north (ROBERTSON & WOODCOCK 1980a). The two opposing interpretations are illustrated in Figure 4a.

We have already redefined the allochthonous Antalya rocks as the Antalya Complex and subdivided them into north-south striking lithotectonic zones. From west to east (Fig. 2) these zones are: a) Bey Dağları Zone; the autochthon, a thick pile of Mesozoic-Tertiary carbonates and later Tertiary ophiolite-derived clastics; b) Kumluca Zone; the Mesozoic passive margin of the carbonate platform autochthon, imbricately stacked at the end of Cretaceous time; c) Gödene Zone; thick late Triassic mafic extrusives with pre-Triassic continental rocks, overlain respectively mostly by deep water sediments, and shallow water carbonate build-ups; also serpentinites and other ophiolitic rocks including diabase, gabbro and ultramafic rocks; d) Kemer Zone; dominated by north-south striking masses of mostly shallow water limestones founded on pre-Triassic sedimentary basement; e) Tekirova Zone; the deeper levels of a late Cretaceous ophiolite suite, and clastic sedimentary rocks related to its tectonic emplacement.

1.2 *Stratigraphy*

Where we have worked in detail we have either modified the existing stratigraphy or defined our own nomenclature according to the principles of the International Stratigraphical Commission (HEDBERG 1976). The current scheme (Fig. 3) applies primarily to the Kumluca Zone, and the north-eastern part of the Gödene Zone. Palaeontological dates are drawn from the published work of DELAUNE-

Fig. 2. Geological map of the south-western segment of the Antalya Complex (simplified from 1:25,000 scale sheets) to show tectonic zones and important localities referred to in the text. Box shows the area in Figure 8a.


KORKUTELI
DÖŞEMEALTI
BAYA
KATRAN DAĞ
ÇATALTEPE
GÜLLÜK DAĞ
KOCA DAĞ
AVLAĞI D.
BEY DAĞLARI ZONE
Bilelyeri
HATIPALANI
SAKLIKENT
FREN DAĞ
KARA DAĞ
FESLIGEN
SIVRI DAĞ
BAKIRLI DAĞ
ÇALBALI DAĞ
DEREKÖY
ÇAKIRLAR
ÇANDIR ÇAY
GIREVIT DAĞ
ANTALYA
DINEK ÇESME
ÇAMDAĞ
GÖDENE ZONE
KARINCALI DAĞ
KUMLUCA ZONE
ÇINARCIK
TEKE DAĞ
KESME BOĞAZI
KOLDRUM TEPE
KEMER ZONE
KEMER
TEKIROVA ZONE
ALAKIR ÇAY
GÖDENE
TAHTALI DAĞ 2366m.
TEKIROVA
GÜMBE YAYLA
SAYRUN
GÖRECE DAĞ
ULUPINAR
EREN TEPE
BELEN
ÇIRALI
KUMLUCA
OMURGA DAĞ
SARISAL DAĞ
ARDRASAN BAY
MARKIZ DAĞ
KIZIL DAĞ
KARAOZ BAY
N
10km
Turkish National Grid indicated at 10km intervals
STRATIGRAPHIC CONTACT
THRUST CONTACT
STEEPLY DIPPING TECTONIC CONTACT
ALLUVIUM
SEDIMENTS ON PRE-TRIASSIC CONTINENTAL BASEMENT
TRIASSIC MAFIC EXTRUSIVES ± THIN SEDIMENT COVER
CARBONATE BUILD-UPS ON SALIC + TRIASSIC MAFIC BASEMENT
ALLOCHTHONOUS SEDIMENTARY SEQUENCES IN THRUST SHEETS
PARTIAL OPHIOLITE SEQUENCE
SERPENTINITE
50
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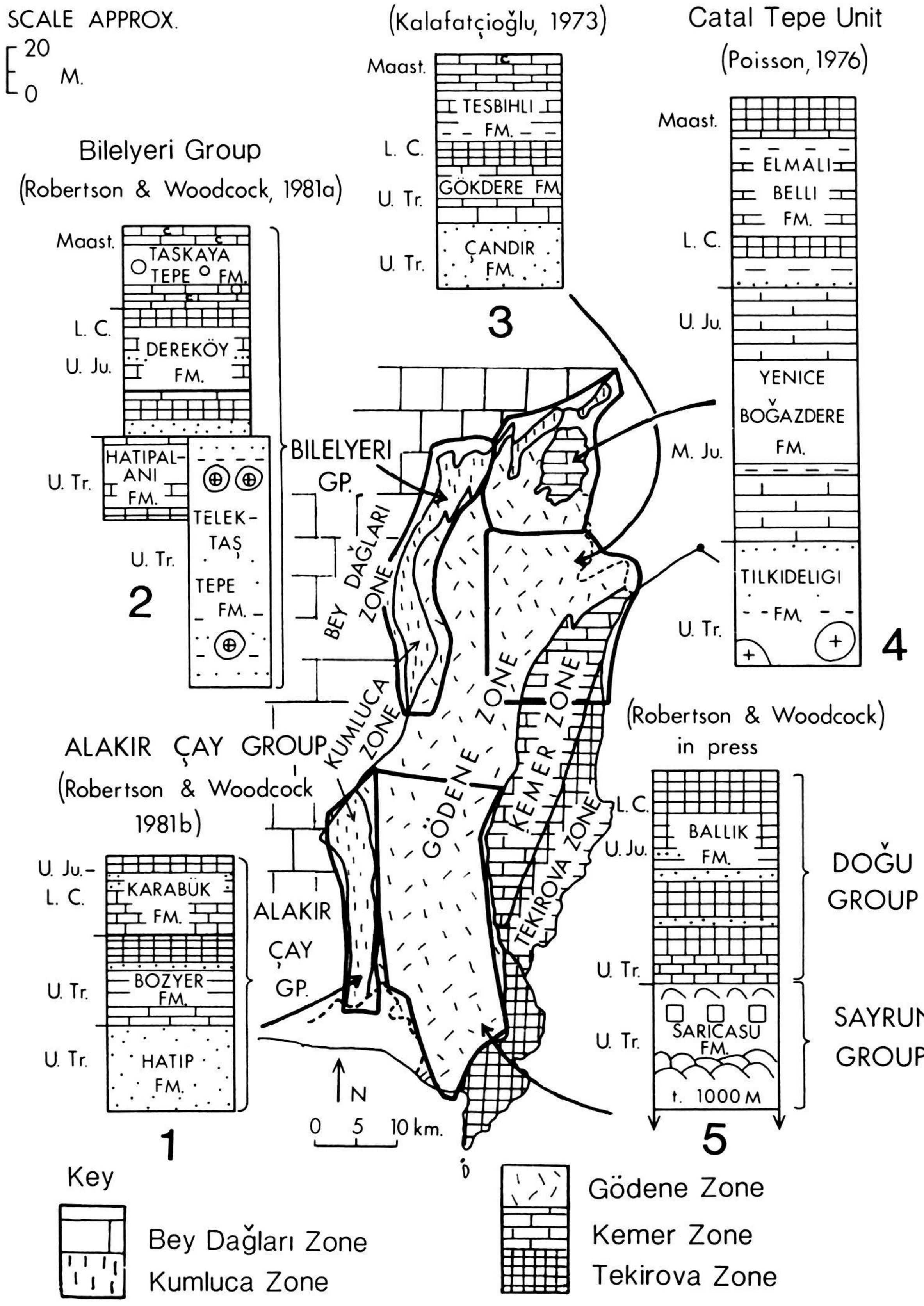


Fig. 3. Generalized sedimentary logs illustrating formally defined stratigraphical nomenclature of basinal facies of the south-western Antalya Complex. Platform and carbonate build-up sequence not formally defined here. Stratigraphy is formally defined within areas enclosed by heavy lines.

MAYERE et al. (1977) and KALAFATÇIOĞLU (1973), supplemented by new determinations, particularly by the Turkish Geological Survey (E. Çatal) and E.A. Pessagno (Radiolaria).

1.3 *Structure*

Palinspastic reconstruction of the Antalya Complex requires a knowledge of the structure within the tectonic zones and the relative displacements between them. The geological map (Fig. 2) and sections (Fig. 4b) summarize our structural interpretation, which we have discussed in more detail elsewhere (WOODCOCK & ROBERTSON 1982).

The Bey Dağları Zone shows a variety of structures near its contact with the Antalya Complex. Large open upright folds dominate the platform limestones in the south and north, with strong minor folding restricted to the overlying Tertiary clastic sediments. In the central area a major high-angle fault forming the boundary with the Antalya Complex exposes more intensely folded platform limestones.

The Kumluca Zone is dominated by east-dipping thrusts which repeat the thin margin sequence as many as twelve times. Folds within thrust sheets trend north-south and verge and face westwards, implying westward stacking of the margin sequence towards the platform. This stacking probably occurred in late Cretaceous time, though final emplacement of the Kumluca Zone onto the platform did not occur until Miocene time. In the south this zonal contact is a steep reverse fault. In

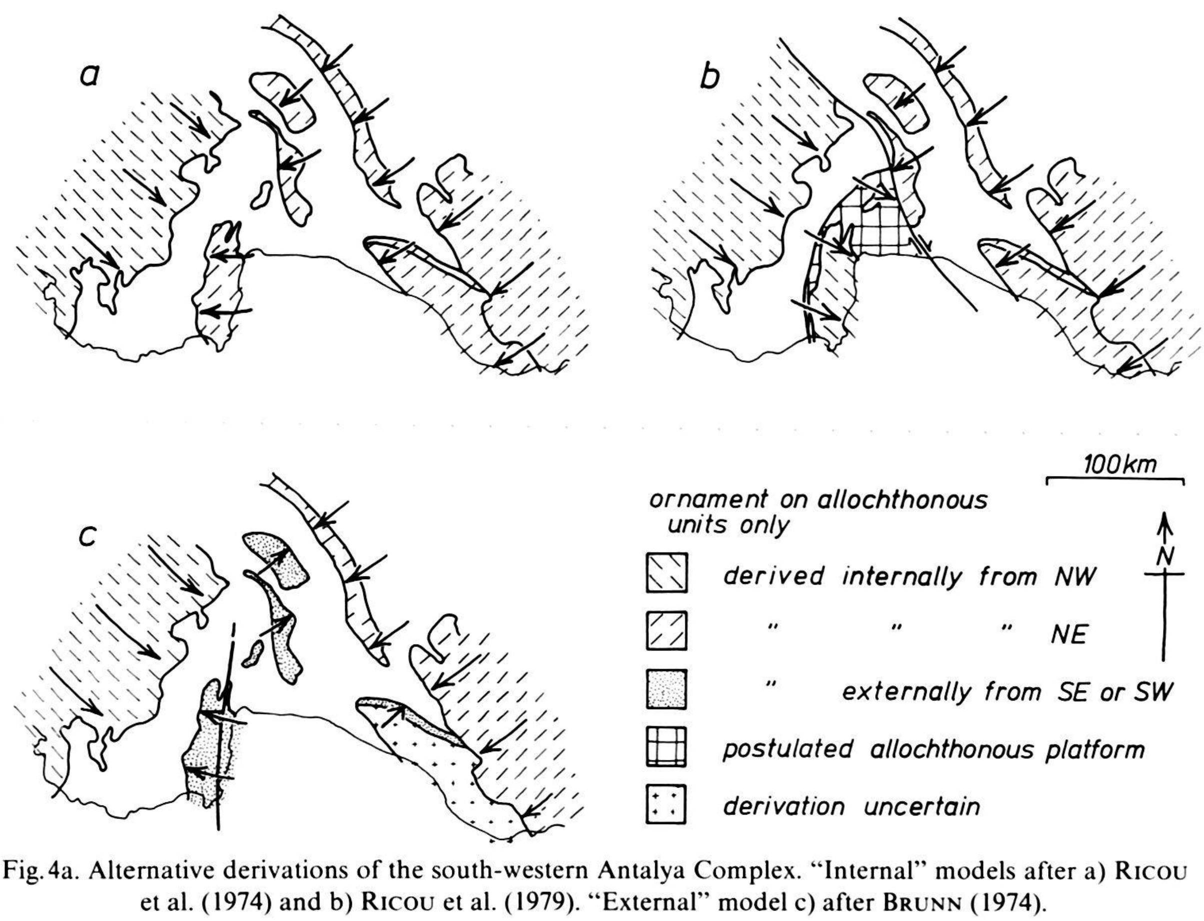


Fig. 4a. Alternative derivations of the south-western Antalya Complex. "Internal" models after a) RICOU et al. (1974) and b) RICOU et al. (1979). "External" model c) after BRUNN (1974).

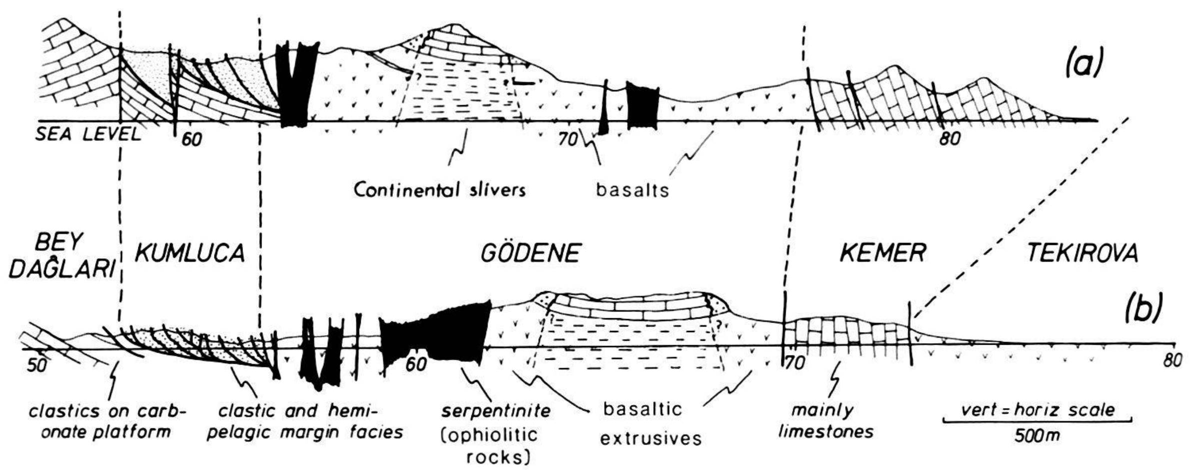


Fig. 4b. East-west cross-sections to illustrate the structure along a) Grid line 75 and b) Grid line 42 (Fig. 2). Note the structural style of the serpentinite protrusions which form anastomosing strands.

the north a moderate-dip reverse fault contact is cut by high-angle faults; in between the Kumluca Zone is completely cut out by later steep faults.

The Gödene Zone also shows strong thrust imbrication of sedimentary sequences and of their extrusive igneous basement, again with a dominant westward sense. However cutting through these thrust terrains are steep anastomosing screens of sheared serpentinite. These have been interpreted as early Tertiary low-temperature "protrusions" of hydrated mafic/ultramafic basement up a then active braided system of strike-slip faults (ROBERTSON & WOODCOCK 1980a; WOODCOCK & ROBERTSON 1981, 1982). These faults may either have post-dated thrusting or accompanied the thrust deformation in a regional transpressive event. The Gödene-Kumluca Zone contact is not affected by strike-slip faults except in the north where the faults cut right across the Kumluca Zone into the Bey Dağları platform.

The Kemer Zone shows several major steeply east-dipping slabs of Mesozoic carbonates overlying pre-Triassic sedimentary basement. Individual slabs, and the Kemer Zone as a whole, are bounded by steep north-south striking faults. The fault slip direction is unknown but, by analogy with the Gödene Zone, probably has a strong strike-slip component (Fig. 4b).

The gross structure of the Tekirova Zone is poorly known, though JUTEAU et al. (1977) document primary ocean floor structures in the ophiolite. Deeper levels of the ophiolite sequence are exposed progressively southwards along the coast.

1.4 *Palinspastic reconstruction*

In the French tectonic scheme of grossly allochthonous nappes (Fig. 4a) the present outcrop pattern could bear little relationship to any original palaeogeography. By contrast our work indicates that the thrust terrains can be unstacked to reveal original facies patterns (e.g. ROBERTSON & WOODCOCK 1981a, b, Fig. 4b). Larger scale thrusting has occurred only in the north-west of the Gödene Zone (e.g. Fesligen-Eren Dağ area, Fig. 2), and then apparently without totally obscuring original facies relationships.

Accurate palinspastic reconstruction is more difficult across inferred strike-slip faults, particularly the serpentinite screens in the Gödene Zone. The amount of offset is usually impossible to determine. However locally, where strike-slip faults cut across the Kumluca Zone into the platform beyond the north-east of the Gödene Zone, offsets are only a kilometre or so and nowhere within the Gödene Zone is there any obvious tectonic duplication of major units of the continent-ocean transition. We assume here that original facies relationships are preserved in areas between major strike-slip strands and that lateral shift of facies along the margin has not been great within the western part of the Gödene Zone. Displacement could increase towards the Kemer Zone contact. Most of the strike-slip motion was taken up along zones of sheared serpentinite, but many other steep faults may have had a strike-slip component. The Tekirova–Kemer contact is a very major crustal discontinuity, possibly a strand in a late Cretaceous to early Tertiary transform zone, which juxtaposed originally widely separated lithosphere fragments of different age.

2. Palaeozoic to mid-Triassic

2.1 *Palaeozoic basement*

Pre-Triassic rocks, best exposed in the Kemer Zone (e.g. Kesme Boğazı, Fig. 5a, b) provide important data on the Palaeozoic history of the area. At the base, Ordovician and Silurian black graptolitic shales and mudstones contain sedimentary structures suggesting relatively shallow marine deposition (e.g. Fig. 5a, log 5). After an interval of dolomitic limestones, the Devonian and Carboniferous comprise quartzarenites, siltstones, mudstones, coals and other sediments typical of deltaic facies. The Permian sequence is dominated by rhythmically bedded grey limestones with an abundant shallow marine fauna including bivalves, brachiopods, echinoderms, benthic foraminifera and crinoids (E. Çatal, pers. comm. 1977; Fig. 5a, logs 1–7). Permian strata also crop out in several of the northern Gödene Zone carbonate massifs (e.g. Bakırlı Dağ, Fig. 5a, log 2). In the north-east area KALAFATÇIOĞLU (1973) recognized a 200 m thick limestone unit overlain by grey crystalline dolomites, up to 250 m thick (Fig. 5a, logs 1, 3, 4).

