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EVIDENCE FOR TURONIAN RIFT-RELATED EXTENSIONAL SUBSIDENCE AND EASTWARD EARLY TERTIARY THRUSTING. WESTERN PAIKON ZONE, NORTHERN GREECE

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ABSTRACT

This paper details new field evidence of sedimentological and structural relations between the Paikon and Almopias Zones (Axios Zone) of Northern Greece. Rather than being simply a shallow-water carbonate platform unit in the Late Cretaceous, our sedimentological data establish an important crustal extension event, preceded by a depositional hiatus, with ferruginous crust development, followed by clastic sedimentation, with detached limestone blocks, overlain by a deep-water pelagic carbonate and radiolarite succession. New radiolarian determinations indicate a Late Cenomanian - Lower Turonian age for this subsidence event. Rifting and subsidence took place elsewhere in the Axios Zone at this time, associated with ophiolite genesis (e.g. Eubeoa, Argolis, Sporades).
Our new structural data indicate that large-scale eastward-directed thrusting and folding took place between the Almopias and Paikon Zones. Full-scale collision appears to have resulted in the expulsion of Almopias Zone ophiolitic units both westwards onto the Pelagonian Zone, and eastwards onto the Paikon Zone.

INTRODUCTION

The Almopias and Paikon Zones, first defined by Mercier (1968), form the western and central units, respectively, of the Axios Zone of northern Mainland Greece (Fig 1a). The Paikon Zone has long been regarded as an area of neritic sedimentation from Triassic to Cretaceous times, whilst the Almopias Zone, classically, was regarded as an area of basinal sedimentation (Mercier 1968, Ferrière et al. 1990).

In this paper we present new sedimentological and structural data from the western margin of the Paikon Zone which document regionally important subsidence of the Paikon carbonate platform in the mid Cretaceous and discuss palaeogeographic implications.

The nature of the Almopias - Paikon Zone contact will also be examined. This major tectonic contact was originally defined by Mercier (1968) as a southwestward-directed thrust contact, placing Cretaceous limestones of the Paikon Zone over pillow lavas and radiolarites of the Almopias Zone. However, mapping now provides clear structural evidence of regionally important thrusting that emplaced lavas and radiolarites of the Almopias Zone towards the northeast over the Paikon Zone in the Early Tertiary.

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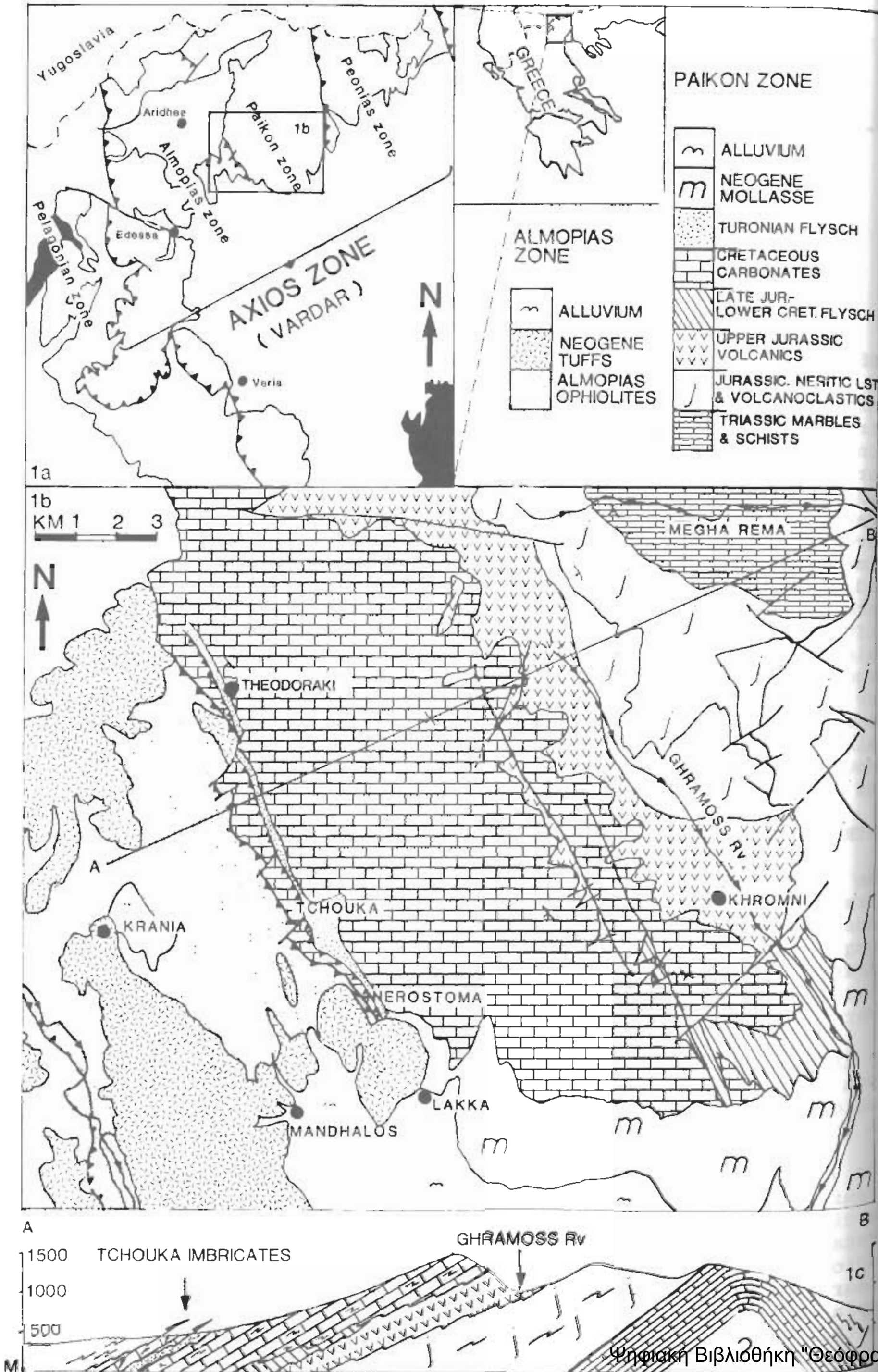