2.2 *Early–Middle Triassic facies*

The first signs of rifting of the Palaeozoic basement are seen in the Lower to Middle Triassic sequences of the Gödene and Kemer Zones. A typical succession (MARCOUX 1974; DELAUNE-MAYERE et al. 1977) is shown in Figure 6, log 3 (Bakırlı Dağ, Gödene Zone). Upper Permian limestones pass conformably up into shallow water limestones, in places oolitic with gypsiferous intercalations (Scythian). Overlying cocquinoid limestones with hardgrounds pass up into marly vermicular limestones (Anisian), and then into red crinoidal limestones with Fe–Mn crusts (Ammonitico rosso facies, Ladinian) and Upper Triassic *Halobia*-bearing micritic limestones.

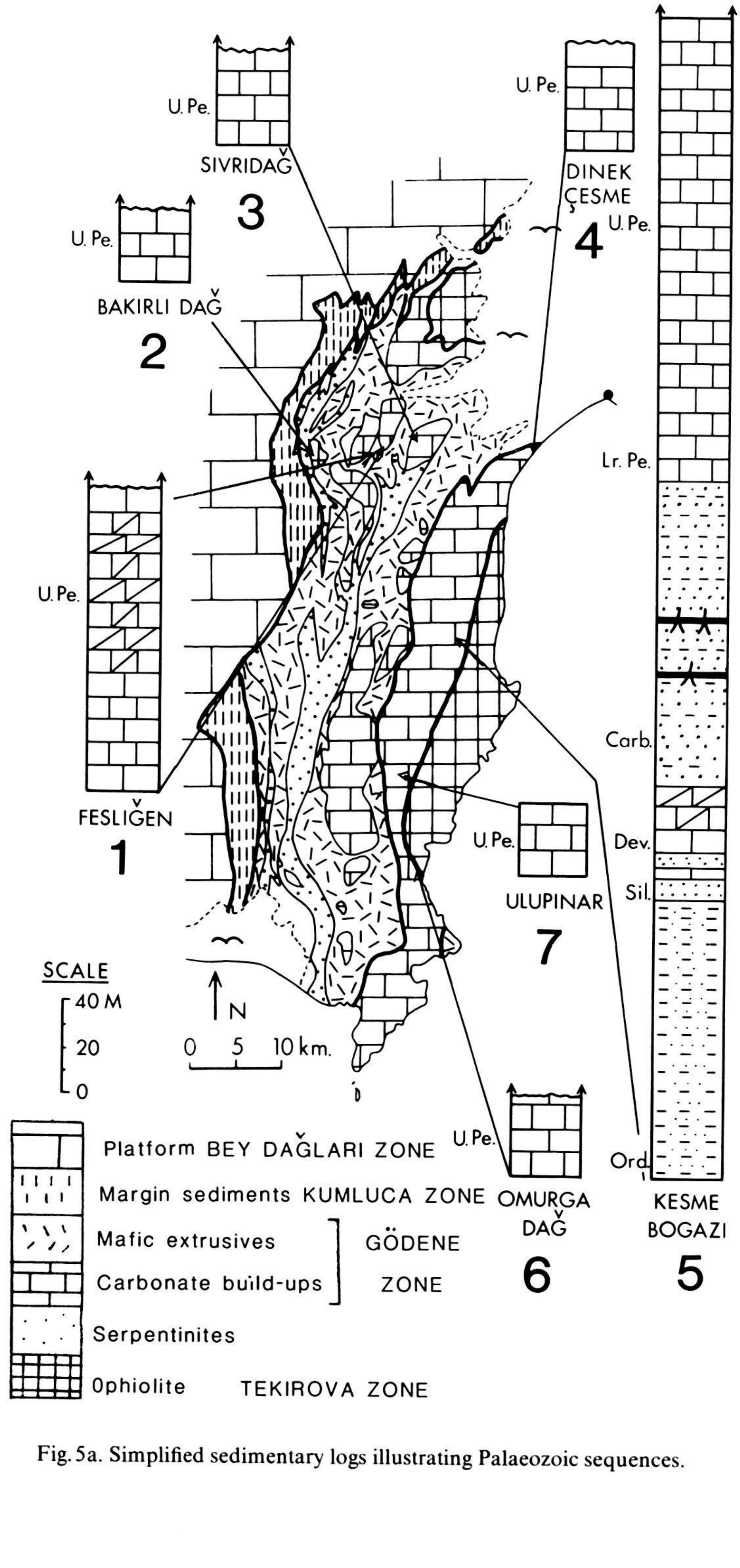


Fig. 5a. Simplified sedimentary logs illustrating Palaeozoic sequences.

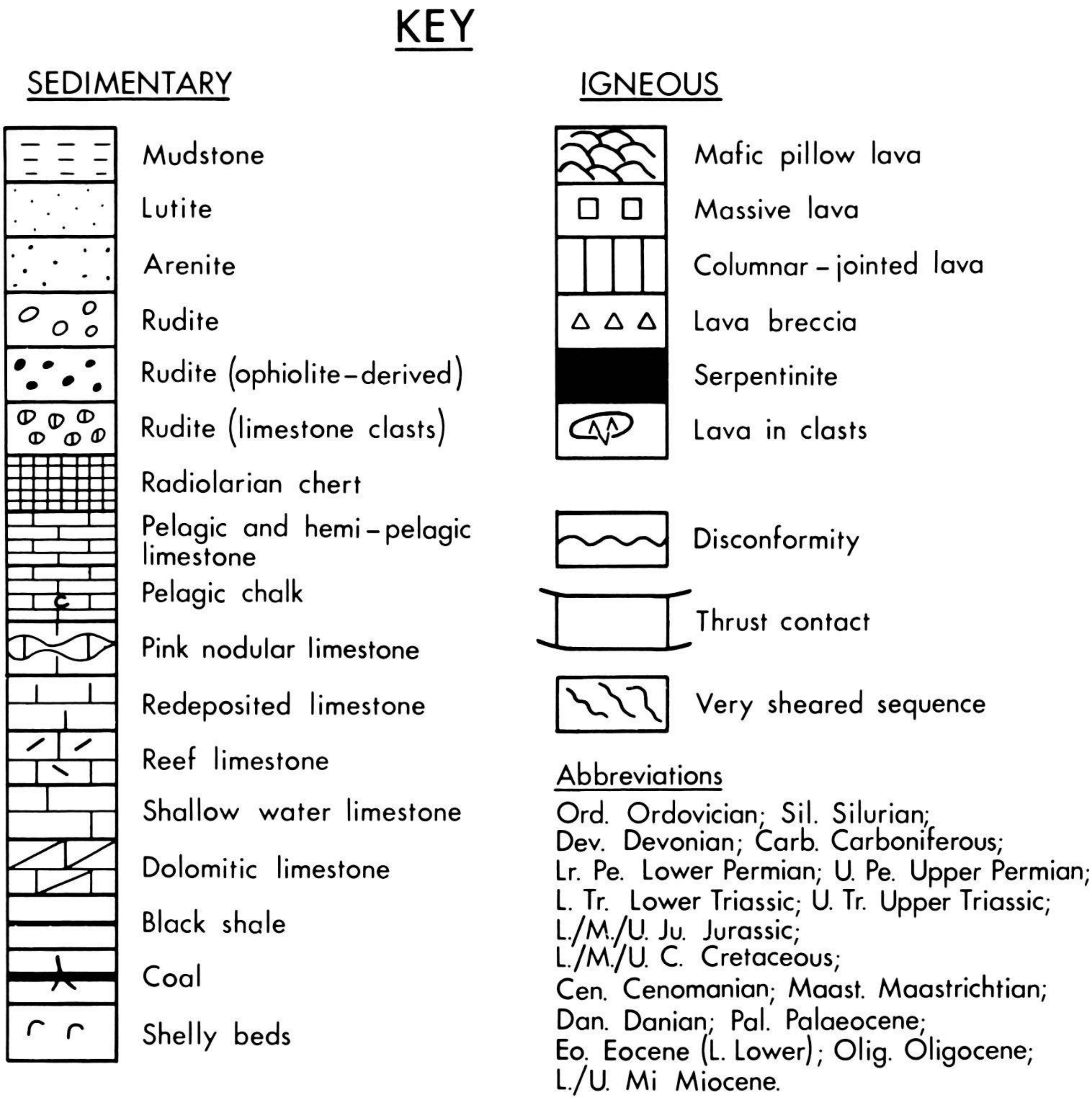


Fig. 5b. Key to sedimentary logs shown in Figures 5a, 6, 11, 13, 16.

By contrast the early Triassic facies of the Kemer Zone include laterally variable neritic limestones and rudites containing Upper Permian clasts. After a hiatus, extensive Ladinian acidic tuffs are followed in some sections by radiolarites or quartzarenites below Upper Triassic pelagic limestones (Fig. 6, logs 1, 4–6).

2.3 *Early Triassic environments*

Early Triassic time saw tectonic differentiation of the late Permian epicontinental seafloor (e.g. MARCOUX 1974). Some areas remained submerged, while elsewhere Upper Permian limestones were uplifted and eroded. Shallow marine areas underwent periodic emergence and evaporite deposition. Lower Ladinian acidic tuffs

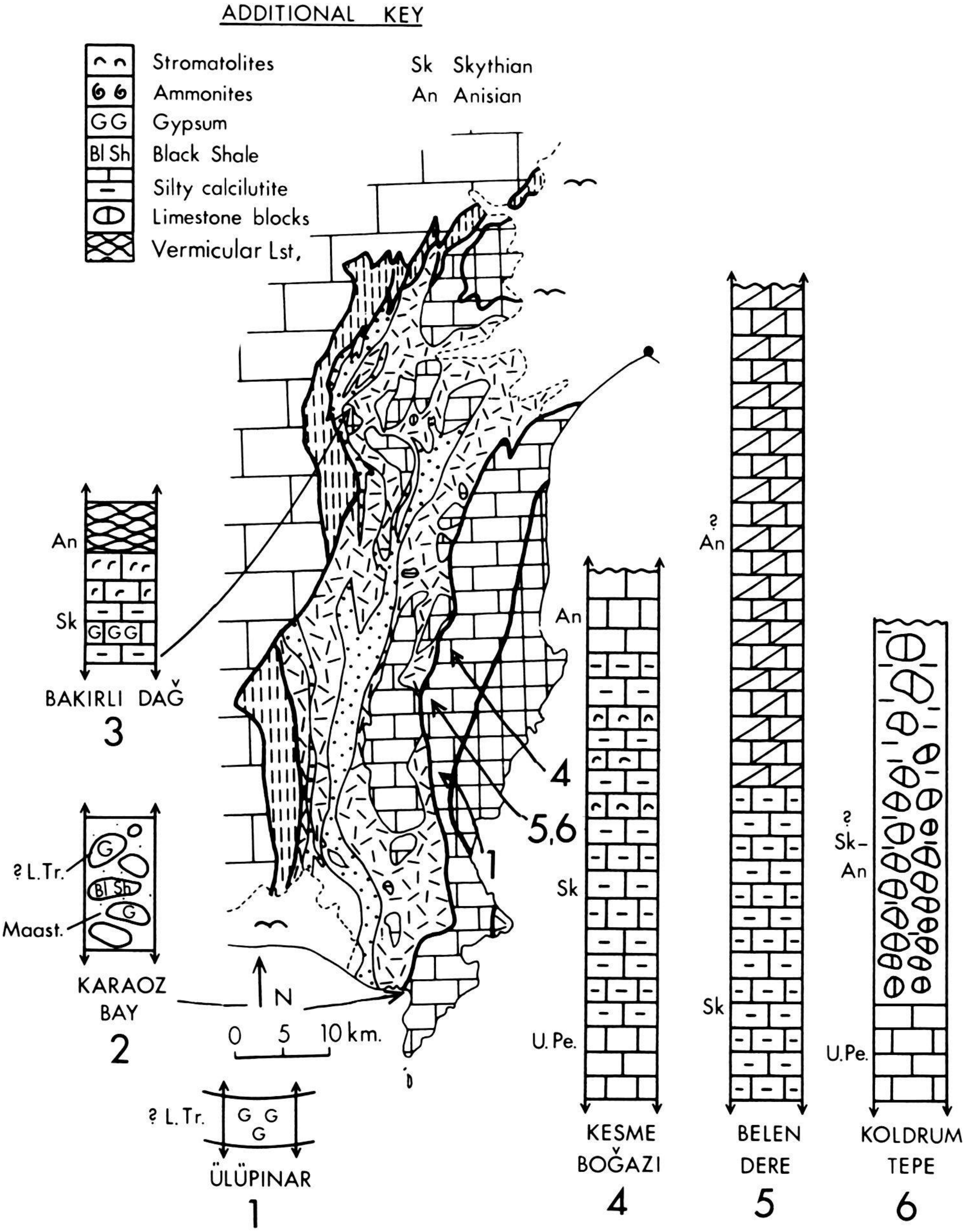


Fig. 6. Sedimentary logs summarizing early-middle Triassic sequences. Key shown in Figure 5b.

indicate onset of volcanism which was followed by regional subsidence and widespread deposition of radiolarites. Erosion had by then reached the Upper Palaeozoic rocks, shedding large volumes of quartzose sands. Condensed Ammonitico rosso facies accumulated on submerged basement highs. The abundant Fe and Mn is seen as predominantly volcanogenic (ROBERTSON 1981). These early Triassic rocks therefore document the earliest stages of continental break-up and volcanism. In general, the shallow water facies are lithologically comparable with the Dachstein facies of the Eastern Alps (GARRISON & FISCHER 1969) and those of deeper water with the Ammonitico rosso of Sicily and the Italian Apennines (BERNOULLI & JENKYNS 1974). In the Western Tethys, rifting and subsidence occurred in mid Triassic time. This was apparently aborted until major renewed block faulting and rotation in the early Jurassic which cut obliquely across older trends (SCANDONE 1975; LAUBSCHER & BERNOULLI 1977; BECHSTADT et al. 1978). In the Antalya Complex, early Triassic faulting and subsidence (Skythian–Anisian) was followed disconformably by more quiescent mid Triassic (Ladinian) pelagic carbonate and radiolarite deposition, prior to onset of major volcanism in late Triassic time.

3. Late Triassic

3.1 *Mafic extrusives*

Thick sequences of mafic extrusives, with no basement exposed, dominate the Gödene Zone. Minor exposures are also seen close to the Kemer–Tekirova Zone contact (e.g. Antalya–Kemer road).

The late Triassic extrusives are of two types; pillowed or massive lavas, and lava breccias. They are thickest, up to 1500 m, in the north-west of the Gödene Zone (Calbalı Dağ, Fig. 2, 7, log 1), where pillowed, massive and columnar-jointed flows predominate, and volcaniclastic material only appears towards the top of the sequence. Some other sequences (e.g. Fig. 7, logs 12, 14) contain abundant volcanic breccias formed by epiclastic, and hyaloclastic processes (e.g. Sayrun Massif, Fig. 2, 7, log 2), already described by us in more detail (ROBERTSON & WOODCOCK 1981c). Locally, near the contact between the Kemer and Gödene Zones, hyaloclastites are abundant (Fig. 9, log 2). Most of the extrusives are mildly to strongly alkalic basalts (JUTEAU 1974). More tholeiitic types have not been detected.

3.2 *Quartzose sediments*

In describing the highly variable late Triassic sedimentary facies, we emphasise areas not previously described by us, particularly in the Kemer Zone. Some sedimentary logs are given on a bed-by-bed basis (Fig. 8a, 9).

Quartzarenites form an important component of the inter-lava and supra-lava sediments of the Gödene Zone, and are also a feature of the Kemer and Kumluca Zones.

In the southern part of the Kumluca zone, deformed medium-grained quartzarenites occur at the base of many of the thrust sheets (Fig. 7, log 4). Bed-thickness

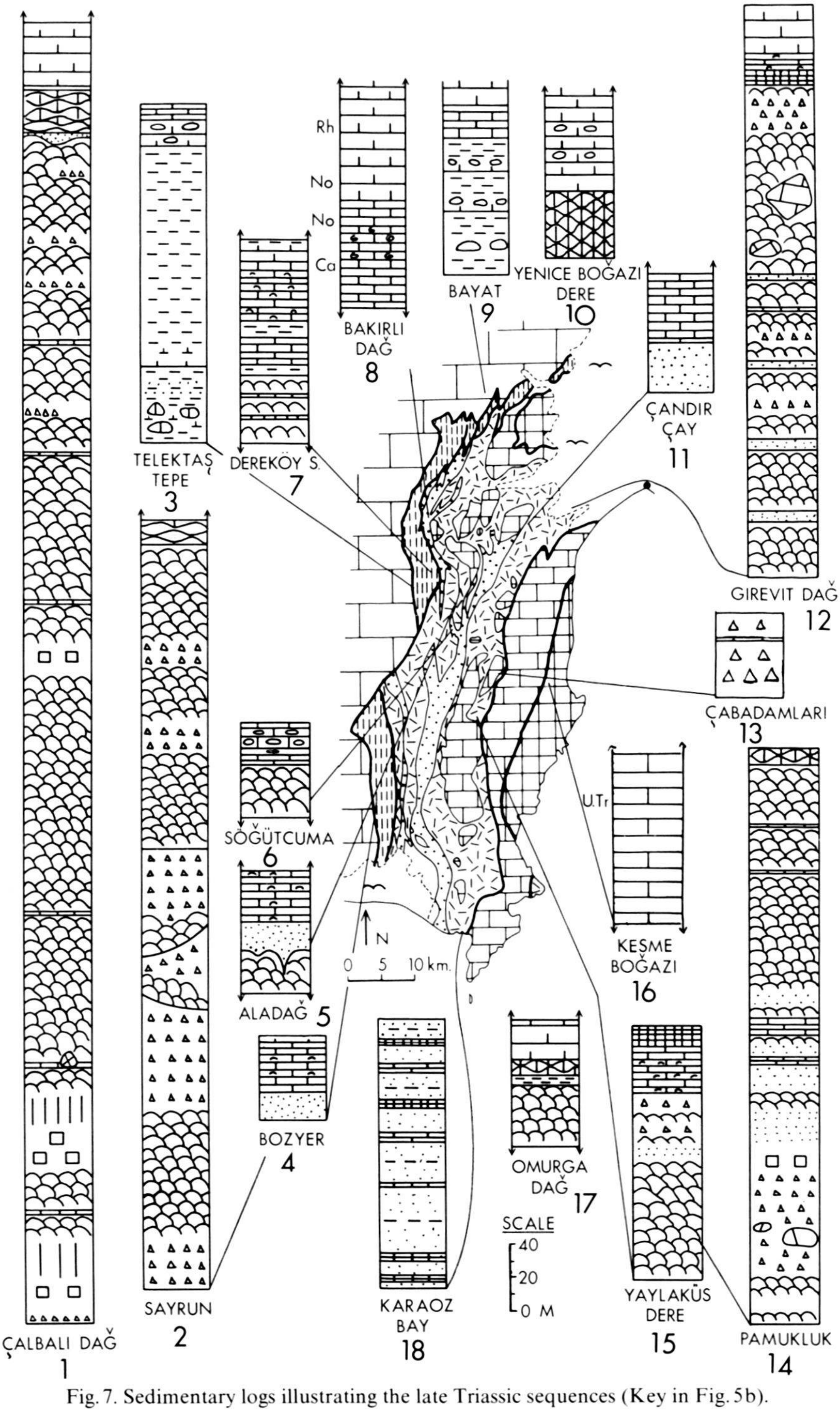


Fig. 7. Sedimentary logs illustrating the late Triassic sequences (Key in Fig. 5b).

rarely exceeds 0.5 m. Most of these sandstones were deposited by turbidity currents though sandstones deposited closer to the Bey Dağları autochthon show extensive current reworking and contain admixed carbonate clasts and wood fragments (ROBERTSON & WOODCOCK 1981b). Further north, turbiditic quartzarenites are only exposed in more westerly sequences close to the Gödene Zone (Fig. 7, log 3). In the north-eastern part of the Kumluca Zone the only quartzose sediments are brown finely laminated calcareous muds and siltstones intercalated with blocks of redeposited reefal material (Tilkedeligi Formation, Çatal Tepe Unit, Fig. 3, 7, log 3, POISSON 1978). Greater thicknesses of turbiditic quartzarenites are exposed in the Gödene Zone particularly in the south-east (Fig. 7, logs 14, 18) and north-east (logs 11, 12). They commonly overlie the lavas in topographic lows and locally rhythmically bedded quartzarenites and quartzlutites fill a steep-sided fault-bounded depression in the lava surface (Fig. 7, log 5). Here the supra-lava sequence also includes matrix-supported rudites with well rounded clasts of grey limestone, black chert, dolomite and trachyte (Fig. 7, log 5).

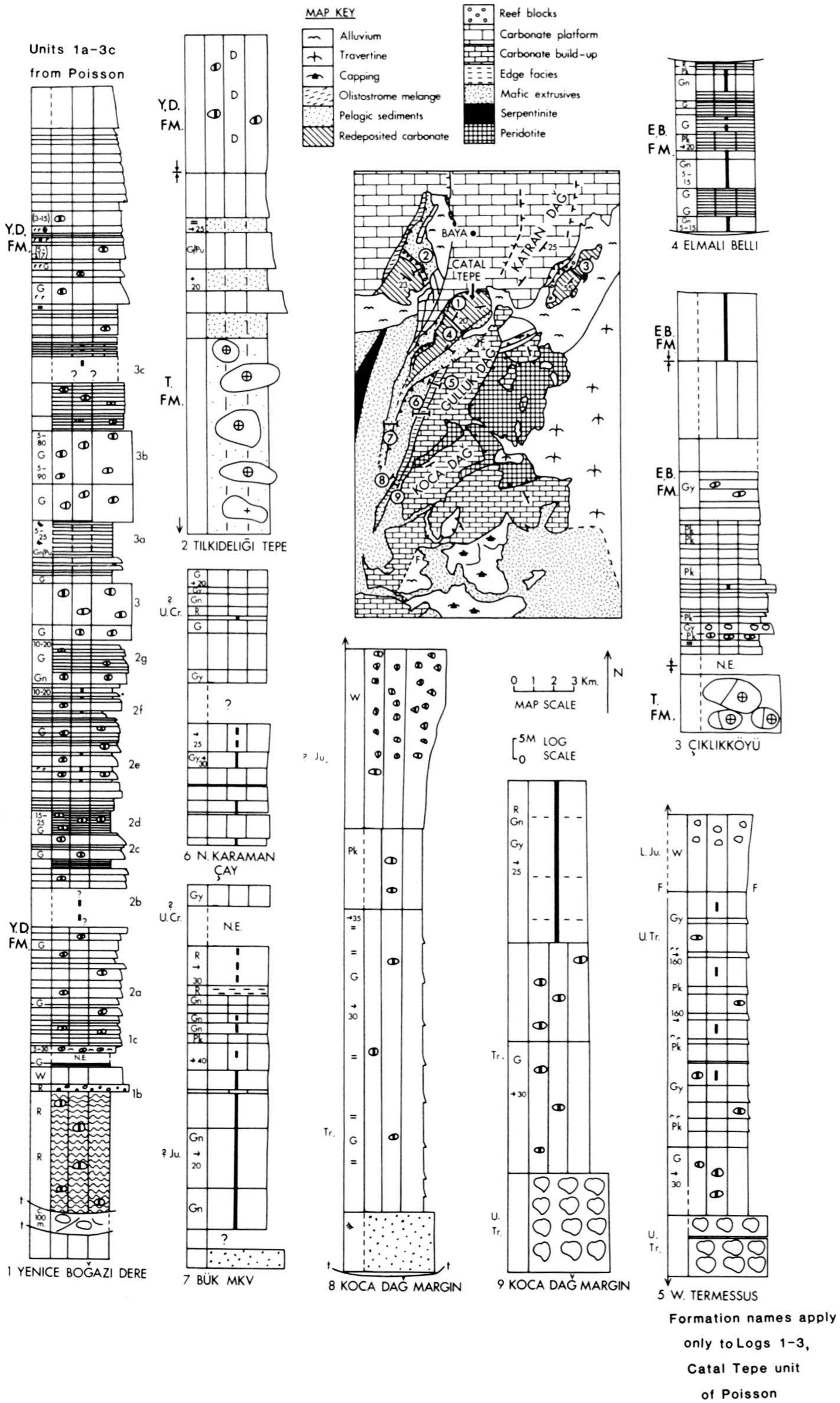
Turbiditic quartzarenites are again conspicuous in sequences laid down around the major limestone massifs in the Kemer Zone. Detailed sedimentary logs on a bed-by-bed basis are given in Figure 9, logs 1-9. In addition to turbidites, these sequences include thick bedded lenticular massive or weakly graded sandstones with occasional dish-structures and other features indicating mass-flow deposition (e.g. Fig. 9, log 3).

3.3 *Limestones*

In situ reefal limestone sequences in the Bey Dağları autochthon exposed adjacent to the south-western Antalya Complex only extend down to the lower Jurassic (Katran Dağ, Fig. 11, log 1, POISSON 1978). Upper Triassic shallow water limestones are not exposed in most of the continental horsts in the Gödene Zone but neritic coral-bearing limestones are known from the Kemer Zone (Fig. 7, log 16). Most Antalya Complex Triassic limestones are redeposited. These include detached blocks (Fig. 7, logs 9, 12, 14; Fig. 8, logs 2, 3), calcirudites, calcarenites, and calcilutites exposed both within the Kumluca margin and around the off-margin basement highs in the Gödene and Kemer Zones.

Detached blocks of reef limestones, up to hundreds of metres in diameter occur in both the northern part of the Kumluca margin and in the Gödene Zone. The north-western Kumluca Zone sequences have blocks of orange or pale brown coral and algal limestone (Bilelyeri and Çatal Tepe Groups, Fig. 3, 7, logs 3, 9; Fig. 8a, logs 2, 3). In the Bilelyeri Group the individual blocks are scattered through lenticular quartzose sandstones and siltstones which were deposited on a tectonically unstable seafloor (Fig. 7, log 3). In the north (Tilkediligi Formation, Fig. 3, POISSON 1978), higher parts of the sequence (Fig. 8a, logs 1-3) are typically lenticular calcarenites and calcilutites rather than individual reef blocks. An extensive fauna of coral, sponges, algae, ammonites, gastropods and benthic foraminifera indicates a late Triassic (Carnian-Norian) age (CUIF 1974).

In the Gödene Zone detached reef limestone blocks occur within or most commonly above the mafic lavas, particularly close to major carbonate massifs (e.g. Calbalı Dağ, Fig. 7, log 1; Girevit Dağ, Fig. 7, log 12). Typically the intra-lava blocks


MAP KEY
Alluvium
Travertine
Capping
Olistostrome melange
Pelagic sediments
Redeposited carbonate
Reef blocks
Carbonate platform
Carbonate build-up
Edge facies
Mafic extrusives
Serpentinite
Peridotite
Units 1a-3c from Poisson
Y.D. FM.
T. FM.
E.B. FM.
BAYA
CATAL TEPE
KATRAN DAĞ
ÇULUK DAĞ
KOCA DAĞ
MAP SCALE
LOG SCALE
N
1 YENICE BOĞAZI DERE
2 TILKIDELIĞI TEPE
3 ÇIKLIKKÖYÜ
4 ELMALI BELLI
5 W. TERMESSUS
6 N. KARAMAN ÇAY
7 BÜK MKV
8 KOCA DAĞ MARGIN
9 KOCA DAĞ MARGIN
Formation names apply only to Logs 1-3, Catal Tepe unit of Poisson

are strongly baked and recrystallized. Supra-lava blocks range up to 1 km in diameter (Fig. 7, log 6). The contact relations of even larger limestone blocks are often obscured by talus; they could be either small *in situ* carbonate build-ups or vast blocks detached from the major carbonate massifs. Most detached blocks in the Gödene Zone are fringed by finer grained redeposited carbonate described below. Derived reef blocks are unknown in the southern part of the Kumluca margin sequence, in contrast with further north (Fig. 7, log 4).

Calcirudites and calcarenites form a minor component of the northern part of the Kumluca margin (Fig. 7, log 3) but an important element of the Gödene and Kemer Zones. In the northern part of the Kumluca Zone, in contrast with further south, medium to coarse grained redeposited carbonates are interbedded with and overlie the reef limestone blocks (Fig. 8). In the south-west (Telektaş Tepe Formation, Fig. 3; Fig. 7, log 10) minor graded calcarenites are seen at the top of late Triassic calcilutite sequences originally deposited closest to the Bey Dağları autochthon to the west (Fig. 7, log 4). Graded calcarenites also occur in proximal sequences laid down around the margins of the carbonate massifs in the Gödene Zone (e.g. Fig. 7,

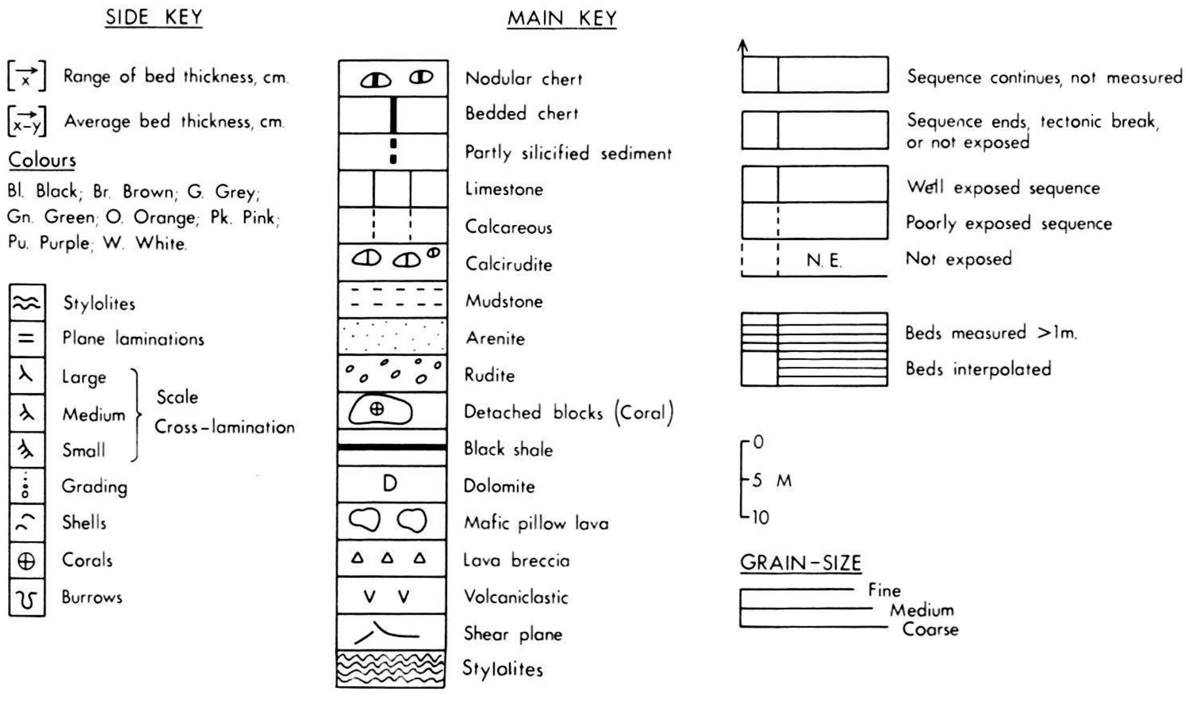


Fig. 8b. Key to detailed sedimentary logs of Figures 8 and 9.

Fig. 8a. Sedimentary logs of Mesozoic sequences around the margin of the Bey Dağları platform (Çatal Tepe unit) and the west margin of the Koca Dağ-Gulluk Dağ off-margin carbonate massif. The geological map showing locations of the sections is modified after Poisson (1978). Note that the key to the bed-by-bed logs differs from the more generalized logs. T. FM. = U. Trias Tilkedelıǧı Formation; Y.D. FM. = Jurassic-Lr. Cretaceous Yenice Boğazıdere Formation; E.B. FM. = U. Cretaceous Elmalı Beli Formation.

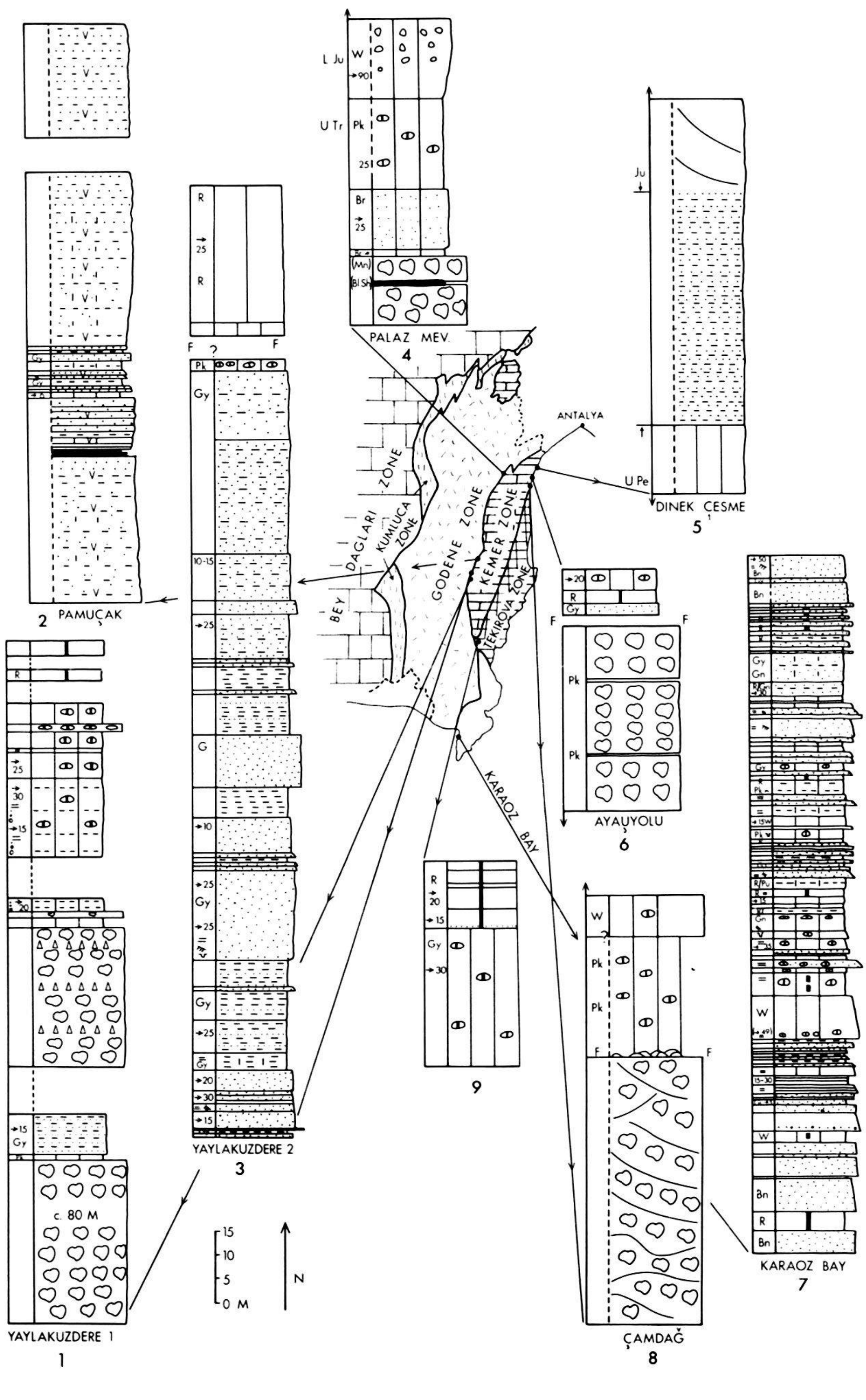


Fig. 9. Detailed upper Triassic sequences exposed around the margins of the Kemer Zone. These sequences establish that the Kemer Zone comprises several major north-south trending carbonate massifs surrounded by late Triassic mafic extrusives. The key shown in Figure 8b for bed-by-bed logs differs from the more generalized logs.

logs 5, 6, 8, 15, 17). Calcirudites are more extensive in the Kemer Zone marginal facies, where they are interstratified with channelized turbiditic sandstones (Fig. 9, logs 4, 6, 7; Fig. 8a, log 5). Calcirudites are also common above the mafic lavas of the Gödene Zone, where they are typically associated with the large detached limestone blocks. Sedimentary structures indicate rapid deposition of these rudites by mass flow and turbidity flow.

Thick-bedded homogeneous calcilutites form the first of four calcilutite sub-facies. This comprises rhythmically bedded calcilutites (up to 0.4 m) in sequences up to 50 m thick. Individual beds are typically stylolitic and contain numerous nodules of dark grey vitreous chert of replacement origin. The calcilutites contain fragments of *Halobia*, other bivalves, and calcite-filled solution moulds Radiolaria in the originally micritic matrix. This sub-facies dominates the later Upper Triassic sequences in the southern Kumluca margin zone (Fig. 7, log 4; Bozyer Formation, Fig. 3; ROBERTSON & WOODCOCK 1981b), but is restricted to the more easterly sequences further north (Fig. 7, log 7; Hatıpalanı Formation, Fig. 3; ROBERTSON & WOODCOCK 1981a). Similar thick bedded limestones are found as lenses up to 50 m thick overlying Gödene Zone lavas particularly near the southern Kumluca margin.

Turbiditic calcilutites superficially resemble those described above, but contain repeated graded and parallel laminated units 10–15 cm thick. Stylolites and nodules are uncommon. They are seen in the most westerly sequences in the southern Kumluca margin zone (Fig. 7, log 4, Bozyer Formation, Alakır Çay Group, ROBERTSON & WOODCOCK 1981b, Fig. 3), and in the inter- and supra-lava sequences of the Gödene Zone (Fig. 7, logs 5, 6, 12, 14, 15; Fig. 8a, logs 5, 9). They are particularly common close to major carbonate massifs (e.g. Fig. 7, logs 5, 6; Fig. 8c, log 8), where they are interbedded with the calcilutites and calcarenites described above.

Pink stylolitic calcilutites, usually highly nodular, occur near the top of the Upper Triassic succession particularly in the northern Kumluca Zone (Çatal Tepe Unit, POISSON 1978). At the base of the Yeniceboğazı Dere Formation, Fig. 3, Fig. 8a, log 1) up to 35 m of pink nodular limestones are overlain by latest Triassic redeposited calcilutites and calcarenites. A separate thrust sheet to the north-east (Fig. 8a, log 3) exposes up to 25 m of pink calcilutites intercalated with coarser redeposited limestones. Elsewhere on the Kumluca margin, the pink stylolitic calcilutites are restricted to the uppermost 10–20 m of the Upper Triassic facies (Fig. 7, log 4). They are also seen as intercalations within and above the Gödene Zone lavas and in the Kemer Zone (Fig. 9, logs 3, 4, 7, 8).

Manganiferous calcilutites occur within and immediately above the highest levels of the mafic lavas of the Gödene Zone. For example, close to the southern Kumluca Zone contact, the highest lavas contain alternating lenses of dark grey calcilutite and red and orange calcilutite. Chemical analyses show strong relative enrichment in Fe, Mn, and a number of trace elements including Cu, Ni, Co, Pb and Rare Earth Elements (ROBERTSON 1981). Grey-brown calcilutites with numerous diagenetic segregations of black manganese oxide overlie lavas at several localities close to carbonate build-ups (e.g. Belen, Sayrun, Bakırlı Dağ, Fig. 2). These calcilutites are typically highly bioturbated and contain abundant bioclastic material including echinoderm plates, bivalves brachiopods, and ammonites. The complete fauna, indicating a Norian age, is described by MARCOUX (1970).

3.4 *Radiolarites*

Thin-bedded "ribbon" radiolarites occur locally both within and immediately overlying the mafic lavas of the Gödene Zone. Interlava radiolarites are particularly abundant near the Kumluca Zone in the south. In the north-east (Girevit Dağ, Fig. 7, log 12), mafic lava breccias are overlain by 5 m of red radiolarites which in turn pass into lower Jurassic hemipelagic and redeposited limestones. Radiolarites are absent from the late Triassic sequences of the Kumluca passive margin, but form important intercalations in the clastic sequences around the Kemer Zone carbonate massifs, for example in the south-east (Fig. 9, log 7), and further north near the Gödene Zone contact (Fig. 9, log 9).

3.5 *Black shales and mudstones*

Black shales and mudstones form interbeds in probable Late Triassic volcaniclastic sequences between the limestone massifs of the Kemer and Gödene Zones (Fig. 9, logs 2, 4). In particular they occur along the west margins of several carbonate massifs in the south of the Kemer Zone (e.g. Omurga Dağ, Fig. 2). Black shales of probable Upper Triassic age also form detached blocks in an Upper Cretaceous melange in the extreme south of the Kemer Zone (Karaoz Bay, Fig. 6, log 2), associated with blocks of quartzarenite, limestone, gypsum and dolomite.

3.6 *Late Triassic palaeogeography*

As shown in Figure 10, a major late Triassic phase of strong crustal extension produced a horst-graben terrain with extensive mafic alkalic volcanism. The Gödene Zone lavas formed a topographically varied seafloor with active fault zones separating relatively stable areas. Large volumes of lava breccia were shed from north-south trending submarine fault scarps. We envisage considerable original lateral continuity of lavas in between off-margin continental slivers, and subsequent dissection into separate blocks during much later ocean-floor genesis, strike-slip faulting and serpentinite emplacement (see below). This differs from JUTEAU's (1975) concept of each lava block as an originally separate submarine stratovolcano.

By late Triassic time the Bey Dağları continental basement formed a faulted horst-graben terrain (Fig. 10). Subaerially exposed horsts shed the large volumes of quartzose sands seen, for example, in the central Kumluca Zone. In the southern Kumluca zone turbiditic sands were locally supplied southwards from a source within the Bey Dağları or Gödene Zones. By contrast the northern Bey Dağları Zone probably remained submerged, and shed no coarse quartzose clastics.

The various turbiditic quartzarenites in the Gödene and Kemer Zones were probably derived from local basement highs exposing, for instance, Devonian and Carboniferous sandstones now seen in the Kemer Zone (Fig. 10). Turbiditic arenites interbedded with radiolarites in the south-eastern Gödene Zone (Karaoz Bay) are strongly channelized (Fig. 2). The quartzarenites were deposited soon after or even during mafic volcanism in the Gödene Zone giving lava-sandstone intercalcations in places. In the north-western Gödene Zone well rounded clasts in local matrix-supported quartzrudites record prolonged transport in a high-energy, possibly beach or alluvial, environment on a adjacent basement high.

By contrast, truly pelagic radiolarites were laid down in deeper water basinal areas floored by late Triassic lavas (Fig. 10). Interlava radiolarites are particularly abundant close to the Bey Dağları margin in the west, possibly reflecting more spasmodic eruption. Late Triassic radiolarites are only interbedded with thick relatively proximal quartzose turbidites in the most easterly part of the Kemer Zone, possibly a sign of open marine areas to the east by this time.

Several of the off-margin basement slivers were sufficiently close together to restrict circulation, leading to local anoxicity and deposition of black muds and silts. This applied particularly to the late Triassic facies between the Teke Dağ (Gödene Zone) and the Tahtalı Dağ (Kemer Zone) to the east (Fig. 10).

During late Triassic time some parts of the Bey Dağları autochthon and the off-margin continental slivers became submerged and initiated growth of coral reefs. By latest Triassic times (Norian) the basement horsts had been peneplaned; general submergence took place allowing extensive carbonate build-ups to develop on both the Bey Dağları platform and on the off-margin highs (Fig. 10). If STANLEY (1979) is correct these reefs may have been large poorly bound carbonate mounds rather than well defined reef complexes. This would explain the large volumes of carbonate silt derived from the carbonate build-ups, in the manner of the peri-platform oozes around the modern Bahamas (SCHLAGER & JAMES 1978). Similar silts are also known to form the Upper Triassic of the western Tethys (DI NOCERA

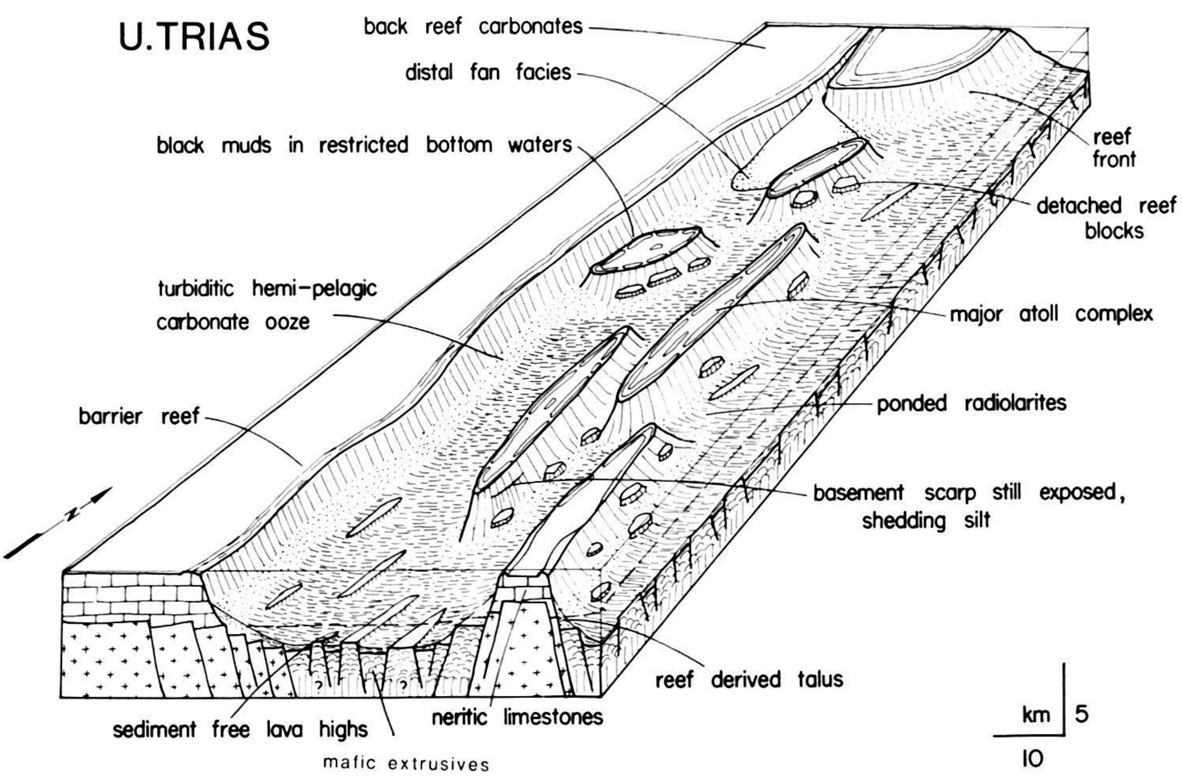


Fig. 10. Block diagram reconstructing the inferred late Triassic palaeogeography.

& SCANDONE 1977). In the south-east carbonate silt was sufficiently abundant to flood over the Kumluca margin onto the Gödene mafic lavas. Many calcilutites were redeposited by turbidity currents, particularly around the off-margin carbonate build-ups where slopes were steepest. Condensed pink pelagic calcilutites (Ammonitico rosso facies) accumulated in sediment-starved areas, both on the submerged basement highs (e.g. Bakırlı Dağ) and directly on adjacent Gödene Zone mafic lavas (e.g. Sayrun). The Fe/Mn and trace metal enrichment is attributed to hydrothermal activity during the final stages of volcanism (ROBERTSON 1981).

Soon after volcanism ended the entire area suffered a major hiatus in deposition coeval with sliding of numerous large blocks of coral limestone onto adjacent Gödene lavas. Metal enriched muds up to 0.4 m thick were deposited on the outer part of the southern Kumluca Zone margin at this time.

In the western Tethys, late Triassic time saw continued crustal extension marked by platform thickness variations (e.g. Pelvoux vs. Brianconnais, MÉGARD-GALLI & BAUD 1977), syndepositional faulting and localized alkalic volcanism (e.g. Lagonegro Zone, WOOD 1981). For example, in the Dolomites, Triassic carbonate build-ups and volcanics clearly overlie a continental basement (ZANKL 1971, BOSELLINI & ROSSI 1974). Deeper water facies can be traced through Yugoslavia and Greece as radiolarites, black shales and varicoloured marls (e.g. Pindos Zone, DERCOURT et al. 1973, GREEN 1982). The Antalya area however is marked by more profound late Triassic subsidence to form deep radiolarite basins floored by thick mafic extrusives.

4. Jurassic to mid-Cretaceous

Jurassic time saw a major switch in all the basinal areas from predominantly calcareous and terrigenous deposition to finer grained mostly siliceous pelagic and hemi-pelagic sedimentation. All radiolaria so far identified by E. A. Pessagno have yielded late Jurassic to mid-Cretaceous ages.

4.1 *In situ limestones*

The major limestone massifs in both the Kemer (Fig. 11, log 11) and Gödene Zones (Fig. 11, log 2) contain sequences of coral- and algal-bearing neritic limestones ranging from Rhaetic to mid-Cretaceous; detailed stratigraphy has only been published for the Koca Dağ massif in the north-eastern Gödene Zone (Fig. 11, log 11, POISSON 1978). There the Lower Jurassic to Cenomanian interval comprises about 1000 m of regularly stratified micrites and biomicrites, in places algal and with abundant rudist fragments. Elsewhere in the north-eastern Gödene Zone, KALAFATÇIOĞLU (1973) has subdivided the Jurassic into Lower, Middle, and Upper Jurassic units. The Lower Jurassic comprises up to 600 m of neritic limestones containing abundant coral, algae, gastropods, and a rich microfauna including 7 species of *Involutina*. The Middle Jurassic consists largely of oolitic limestones, overlain by a further several hundred metres of coral and algal neritic limestones in the Upper Jurassic. Similar sequences occur in the Kemer Zone to the west, particularly in the Tahtalı Dağ (Fig. 2). In the Bey Dağları autochthon shallow water carbonates are exposed down to Lower Jurassic (Fig. 11, log 1).

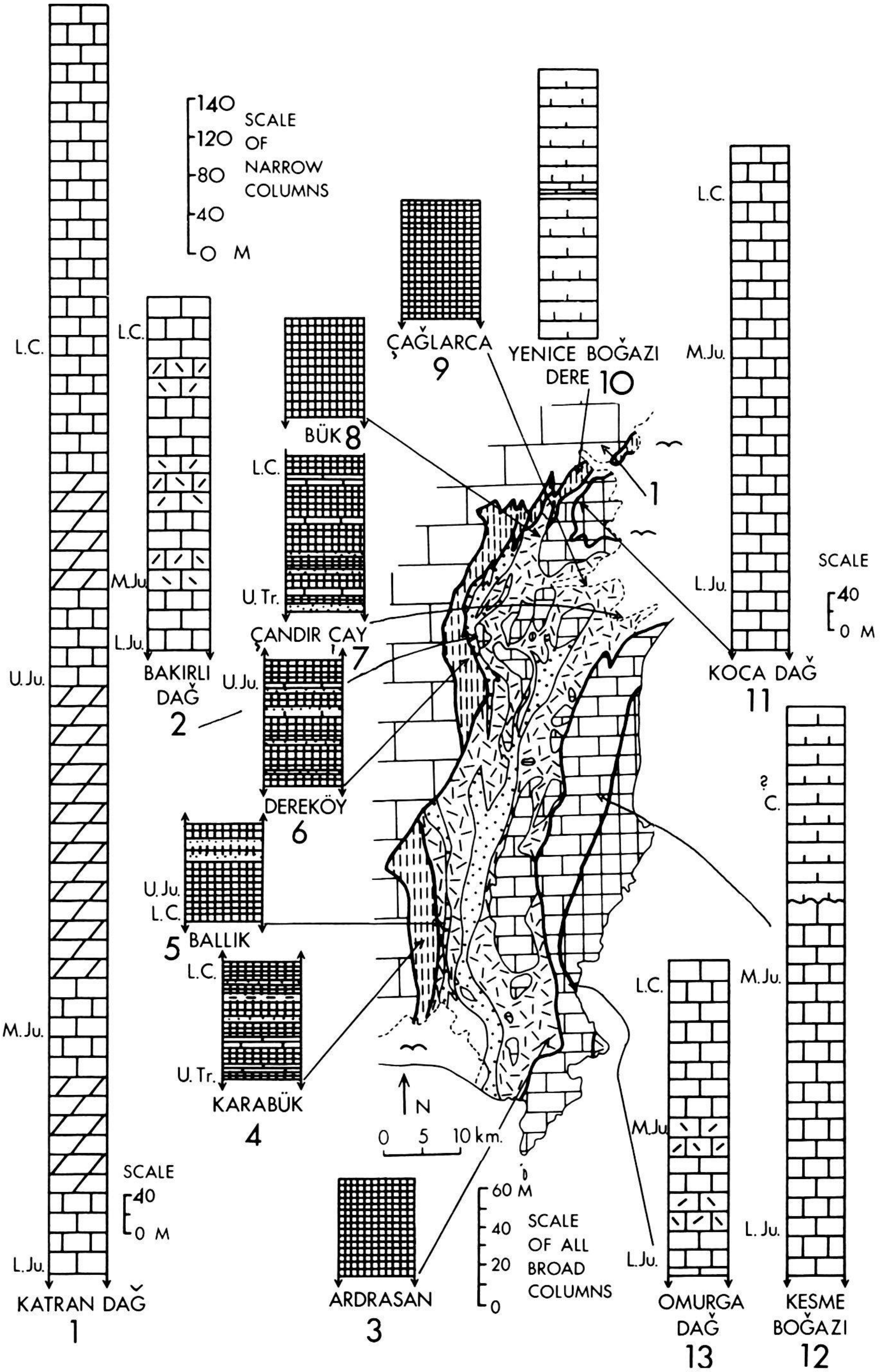


Fig. 11. Sedimentary logs summarizing sequences in the Jurassic to early Cretaceous. See Figure 5b for key.

4.2 *Redeposited limestones*

Redeposited limestones are exposed around the margins of the major carbonate build-ups in the Gödene (Fig. 11, log 2) and Kemer Zones (Fig. 11, logs 12, 13), and also dominate the exposed Jurassic to mid-Cretaceous sequences in the northern Kumluca Zone (Çatal Tepe Unit, Fig. 8a, logs 1, 3; Fig. 11, log 10; POISSON 1978).

Limestone rudites which overlie Jurassic shallow-water limestones in the type section of the Kemer Unit (Kesme Boğazı, Fig. 11, log 12), are probably mostly Cretaceous in age. Individual rudite horizons are up to 5 m thick. The clasts are typically grey calcilutite, often recrystallized, in a micritic matrix. Most rudites are matrix-supported. Some are organized with bedding-parallel clast-fabrics but many are totally disorganized.

Bioclastic limestones occur in thick wedges around the exposed margins of many of the carbonate massifs, in the Gödene Zone. In places they directly overlie the mafic extrusives, for example in the north-east (Fig. 8a, log 5), and near the Girevit Dağ (Fig. 7, log 12) where lava breccias are overlain by Liassic shelly bioclastic limestones (KALAFATÇIOĞLU 1973). These redeposited limestones are easily distinguishable from *in situ* organic limestones on weathered surfaces.

Stratified calcirudites and calcarenites are seen only in the northern Kumluca margin zone, particularly in the type section of the Yenicebogazı Dere Formation (POISSON 1978). The sequence consists of rhythmic alternations of redeposited calcirudites and calcarenites with several intercalations of *in situ* pink calcilutites and background sediments composed of red calcareous thin bedded radiolarite (Fig. 8a, logs 1, 3). Individual calcirudite beds are massive or roughly size-graded. Clasts are typically sub-rounded, up to 0.4 m in diameter, with corals, algae, and shell debris including Megalodonts and an extensive microfauna (POISSON 1978). The fauna is essentially contemporary and does not include significantly older material. Calcarenite beds can be traced laterally for at least 100 m and show turbidite structures. Individual redeposited horizons have a lower matrix-supported calcirudite unit passing up into graded turbiditic calcarenite. The turbiditic calcarenites may show strong lateral thickness variation over several tens of metres, whereas the thicker calcirudites are laterally more persistent.

Turbiditic calcilutites, generally pink, thinly-bedded and well laminated occur on the southern Kumluca margin (Karabuk Formation Fig. 11, log 4) and around several of the off-margin massifs (e.g. Fig. 11, log 7). Here the calcilutites consist of finely divided shell fragments and scattered Radiolaria in a micritic matrix.

4.3 *Orthoquartzites*

Post-Triassic quartzose sandstones have only been seen in the southern part of the Gödene Zone where they are interbedded in the upper part of the siliceous pelagic sequence overlying mafic lavas. They are thick bedded (to 1.5 m) orange or yellow pebbly orthoquartzites with partings of finely laminated mudstone. They show a bimodal texture with large well-rounded grains in a matrix of smaller more angular grains. Texturally identical sandstones are known in southern

Cyprus as the Parekklisha and Akamas Sandstones (SWARBRICK & ROBERTSON 1980) but are not known elsewhere in south-western Turkey.

4.4 *Siltstones*

Thin bedded turbiditic siltstones are important in the Jurassic to mid-Cretaceous interval of the more distal sequences of the Kumluca margin. In the south (Karabuk Formation, ROBERTSON & WOODCOCK 1981b), thin bedded, often mottled pink grey and purple turbiditic silts are intercalated with radiolarian mudstones and radiolarites of late Jurassic to early Cretaceous age (E.A. Pessagno, pers. comm. 1980) which then pass into pink calcilutite containing planktonic foraminifera (Fig. 11, log 4). In the central area (Dereköy Formation, Fig. 3; ROBERTSON & WOODCOCK 1981a), the siltstones are typically medium to dark grey, often show a "micro-flaser" fabric, and are interbedded with black shales (Fig. 11, log 6). Coeval red oxidised siltstones reappear in the northern area, where thick redeposited calcirudites and calcarenites pass southwards into finer grained siliceous and pelagic facies (Fig. 8a, log 7). These are best exposed along the west margin of the Gulluk Dağ carbonate massif where the succession is locally seen to rest on mafic lavas of the Gödene Zone (Fig. 8a, logs 5, 9).

Interbeds of white graded turbiditic siltstones form distinctive marker horizons in the upper (?lower Cretaceous) part of the radiolarian chert sequence in the south-western Gödene Zone, though generally this zone is free of silicic clastics, other than mudstones (Fig. 11, log 4).

4.5 *Mudstones*

Finely laminated grey, purple, red or green mudstone occur together with the siltstones described above. Geochemical analysis, particularly Al content relative to other major elements (Mg, Fe, Ti), indicates a terrigenous origin (ROBERTSON 1981). Similar mudstone intercalations are seen around the margins of the carbonate massifs in the Gödene Zone, including the Gulluk Dağ (Fig. 8a, logs 6, 7).

4.6 *Radiolarites*

Radiolarites dominate the Jurassic to mid-Cretaceous interval of the basinal area of the Gödene Zone and the distal (eastward) parts of the Kumluca margin. In the Kumluca Zone the radiolarites are usually interbedded with mudstones, siltstones and calcilutites (Fig. 11, log 4). In the Gödene Zone, sequences of radiolarite and radiolarian mudstone devoid of other lithologies reach up to 80 m in thickness (Fig. 8a, log 7; Fig. 11, logs 5-9). Sedimentary features have been described in more detail elsewhere (ROBERTSON & WOODCOCK 1981a). Jurassic to Cretaceous marginal facies around the Kemer Zone limestone massifs are not well exposed, though locally dark grey cherts occur above mafic lavas (Fig. 9, log 6) are present.

4.7 *Manganiferous intercalations*

The lower and middle parts of the radiolarian chert sequences, of upper Jurassic to lower Cretaceous age (E.A. Pessagno, pers. comm. 1980), are often intercalated with thin lenses of black manganiferous mudstone and pure manganese ore (pyrolusite). They are strongly enriched in Mn, sometimes in Fe, and trace metals as in the underlying inter- and supra-lava sediments (e.g. Fig. 11, log 5; ROBERTSON 1981).

4.8 *Jurassic to mid-Cretaceous palaeogeography*

On the Bey Dağları autochthon (Fig. 12) progressive subsidence during this interval was balanced by deposition of up to 2000 m of shallow water carbonates (POISSON 1978). Similar carbonates reach thicknesses of 750 m on the offshore massifs in the Gödene Zone floored by slivers of pre-rift continental basement.

As shown on Figure 12, coarse limestone debris was shed down the steeply dipping Bey Dağları platform edge to form sequences in the north of the Kumluca Zone. The rudites were transported mostly by mass-flow and the lenticular calcarenites by channelized turbidity flow. Sequences in the type section (Yeniceboğazı Dere Formation, Fig. 3) are much thicker than lateral equivalents (Fig. 8a, logs 1, 3), suggesting a submarine fan adjacent to a major supply area on the platform (Fig. 12). Further south in the Kumluca Zone thick redeposited limestones are rare. Either the platform edge facies was not deposited there, or more probably it has been overthrust by the Kumluca Zone along a basal thrust originally located in a more distal position on the margin than in the north.

Calciturbidites were again deposited in the distal (easterly) sequences of the central Kumluca Zone (Dereköy Group), apparently from a source to the east

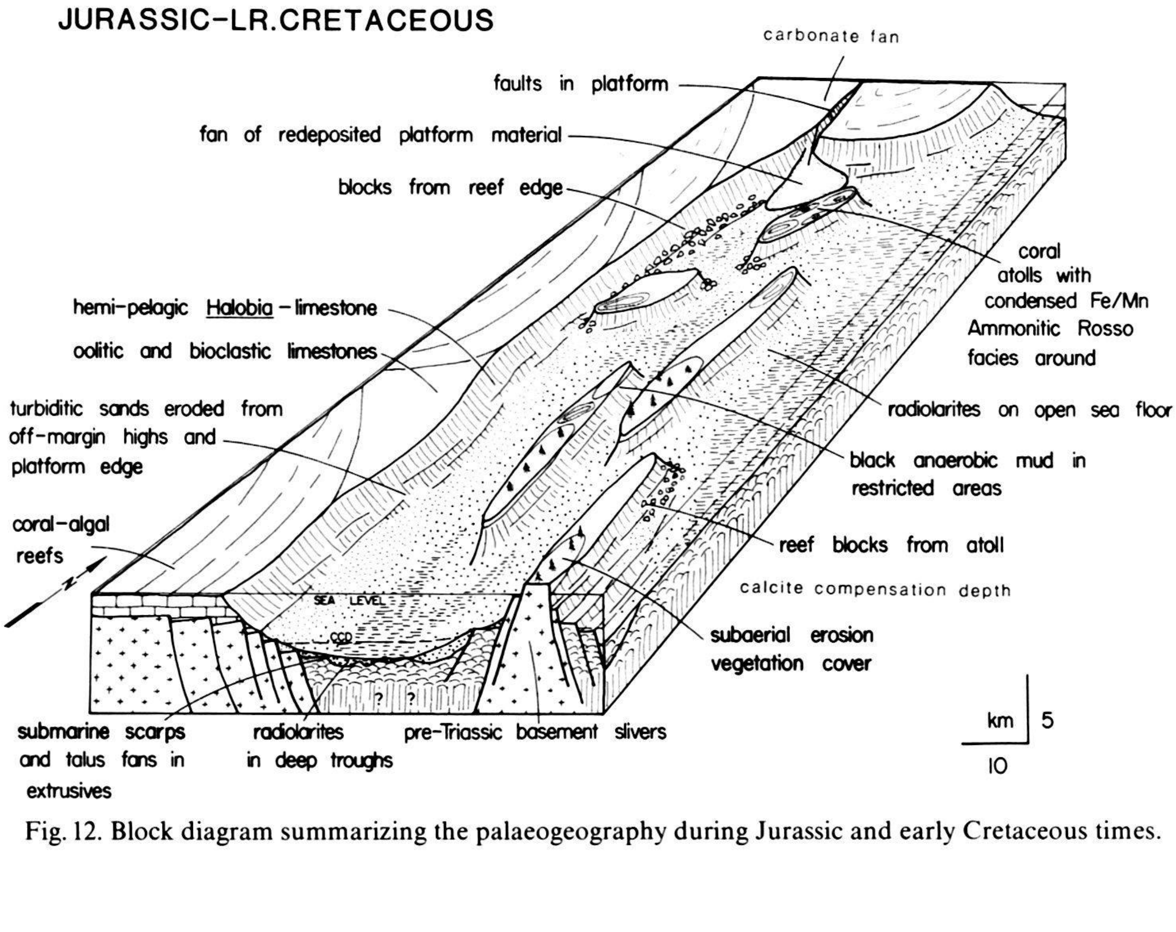


Fig. 12. Block diagram summarizing the palaeogeography during Jurassic and early Cretaceous times.

within the Gödene Zone. Redeposited bioclastic talus fringes many of the carbonate build-ups in the Gödene Zone, though major calcarenite intercalations are absent. This contrasts with the more widely dispersed carbonate detritus in the late Triassic, perhaps because by Jurassic time coral-algal barrier reefs had formed along the platform edge and as off-margin atolls (Fig. 12).

Fine grained redeposited hemi-pelagic limestones are found in the Kumluca Zone and around the offshore carbonate build-ups. Intercalated siltstones may be derived either from sedimentary basement areas still uplifted as horsts or possibly by reworking of the late Triassic quartzarenites. Black muds accumulated in local basins isolated from open marine circulation. Areas particularly affected were the central Kumluca Zone (Dereköy Formation), which formed a narrow deep basin between the Bey Dağları platform and an adjacent offshore carbonate build-up (Fig. 12), and troughs between several of the carbonate build-ups between the Gödene and Kemer Zones.

Radiolarites accumulated in deep water below the carbonate compensation depth along the outer margin of the Kumluca Zone, around the carbonate massifs in the Gödene and Kemer Zones, and particularly in the deep Gödene Zone basins floored by mafic extrusives. The radiolarites are bright red oxidized facies except locally where bottom waters were restricted. Radiolarian age determinations indicate that the bulk of these radiolarites were deposited in the upper Jurassic to lower Cretaceous interval. This implies that the early to mid Jurassic may have been a time of minimal pelagic sediment deposition or even submarine erosion by bottom currents. Major, trace and Rare Earth Element analyses show that occasional intercalations of manganiferous mudstones were formed from hydrothermal discharge during late Jurassic to mid-Cretaceous time.

In the western Tethys the late early to mid-Jurassic saw block faulting, collapse and disintegration of carbonate platforms (BERNOULLI & JENKYNS 1974). High initial subsidence rates may reflect listric faulting at depth (GRACIANSKY et al. 1979). Sea floor spreading was delayed until early late Jurassic time (BERNOULLI et al. 1979; ?Callovian-Oxfordian, GRACIANSKY et al. 1979). Solution of calcareous sediments increased with deeper waters until radiolarites accumulated (BOSELLINI & WINTERER 1975). By contrast, after the major late Triassic faulting and volcanism, in the Antalya Complex Jurassic to early Cretaceous time was tectonically more quiescent. Finer grained pelagic and hemi-pelagic deposition occurred both along the margins of the main Bey Dağları carbonate platform and around the subsiding horsts capped by carbonate build-ups.

5. Mid-late Cretaceous

5.1 *Ophiolitic rocks*

Several of the wider screens of serpentinite within the Gödene Zone include less altered bodies of tectonized diabase, gabbro, and ultramafic rocks including harzburgite and lherzolite (JUTEAU 1975; YILMAZ 1978; YILMAZ et al. 1981; e.g. Gödene and Saklıkent areas, Fig. 2). Mafic intrusive are tholeiitic, in contrast to the Upper

Triassic alkalic lavas. K-Ar dates suggest late Cretaceous ages for gabbros in the Gödene Zone (YILMAZ et al. 1981). Some of the mafic lavas seen by us are interbedded with and overlain by Upper Cretaceous pelagic chalks (e.g. Saklıkent and the Gödene to Soğutcuma road). A sample of nodular chert intercalated with mafic lava east of Dereköy (Fig. 2) gave a late Jurassic to early Cretaceous age (E. A. Pessagno, pers. comm. 1981). Thus, although now tectonized within serpentinite strands, the Gödene Zone ultramafic, mafic intrusives and some extrusives probably represent parts of a dismembered Upper Cretaceous ophiolite.

To the east, the Tekirova Zone comprises the lower levels of a much better documented ophiolite dated radiometrically as late Cretaceous (THUIZAT & MONTIGNY 1979). Southwards along the coast, progressively deeper levels of the ophiolite are exposed, including minor sheeted dykes (Kemer area, Fig. 2), layered and isotropic gabbros, and mantle tectonites (JUTEAU 1975; JUTEAU et al. 1977).

5.2 *Shallow water limestones*

In the northern Bey Dağları platform mid-Cretaceous bioclastic rudist-bearing limestones have a micro-fauna signifying fully open marine conditions for the first time (Katran Dağ, Fig. 11, log 1, Fig. 13, log 5; POISSON 1978). A similar facies transition is seen in the Gulluk Dağ off-margin massif in the north of the Gödene Zone (Fig. 8a, POISSON 1978).

5.3 *Redeposited carbonates*

A thick wedge of redeposited calcarenite and calcirudite crops out in the west of the central part of the Kumluca Zone (Taşkaya Tepe Formation, Fig. 3, Fig. 13, log 7; ROBERTSON & WOODCOCK 1981a). More eastern, distal sequences of pelagic chalks contain numerous beds of turbiditic calcarenite and matrix-supported calcirudite deposited by mass-flow. Graded calcarenites also occur to the north (Fig. 8a, Fig. 13, log 4; Elmalı Belli Formation, POISSON 1978), but are absent in the southern Kumluca Zone sequences of late Cretaceous age (Fig. 13, log 2).

5.4 *Pelagic limestones*

In many areas of the Bey Dağları carbonate platform, Upper Cretaceous sequences become first hemi-pelagic and then fully pelagic (POISSON 1978). On the southern Bey Dağları, pelagic carbonate deposition continued into early Tertiary times (Fig. 13, log 3).

Pink pelagic foraminiferal marls appear in the proximal Upper Cretaceous sequences in the southern part of the Kumluca margin zone (Fig. 13, log 2). Similar pink and gray foraminiferal carbonate dominates the upper levels of the distal sequences in the central part of the Kumluca zone (Fig. 13, log 7; Taşkaya Tepe Formation, ROBERTSON & WOODCOCK 1981a). In the northern area pelagic calcilutites are interbedded with siltstones and radiolarites (Fig. 13, log 4; Elmalı Belli Formation, POISSON 1978).

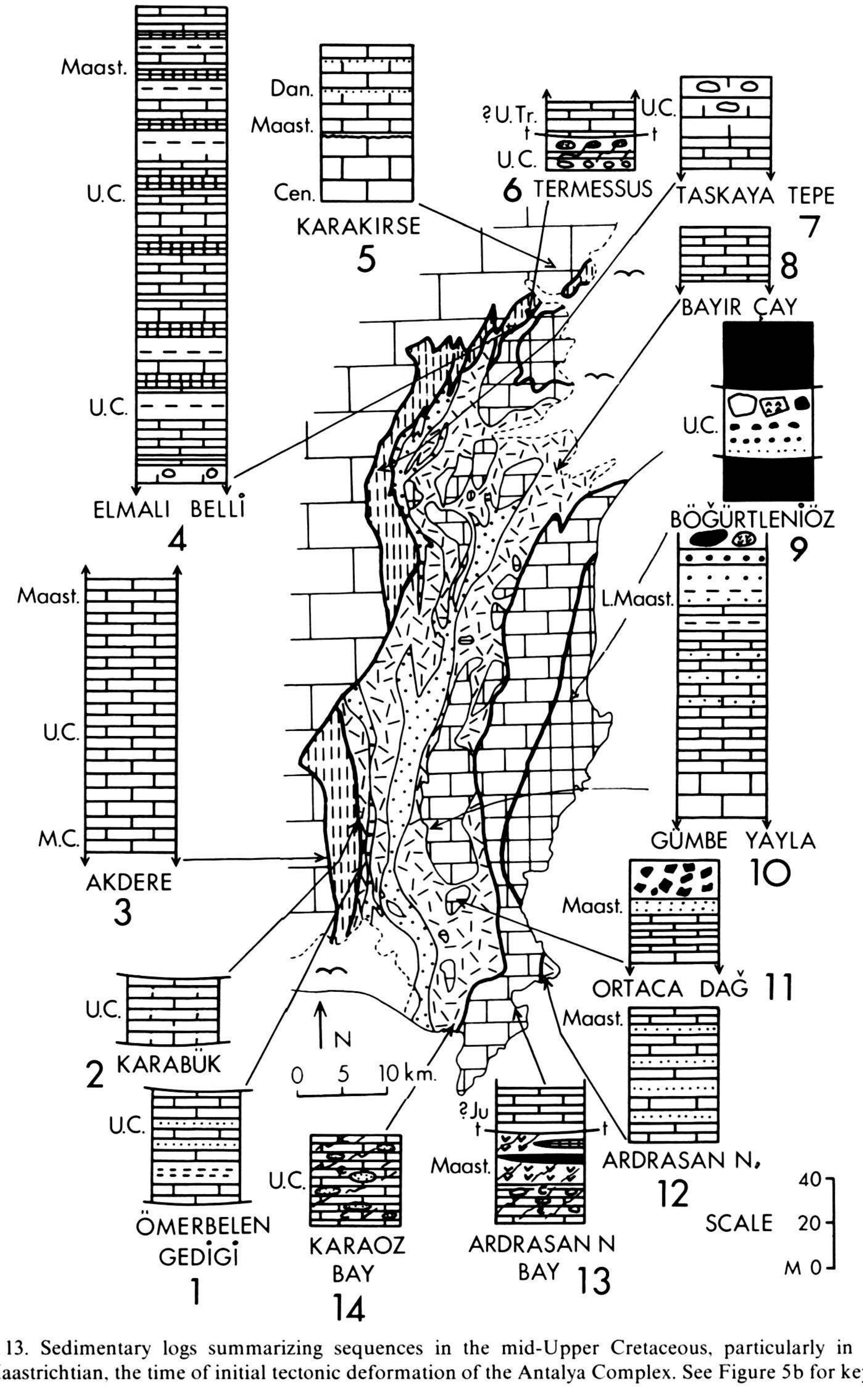


Fig. 13. Sedimentary logs summarizing sequences in the mid-Upper Cretaceous, particularly in the Maastrichtian, the time of initial tectonic deformation of the Antalya Complex. See Figure 5b for key.

Gödene Zone carbonate build-ups show a transition to Upper Cretaceous pelagic carbonate similar to that on the main Bey Dağları platform (e.g. Gümbe Yayla, Fig. 13, log 10). In the Gödene Zone, sequences fringing carbonate-build-ups locally pass up into pelagic chalks similar to those in the southern Kumluca Zone (e.g. Bayır Çay, Fig. 13, log 8). Close to the southern margin of the Kumluca Zone, large slumped masses of silty pelagic carbonate are exposed (Fig. 13, log 1).

5.5 *Radiolarites*

Radiolarites are known to continue up into the Maastrichtian in the northern Kumluca Zone (Fig. 8a, log 4, Elmalı Belli Formation, POISSON 1978) where they are intercalated with calciturbidites, siltstones, mudstones and pelagic limestones (Fig. 13, log 4). The Gödene Zone radiolarites examined by E. A. Pessagno have all indicated late Jurassic to early Cretaceous ages.

5.6 *Manganiferous mudstones*

Intercalations of black manganiferous mudstones are known in the Upper Createaceous only in the Elmalı Belli sequence of the northern part of the Kumluca Zone (Fig. 13, log 4).

5.7 *Mid-late Cretaceous palaeogeography*

Pronounced deepening from mid to late Cretaceous times resulted in a switch to first hemi-pelagic then pelagic carbonate deposition over much of the Bey Dağları platform and the off-margin carbonate banks. In the Katran Dağ (Fig. 2) up to 2000 m of neritic limestones were deposited during Cenomanian time (POISSON 1978). Although the late Cretaceous is thought to have been a time of rising sea level (VAIL et al. 1977) the general switch to hemipelagic and pelagic deposition for the first time is attributed to marked regional subsidence, associated with some form of seafloor spreading in adjacent areas (see below). By mid-Cretaceous time, greatly increased abundance of planktonic foraminifera (BOSELLINI & WINTERER 1975) had depressed the carbonate compensation depth, explaining the incoming of calcareous pelagics on both the Kumluca passive margin and around the margins of the offshore carbonate banks. Topographic highs in the lava basement, which had remained exposed since late Triassic time, were blanketed for the first time by pelagic carbonates. However the absence of these carbonates above the basinal radiolarian chert sequences suggests that these areas may have remained below the late Cretaceous carbonate compensation depth.

The thick wedges of redeposited limestone in the central Kumluca Zone suggest differential movements between the Bey Dağları platform and Gödene marginal oceanic crust during late Cretaceous time. Manganiferous intercalations in central and northern distal sequences (away from the Bey Dağları Zone) are taken to indicate hydrothermal discharge onto the seafloor. The exceptionally thick radiolarites interbedded with pelagic chalks in the northern area could reflect enhanced primary productivity along this part of the margin. In the north-eastern Gödene

Zone, micrites were redeposited into a background radiolarian chert sequence (Elmalı Belli Formation).

5.8 *Seafloor spreading history*

One outstanding problem in the Antalya area is the exact timing, location and duration of seafloor spreading. There are two main possibilities. The first is that the late Triassic rifting and volcanism marked the onset of seafloor spreading in adjacent areas to the east not now preserved in the Antalya Complex. Such early seafloor spreading would be consistent with the relatively passive subsidence of the Antalya area during Jurassic to early Cretaceous time. In this manner, SEARLE et al. (1980) have proposed that the alkalic to transitional tholeiitic mafic extrusives of the Haybi Complex in Oman (GLENNIE et al. 1973) mark the onset of seafloor spreading as early as late Triassic to early Jurassic time. Notably, in Greece, seafloor spreading was probably initiated in early to mid-Jurassic time, followed by tectonic emplacement of the Othris ophiolite prior to early Cretaceous (SMITH & WOODCOCK 1976).

Alternatively, the Upper Triassic of Antalya could represent a major failed rift which only fully separated in late Jurassic to early Cretaceous or later time, partly then along new structural lines. This pattern would approximate to the western Tethys (e.g. BERNOULLI & JENKYNS 1974). Consistent with this, Upper Jurassic to Lower Cretaceous sequences of the rift margins are marked by localized redeposition of texturally mature shallow water quartzose sands into deeper water, and extensive hydrothermal manganese accumulation. Also, ophiolitic rocks in the Gödene Zone, presumed to be marginal (see below) are dated as late Cretaceous; Jurassic ophiolitic rocks are not known. During mid-late Cretaceous time both the Bey Dağları platform and the offshore horsts switched to pelagic accumulation, consistent with rapid subsidence.

The Upper Cretaceous ophiolitic rocks in the Gödene Zone could be explained in several ways. They could be fragments of younger oceanic crust entrained along the margin by later emplacement-related strike-slip faulting. YILMAZ & MAXWELL (1981) suggest that they were formed and emplaced along a mega-crustal shear zone, by analogy with the western USA. In this case the various Gödene ophiolitic fragments could be of different age and origin from the Tekirova ophiolite to the east. Another possibility is that the Gödene ophiolitic rocks formed essentially in their present position during the onset of the seafloor spreading that produced the Tekirova ophiolite.

The first possibility is opposed by the absence of any definite major duplication of the continent/ocean transition along the Antalya margin. Moreover, the various carbonate massifs in the Gödene and Kemer Zones are interpreted as carbonate build-ups on older continental horsts within the late Triassic rift zone rather than merely as slices of the edge of a single carbonate platform (ROBERTSON & WOODCOCK 1981c). The second possibility, involving opening and closing of ophiolitic basins, is most unlikely, as margin sediments remained undeformed until latest Cretaceous time. Convincing and consistent age differences within the ophiolites have yet to be established.

The option that we favour is that regardless of the earlier history (aborted rift or older nearby seafloor spreading) the Antalya margin came under renewed crustal extension during late Jurassic to early Cretaceous time, with associated tilting, hydrothermal activity and genesis of oceanic crust. The older Triassic rift zones broke up as new oceanic crust formed both within the Gödene Zone and the Tekirova Zone. Continental slivers were thus further rifted off and isolated from the parent Bey Dağları platform edge. These marginal zones of oceanic crust were exploited during later strike-slip tectonics, when ultramafic rocks were hydrated and moved upwards to form the typical anastomosing strands of sheared serpentinite.

6. Maastrichtian (latest Cretaceous)

The Maastrichtian sequences document the first major tectonic deformation of the Antalya Complex following the creation of oceanic crust. Evidence of this is seen in all tectonic zones except the Bey Dağları autochthon in the west, which remained unaffected until Palaeocene time.

6.1 *Ophiolitic siltstones and sandstones*

An upward passage from typical late Cretaceous pelagic chalks to ophiolite-derived sediments is well exposed on the Teke Dağ, a major off-margin massif in the southern part of the Gödene Zone (Gümbe Yayla, Fig. 13, log 10). The sequence coarsens upwards from thin beds of calcareous mafic silt to turbiditic ophiolite-derived arenites, and then to substantial detached blocks of ophiolitic rocks, including serpentinite.

6.2 *Ophiolitic olistostrome melange*

Olistostrome melange is seen at several localities along the contact between the southern part of the Kemer Zone and the Tekirova Zone and more locally in the north-eastern Gödene Zone. In the south-east (Karaoz Bay, Fig. 13, log 4), the melange comprises olistoliths of medium grained grey ophiolite-derived calcareous arenite in a matrix of sheared silty pink marl. Further north, along the south side of Ardrasan Bay (Fig. 13, log 13), 50 m of strongly sheared olistostrome melange is intercalated between serpentinized harzburgite of the Tekirova Zone and the Kemer Zone limestones. This olistostrome contains clasts (to 0.3 m) of red chert, ophiolite-derived arenite, diabase, lava, recrystallized limestone and white calcilutite, set in a matrix of chalky marl. These lithologies suggest a provenance in the Gödene Zone. A sliver of tectonized olistostrome melange can be traced northwards for 10 km along the Kemer–Tekirova Zone contact (Fig. 13, log 12). In the north-east, olistostrome melange is in tectonic contact with the northern edge of the Gulluk Dağ carbonate massif (Fig. 13, log 6). It contains small clasts (up to 0.15 m) of limestone, chert, siltstone and lava, again set in a sheared chalky matrix.

6.3 *Serpentinite clastics*

Serpentinite clastics form the highest exposed stratigraphic levels above Maastrichtian chalks and intercalated ophiolite-derived sediments in the southern part of the Teke Dağ carbonate massif (Ortaca Dağ, Fig. 13, log 11). They are crudely stratified horizons up to 5 m thick with well rounded polished clasts of serpentinite up to 0.30 m in diameter. Some beds also contain clasts of radiolarian chert and pillow lava.

6.4 *Ophiolite-derived rudites in the Tekirova Zone*

As noted earlier, the Tekirova Zone exposes a 60 × 8 km, north–south trending, segment of the deeper levels of the late Cretaceous ophiolite suite. Sheeted dykes are exposed locally north of Kemer (JUTEAU 1975), while progressively deeper levels of the ophiolite are exposed southwards from Kemer. Along the coast the Tekirova ophiolite strikes east–west and is apparently structurally intact. By contrast the ophiolite is highly sheared close to the contact with the Kemer Zone to the west and is intercalated with a variety of mostly gently dipping ophiolite-derived rudites (Fig. 13, log 9). These include sheared soft mafic mudstone matrix-supported rudites and matrix-free ophiolitic mega-breccias (Fig. 14b). The mudstones are often pyritous, rich in plant material, and contain bivalves and other shells of late Cretaceous age. Derived clasts include all the ophiolitic rocks including mafic lava, radiolarian chert and pelagic limestone. In several cases crudely stratified ophiolite-derived arenites contain entire lava pillows with interstitial Fe-oxide material (Fig. 14c).

In the most spectacular road-cut through the rudites (Fig. 14a) laminated mudstones and sandstones pass into matrix-supported rudites, with a strongly scoured base, containing abundant lava and diabase. Overlying rudites containing numerous blocks of gabbro which become smaller upwards. The highest exposed levels of the road-cut consist of blocks of serpentinite up to 9 m in diameter.

6.5 *Late Cretaceous events*

Sedimentary sequences throughout the Antalya Complex terminate in the Maastrichtian. By contrast Bey Dağları pelagic sequences continue unbroken into the Palaeocene. Only locally in the north (Katran Dağ, POISSON 1978) do Maastrichtian (? Danian) pelagic chalks contain grains of red chert, mafic and ultramafic rocks presumably derived from the Antalya Complex. The various ophiolitic olistostromes and ophiolite-derived clastics therefore document the onset of tectonic slicing of the ophiolitic rocks of the Gödene and Tekirova Zones though at some distance from and probably topographically lower than the Bey Dağları platform (Fig. 15).

In each case the olistostromes and clastics reflect relatively local parent rock types rather than being, for example, derived from a major advancing ophiolite nappe. The serpentinite clastics in the Gödene Zone (Ortaca Dağ) were thus apparently derived from the nearby serpentinite screens to the north-west. Our structural work (WOODCOCK & ROBERTSON 1981, 1982) suggests that east–west shortening linked with north–south strike-slip faulting was initiated in latest Cretaceous time. This mobilized underlying ophiolitic ultramafic rocks as serpentinite diapirs which protruded up the active fault zones. Serpentinite reached sufficiently high levels for material to be eroded and redeposited directly onto the adjacent former carbonate banks. Further west at this time the Kumluca margin was

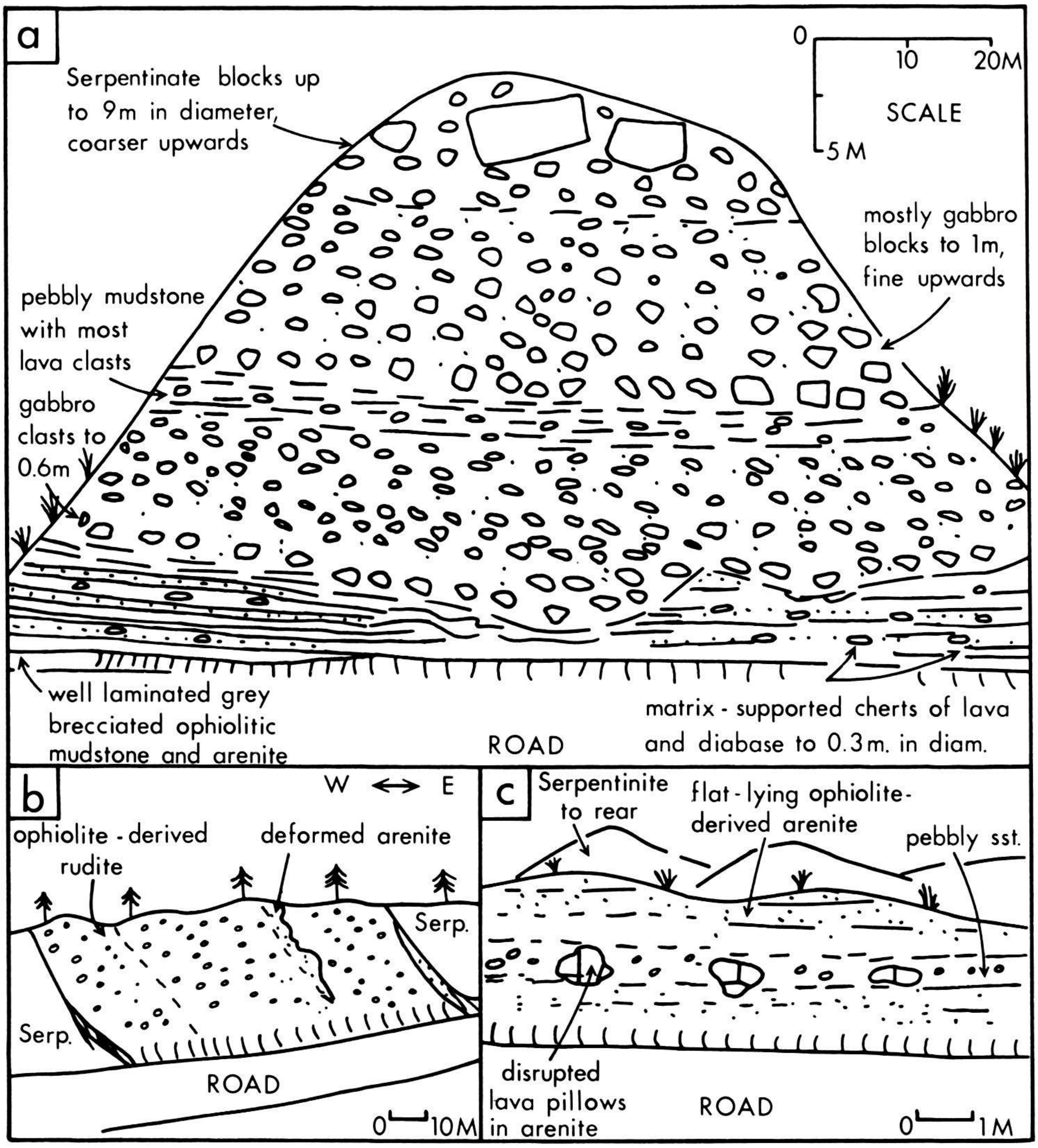


Fig. 14. Field sketches of ophiolite-derived sediments tectonically intercalated with upper Cretaceous ophiolites of the Tekirova Zone. See text for full explanation.

being tectonically imbricated. The late Cretaceous pelagic carbonates were still unconsolidated and the higher levels of the more distal Kumluca margin facies slid westward to form the series of highly deformed allochthonous masses close to the actual contact with the Gödene Zone. Along the Gödene–Kemer Zone contact late Cretaceous marls form the matrix of the olistostrome melange. The absence of harzburgite derived from the now adjacent Tekirova Zone implies that, at least in the south, lower parts of the Upper Cretaceous ophiolite had not yet been uplifted.

The localized olistostrome melange in the north-east of the Gödene Zone is attributed to compression and uplift of late Triassic ophiolitic rocks between the

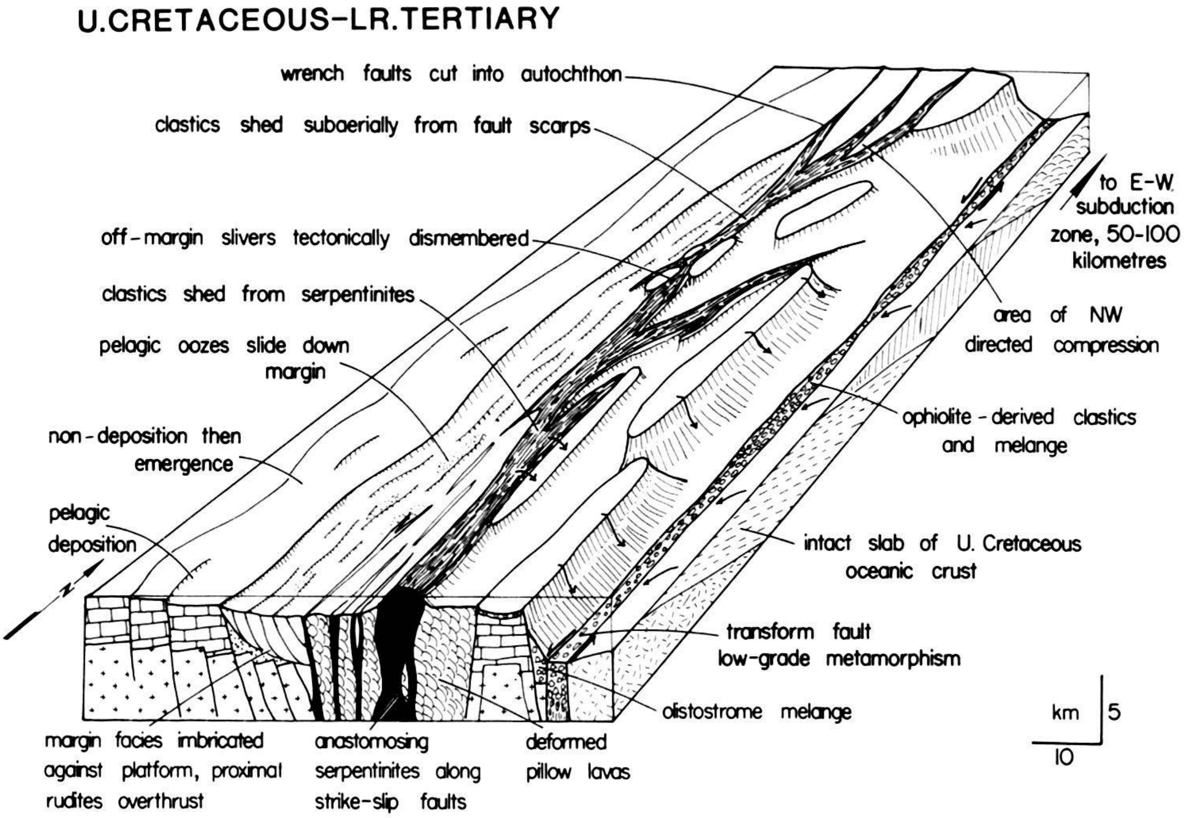


Fig. 15. Block diagram illustrating the palaeogeography during Maastrichtian to early Tertiary time.

Kumluca margin (Çatal Tepe unit) and Gulluk Dağ off-margin carbonate massif to the south (Fig. 15).

The ophiolitic rudites along the western edge of the Tekirova Zone were rapidly deposited during tectonic emplacement of the Tekirova ophiolite. The abundant mafic lavas, cherts and pelagic limestones probably derive from the original upper levels of the ophiolite. Close to the Kemer Zone the ophiolite now exists as detached blocks and irregularly shaped sheets up to 1 km in diameter intercalated with ophiolite-derived sediments which locally show a reversed ophiolite stratigraphy, from mafic extrusive to serpentinites. By contrast, along the coast, the Tekirova ophiolite is an intact mass dipping consistently northwards. The Kemer–Tekirova Zone contact shows intense shearing and low grade metamorphism of limestones, mafic lavas and radiolarites, seen elsewhere only locally along the Kemer–Gödene Zone contact in the extreme south-east. Along this line an Upper Cretaceous ophiolite is in near vertical tectonic contact with much older carbonate margin and basement rocks (Kemer Zone). In addition Miocene marine limestones south of Kemer show a north–south oriented subvertical spaced cleavage, unusual in Antalya Complex rocks. Our view is that during latest Cretaceous time the Kemer–Tekirova contact acted as north–south striking sinistral transform fault linking east–west subduction zone segments to the north-east and south-west (Robertson & Woodcock 1980b). In this model, eroded sediment and detached blocks slid westwards from the Tekirova zone as it moved northwards and were deposited in a trough adjacent to the Kemer Zone (Fig. 15).

Finally it should be noted that the mapped pattern of braided anastomosing strands of serpentinite and other ultramafic rocks is not a melange composed of discrete clasts in a sedimentary matrix (cf. YILMAZ & MAXWELL 1981). This, together with the observation that adjacent Bey Dağları carbonate deposition continued into the Palaeocene, opposes an origin as an "obduction melange" formed beneath a major nappe advancing in Late Cretaceous time (YILMAZ & MAXWELL 1981) like the Semail Nappe, Oman (GLENNIE et al. 1973).

7. Cenozoic

7.1 *Tertiary sediments - Bey Dağları Zone*

In the southern Bey Dağları (Fig. 16, log 2) pelagic deposition continued from Maastrichtian into Palaeocene time without a break. By contrast, north of the Antalya to Korkuteli road, upper Cretaceous and Danian pelagic carbonates (POISSON 1978) are overlain by olistostrome melange dated as Palaeocene and early Eocene. In good exposures near Bademağaci (Fig. 16, log 5) initial mafic silts and marls are overlain by turbiditic arenites and then olistostrome melange containing detached blocks of serpentinite up to 1.5 m in diameter.

From Palaeocene to Oligocene time strongly condensed sequences (POISSON 1978) in the inner, western, areas of the Bey Dağları contrast with more basinal facies along its eastern edge (Fig. 16, log 3, HAYWARD & ROBERTSON 1982). For example in the Eocene, at a time when parts of the autochthon were emergent (bauxites), up to 150 m of redeposited carbonates accumulated along the eastern edge of the autochthon. These include calcirudites laid down by mass flow and calciturbidites with interstratified pelagic micrites (Fig. 16, log 3, HAYWARD & ROBERTSON 1982). In the north (e.g. Hatıpalanı, Fig. 16) these basinal Eocene facies are seen *in situ* beneath the thrust Kumluca Zone rocks, whereas in the south identical facies form a tectonic slice between the Miocene sequences of the adjacent autochthon and the allochthonous Kumluca Zone (Fig. 16, log 9, WOODCOCK & ROBERTSON 1981).

Miocene time saw a marked switch from mostly calcareous to coarse ophiolite-derived clastic sedimentation. In the east Bey Dağları, Miocene sequences only occur in the south, close to the tectonic contact with the Kumluca Zone. They comprise 200 m of early Miocene ophiolite-derived arenites and rudites with lutites interstratified with thin beds of foraminiferal chalk (Fig. 16, log 2). Clasts of all important Kumluca and Gödene Zone lithologies are present, usually extremely well rounded. Substantial lenses of calcirudites and calcarenites up to 50 m thick are also present. The derived carbonate matches the late Cretaceous and early Tertiary interval of the subjacent Bey Dağları sequence. By contrast, contemporaneous sequences further west (Fig. 16, log 1, HAYWARD & ROBERTSON 1982) consist of up to 350 m of mafic sandstones, interbedded with mudstones and pelagic chalk. In both areas sedimentary structures indicate transport mostly from the east and north-east.

Later Miocene ophiolite-derived clastics are known only from the inner western parts of the Bey Dağları. For example in the Akçay valley (Fig. 16, log 1) about

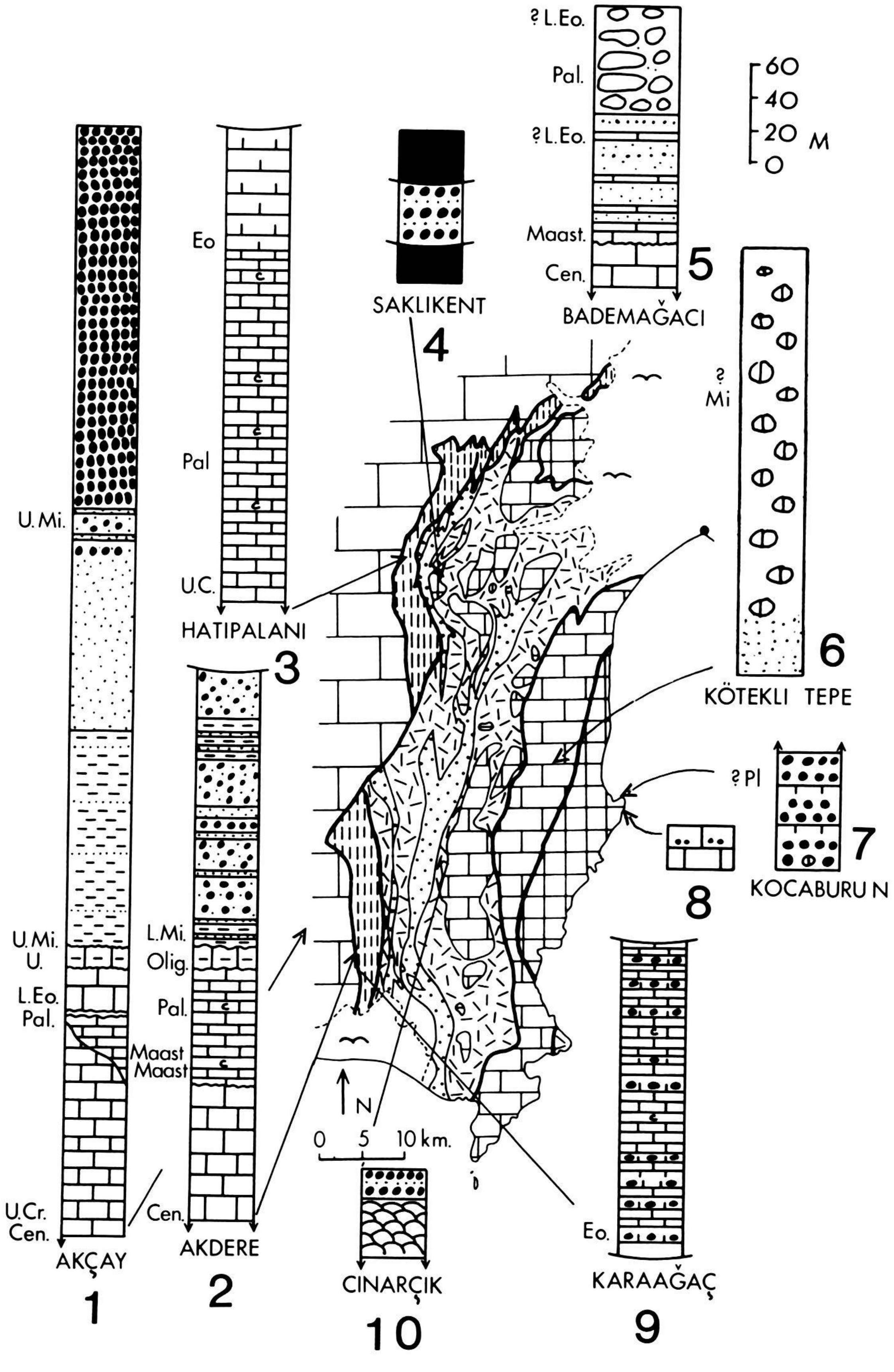


Fig. 16. Sedimentary logs summarizing deposition in the early-mid Tertiary.

200 m of poorly stratified ophiolite-derived rudites are interbedded with minor arenites and mudstones. Rootlets and caliche horizons indicate subaerial exposure (HAYWARD & ROBERTSON 1982). By contrast along the eastern edge of the Bey Dağları the early Miocene clastic sequence passes up abruptly into 70 m of tectonic melange, containing blocks of mostly Kumluca Zone rocks in a matrix of disrupted ophiolite-derived sediments, and then into tectonically overlying Kumluca Zone sheets. Thick clast-supported rudites seen to the west are absent.

Post-Miocene sediments are only known in the western Bey Dağları (Kasaba Basin) where they consist of subaerially reddened fluvial ophiolite-derived rudites and arenites (HAYWARD 1982).

7.2 *Tertiary sediments in the Antalya Complex*

The only dated Tertiary rocks within the Antalya Complex are small outcrops of Miocene shallow marine limestone overlying the Tekirova ophiolite south of Kemer (Fig. 16, log 8). As noted above, by early Miocene times well rounded ophiolite-derived rudites were being supplied westwards from the Antalya Complex onto the Bey Dağları zone (Fig. 16, logs 1, 2). Because the debris can only have been rounded in a fluvial environment, at least the southern area of the complex was subaerially exposed and undergoing rapid erosion at this time. Locally (Fig. 16, log 6), on the Antalya-Kemer road, about 250 m of rudites composed of well rounded clasts of limestone and replacement chert (without ophiolitic debris) are intercalated with brown calcareous mudstone. Contrasting unfossiliferous subaerially deposited ophiolite-derived clastics are present as deformed intercalations within the ophiolitic rocks of the Gödene Zone (ROBERTSON & WOODCOCK 1980a). These sediments range from well stratified arenites (Fig. 16, log 10) to matrix supported disorganized rudites (Fig. 16, log 4). Sedimentary features indicate rapid deposition from ephemeral fault scarps. Often the clast compositions bear little relation to presently adjacent rocks.

7.3 *Interpretation*

During late Cretaceous time strong east-west compression was coupled with major uplift. Specifically serpentinites, including harzburgites, in places (Teke Dağ) reached a higher structural level than adjacent carbonate build-ups, a local uplift of greater than 10 km. However, at this time, the Antalya Complex remained isolated from or topographically lower than the Bey Dağları platform to the west, since no sediments were shed onto the platform from the complex. In the north, ophiolitic olistrostromes were first shed onto the Bey Dağları Zone in Palaeocene to early Eocene times (Fig. 17) but further south ophiolite debris does not appear until early Miocene time. During early Tertiary time, western areas of the Bey Dağları were emergent whilst eastern areas received redeposited carbonate facies.

During late Cretaceous to Miocene time wrench-faulting within the Antalya Complex produced a series of small basins which are infilled by subaerial clastic sediments and then deformed by continued faulting (ROBERTSON & WOODCOCK 1980a). By early Miocene time renewed west directed compression allowed material from the complex to be shed directly onto the Bey Dağları autochthon. The Antalya Complex existed as a deeply-dissected landmass separated from the Bey Dağları Zone by a narrow north–south trending marine trough (Fig. 17). A number of small submarine fans prograded westwards into this trough (HAYWARD & ROBERTSON 1982). Accompanying fault-dissection of the autochthon produced large volumes of carbonate clastics.

The absence of ophiolite-derived material on the Bey Dağları adjacent to the central Kumluca Zone (Bilelyeri Group) and the east and north-east source for the ophiolite-derived clastics implies that the northern edge of the Bey Dağları Zone was tectonically overridden relatively early. Miocene clastics may be present to the north-west beneath the Lycian nappes. In the south the submarine fan phase was itself abruptly terminated in the later Miocene by westward overthrusting of the Antalya Complex to near its present position, forming a basal tectonic melange. Slivers of the Eocene Bey Dağları facies were stripped off and entrained along the base of the Antalya allochthon. Alluvial fans then prograded westwards over the autochthon, where rapid coarse grained ophiolite-derived deposition continued into the Pliocene (Fig. 17). An alternative explanation for the absence of pre-Miocene ophiolite-derived sediment in the Bey Dağları sequences is that the Antalya Complex only reached its present position by strike-slip faulting in Miocene time. In this case the present Kumluca Zone basal thrust would conceal an earlier strike-slip

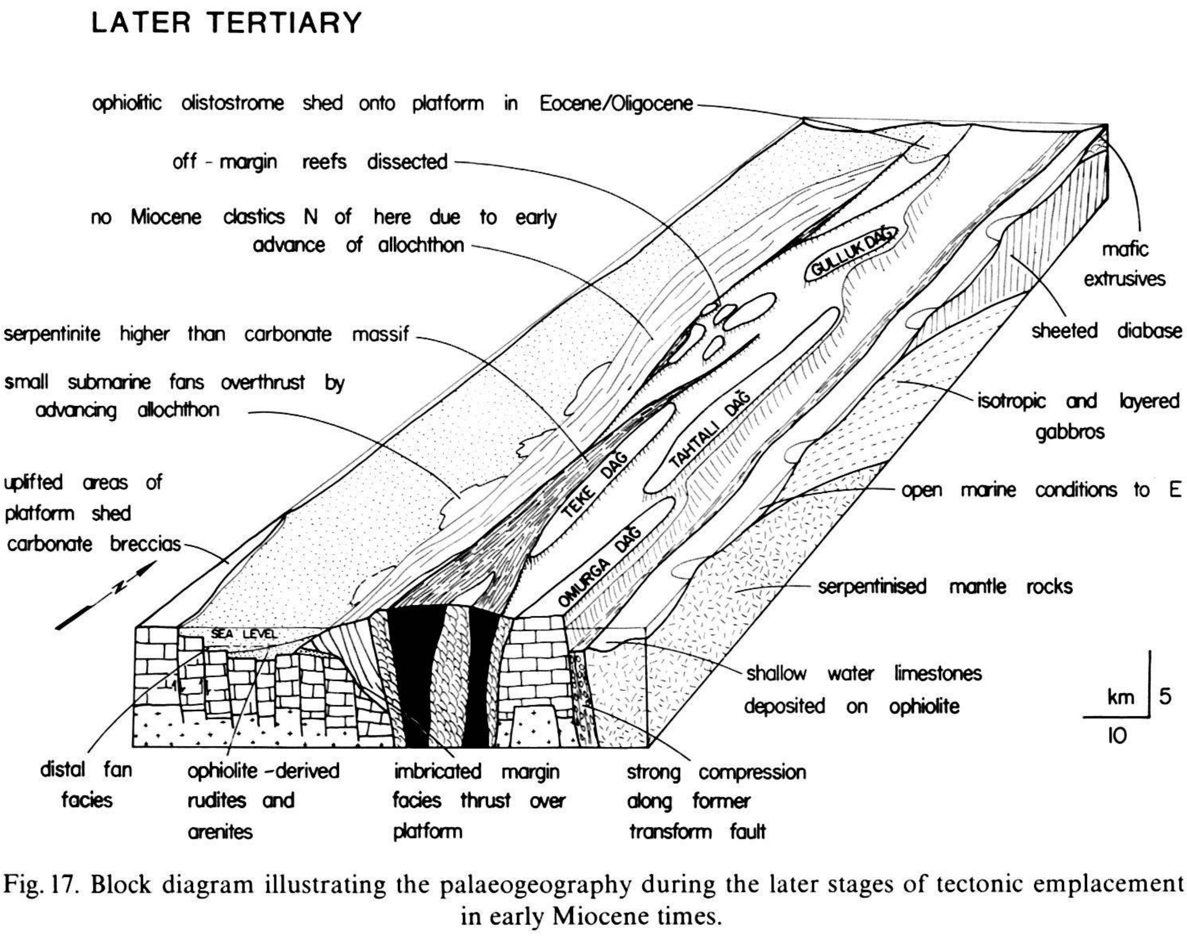


Fig. 17. Block diagram illustrating the palaeogeography during the later stages of tectonic emplacement in early Miocene times.

fault. However this interpretation seems unlikely as the Kumluca Zone itself shows no signs of strike-slip faulting, which is instead concentrated in the Gödene Zone to the east. Most Tertiary strike-slip faulting was probably concentrated along the Kemer-Tekirova tectonic contact. This is particularly suggested by extensive shearing of the adjacent Kemer limestones and other rocks including mafic lavas radiolarian cherts and pelagic limestones, which have locally been converted to low grade metamorphic rocks (e.g. Antalya-Kemer road sections). During Miocene time, open sea already lay immediately to the east of the Kemer Zone. The only other ?Miocene sediment within the Antalya Complex are possible limestone-derived alluvial fan facies seen locally to the east of the Antalya-Kemer road. As these are vertically dipping, deformation must have continued at least along the Kemer-Gödene Zone contact.

7.4 *Neogene history*

Extensive areas of the Antalya Complex, particularly in the east, are obscured by thick wedges of subaerial limestone breccias up to 250 m thick. These rudites have not been dated but are probably Pliocene and/or Pleistocene in age. Rudite wedges radiate outwards from the major carbonate massifs in the Gödene and Kemer Zones. The thickest remaining rudites blanket the east side of the Tahtalı Dağ (Kemer Zone). Some marine calcirudites are present along the Antalya-Kemer coast (Fig. 16, log 7). Most rudites are composed entirely of angular limestone clasts up to 0.3 m across but locally, adjacent to the Tekirova Zone, the basal rudites are highly angular breccias of mafic and ultramafic ophiolitic rocks.

The Neogene rudites imply strong relative uplift of the carbonate massifs following late Miocene deformation. By Neogene time the Tekirova Complex was also uplifted and undergoing erosion.

8. Summary and comparisons

We have described the Mesozoic and Cenozoic history of the south-western segment of the Antalya Complex, which we interpret as a deformed Mesozoic passive margin dating back to mid-late Triassic continental rifting and subjected to strike-slip dominated tectonics in latest Cretaceous to early Tertiary time.

During late Triassic time a complex palaeotopography existed, with continental horsts capped by carbonate build-ups and deep basins floored by thick alkalic mafic extrusives and radiolarites. Evidence is at present inadequate to say whether this late Triassic rifting marked the onset of seafloor spreading in areas to the east or whether, as in the western Tethys, seafloor spreading was delayed at least until late Jurassic time. This is important in the light of arguments by PEARCE (1980) that the Upper Cretaceous Troodos ophiolite could have developed above a subduction zone. This hypothesis requires that older oceanic crust must have existed in the area. To date no evidence of such crust has been found, for example as Upper Triassic transitional alkalic/tholeiitic extrusives or Jurassic ophiolites.

There is definite evidence of instability and hydrothermal activity along the Antalya margin during late Jurassic to early Cretaceous time. Texturally mature quartzitic sands were locally redeposited into deeper water. Extensive manganese is volcanic exhalative in origin. Then, during mid-late Cretaceous time, the whole of the Bey Dağları carbonate platform and adjacent build-ups show a switch to deep water pelagic carbonate deposition, consistent with rapid subsidence. These events could either represent the first major ocean-floor spreading superimposed on older Triassic continental rifts, or could conceivably record the initiation of a younger marginal basin related in some obscure way to subduction. In either interpretation, oceanic crust formed in both the Tekirova and Gödene Zones in late Cretaceous time. The passive margin phase ended in Maastrichtian time with substantial east-west shortening, though the adjacent carbonate platform was not affected until well into the Tertiary.

During early Tertiary time much of the Antalya Complex was probably subaerially exposed and undergoing pervasive strike-slip faulting. Specifically, the major crustal discontinuity between the Kemer and Tekirova Zones is interpreted as a major transform fault, possibly separating an "Apulian micro-plate" to the west from an "Anatolian micro-plate" to the east (BIJU-DUVAL et al. 1977). By early Miocene time renewed east-west compression brought the already deformed Antalya Complex against the Bey Dağları carbonate platform, shedding large volumes of ophiolite-derived clastics.

In the discussion above, and in our earlier papers dealing with specific aspects of the Antalya Complex, we have already stressed comparisons with continental margin development elsewhere in the East Mediterranean and the Tethys generally. Notably, the mid-late Triassic crustal extension phases in the western Tethys are similar to the Antalya Complex, although possibly less highly developed. However, doubt about the timing of seafloor spreading in the Antalya Complex clouds later comparisons with the western Tethys. The dominantly strike-slip tectonic emplacement of the Antalya Complex contrasts with many other parts of the Tethys, for example Oman.

Here we conclude by briefly examining two possible analogues not yet tectonically emplaced; the Miocene to Recent of the Red Sea and the Mesozoic history of Belize in the Caribbean.

In the Red Sea, after a major rift phase, magnetic anomalies confirm seafloor spreading since 2.4 m.y. (Pliocene, e.g. COLEMAN 1974). The Deep Sea Drilling Project cored lithologic units in the Red Sea ranging from Miocene to Recent (WHITMARSH et al. 1974). The lowest unit, of late Miocene and older age, comprises evaporites with minor metal-rich black shales, which apparently relate to the late Miocene dessication of the Mediterranean (HSÜ et al. 1973). Within and above the evaporites are grey dolomitic silty claystones which bear comparison with local organic-rich dolomitic shales in the Antalya Complex Kemer Zone. The overlying units, also of late Miocene age are composed of grey nannoplankton silty claystone rich in plagioclase with subordinate mica and quartz. The highst unit, of Pliocene to Recent age, is more pelagic, dominated by planktonic foraminifera and pteropods but with clastic input continuing in response to Plio-Pleistocene pluvials and coeval shallow marine to subaerial volcanism.

Although also produced by continental rifting, the Antalya Complex differs from the Red Sea. a) Rifting of the Red Sea was preceded by vast outpouring of plateau lavas, reflected in the Miocene plagioclase-rich sediments, whereas in Antalya volcanism is virtually restricted to the rift zone. b) Unlike the Red Sea, the Antalya area was already an epicontinental sea prior to rifting. Rift-related evaporites are minor and localized rather than basin-wide. c) Almost all the Antalya alkalic rift volcanism was submarine, mostly in deep water, so that true tuffs are virtually unknown after the early mid-Triassic. d) Pelagic deposition in the Red Sea is delayed until seafloor spreading during the Pliocene formed a marine connection with the Indian Ocean, whereas in Antalya pelagic sediments were deposited from the time of the early mid-Triassic rifting.

A possibly closer analogy exists between the south-western segment of the Antalya Complex and the continental margin off Belize (British Honduras), south-western Caribbean (Fig. 18). There the margin is dominated by *en echelon* ridges trending north-east, which merge southwards towards the margin. The inner ridges are capped by classic coral atolls (JAMES & GINSBURG 1979) floored both by older Palaeozoic basement lithologies and mafic intrusive rocks (e.g. diabase; DILLON

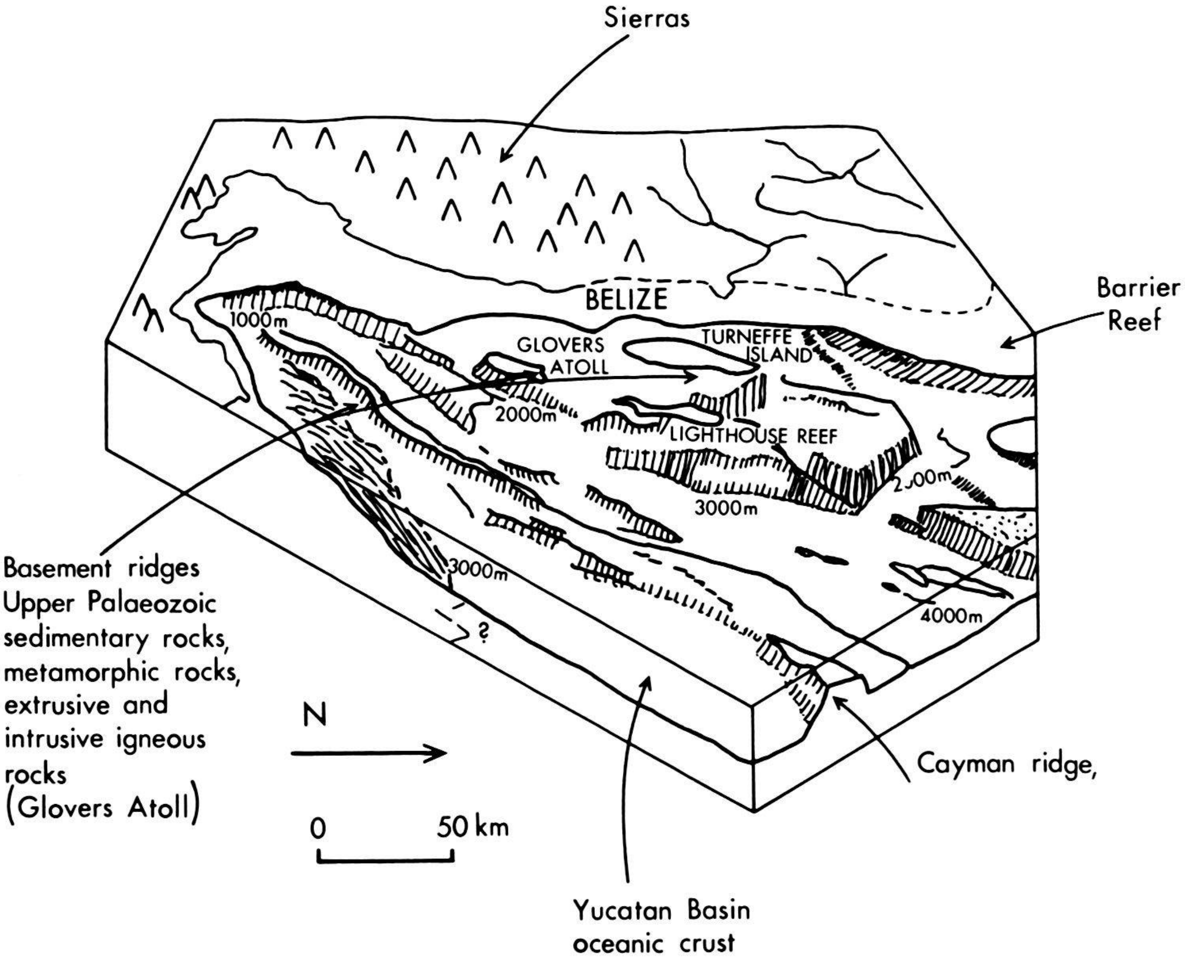


Fig. 18. Block diagram to illustrate the similarity between the inferred palaeogeography of the Antalya Complex during its passive margin phase with the Belize continental margin in the south-western Caribbean. Viewed west over the Cayman trough (oceanic crust) showing three offshore reef complexes and atolls bordering a long narrow continental shelf and barrier reef. Simplified after DILLON & VEDDER (1973).

& VEDDER 1973; UCHUPI 1973). By contrast the outer basement highs appear to be oceanic crust. Regional syntheses indicate that the margin formed in two stages, an initial "sphenochasmic" opening phase in late Jurassic time followed by renewed off-margin spreading after late Cretaceous. As the margin subsided thick coral atolls grew on the offshore ridges, adjacent to a barrier reef on the main margin. JAMES & GINSBURG (1979) note two types of marginal slope. Steep fore-reef slopes extend to more than 1000 m without a break. Downward sediment movement is mostly by mass flow, including sliding of substantial detached blocks of reef limestone down to depths over 2000 m. By contrast, between the off-margin atolls and the barrier reef, the reef slope flattens out between 300 and 400 m into a gently sloping bottom area dominated by calcareous pelagic sediments. Submersible and seismic studies indicate that most of the sediment reaching deep water is derived from the intermediate and deep zones of the living reef and to a lesser degree from the reef wall itself. Shallow water material (less than 20 m) is mostly carried backwards towards the reef flats.

The reconstructed palaeogeography of the south-western Antalya Complex margin segment is also dominated by a series of linear off-margin basement highs capped by carbonate banks, adjacent to a major barrier reef complex, the Bey Dağları. The analogy is strengthened by the possibility in the Antalya Complex of a two-stage opening history, a rift phase followed by later ocean floor spreading. The evidence of upslope sediment transport of shallow water carbonate material in Belize helps to explain the paucity of redeposited carbonate material around the off-margin atolls in the Gödene and Kemer Zones during the passive margin phase. In Belize the deep structure of the crust landward of the offshore atolls is believed to be tilted continental basement blocks, possibly similar to the Antalya Complex.

The thrust and wrench tectonics which took place during latest Cretaceous and Tertiary time has no clear recent analogue. Elsewhere (ROBERTSON & WOODCOCK 1980b) we have speculated that deformation occurred in a major north–south sinistral transform zone linking two east–west trench segments where crust of the Troodos ocean basin was being subducted northwards beneath the Turkish continent. Comparable modern settings are trench-related transforms close to continental margins, such as New Zealand (SPÖRLI 1980) and the El Pilar-Oca fault system on the south side of the Caribbean. However, neither of these areas expose the intimate juxtaposition of oceanic and continental crust so well seen in the Antalya Complex. Another comparison is with strike-slip belts which occur behind and parallel to trenchs, such as the Sumatra fault system (PAGE et al. 1979) and the median tectonic fault of Japan (KANEKO 1966). The Sumatra system includes slivers of serpentinized ultramafic rocks along some faults, as in the Gödene Zone, but the areas differ in many other respects, particularly the absence of a volcanic arc in the Antalya Complex. Among ancient strike-slip terrains, the Kings-Kaweah ophiolite belt in California (SALEEBY 1977, 1979) shows some similarities with the Antalya Complex, in having ophiolitic rocks involved in a continental margin strike-slip belt.

The Antalya Complex differs from most other well-described Tethyan ophiolite terrains in the importance of strike-slip tectonics. Large-scale overthrusting of an ophiolite nappe has not taken place (cf. Semail Nappe, Oman, GLENNIE et al. 1973), explaining why the passive margin sediments are so well preserved.

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