FIG. 1. SIMPLIFIED GEOLOGICAL MAP OF STUDY AREA (after Mercier, 196

TURONIAN EXTENSION ON THE WESTERN PAIKON MARGIN.

Stratigraphy

The Cretaceous platform carbonates of the Paikon Zone unconformably overlie a thick pile of interbedded Jurassic bimodal volcanics and neritic limestones (Fig 1b & c). Numerous authors (e.g. Mercier 1968, Vergely 1984, Bébien et al. 1987) interpret this sequence as representing island arc volcanism, followed by compression in the Late Jurassic, which resulted in "flysch" sedimentation and a major unconformity prior to the re-establishment of neritic carbonate sedimentation in the Late Albian.

During the Late Albian to Early Turonian, sedimentation in the Paikon Zone was dominated by shallow marine carbonate and dolomitic limestones, generally rich in coral and rudist faunas, resulting in a thick, uniform, sequence of platform carbonates deposited during a passive tectonic period. The platform carbonates are overlain by flysch-type sediments from which Mercier (1968) obtained a Campanian fauna. Mercier (op. cit.) also suggested that the re-establishment of carbonate sedimentation above flysch took place in the Maastrichtian.

This study concentrates on the transition from platform carbonates to flysch, which is well exposed along the western margin of the Paikon Zone. We have studied three separate localities: Theodoraki, Tchouka and Nerostoma, from north to south respectively (Fig 1b).

Top of the carbonate Platform

At all three localities, and indeed all along the western margin of the Paikon Zone, the uppermost platform carbonates are represented by milliolid, peloidal and oolite-rich carbonates, with local rudist-rich horizons. In thin section, micritized intraclasts and aggregate grains are common, and the development of early isopachous fringe cements is widespread. The platform carbonates contain a diverse fauna, including a rich foraminiferal assemblage (Milliolids, Cuneolina sp., Cyclolina sp., Nezzazatinella picardi, Nezzazata simplex, Pseudolituonella sp. and Praealveolina simplex ?) which indicates a Cenomanian - Turonian age. The Rudist, Sauvageria sp. is also present (Mercier 1968).

The stratigraphically highest levels of the carbonate platform are marked by up to 5m of mottled, putrid smelling, extremely bioturbated wackestone. Replacement chert, coinciding with areas of bioturbation, is locally developed. Reworked and highly micritized intraclasts and shell fragments are a common feature of this interval, and are surrounded by fine-grained micritic sediment which shows extensive bioturbation and local occurrence of Globotruncana. A ferruginous crust is widely developed on the upper surface of this unit, and is locally accompanied by an intraformational conglomerate horizon, in which individual clasts are coated with ferruginous oxides. This iron-rich layer at the top of the platform is a laterally extensive marker horizon and is always immediately overlain by thin-bedded, buff, pelagic carbonates.

Overlying thin-bedded pelagic carbonates form a 5 - 10m thick horizon that is extremely rich in Globotruncana sp., Globigerinids, Calcisphaerula, Pithonellids (ovalis?) and radiolarians. Small, rare redeposited rudist and echinoderm fragments are also present. Stylolitic bedding-parallel clay horizons are ubiquitous, often showing a concentration of ferruginous material and rare detrital mica. Secondary quartz and albite are widely developed, and commonly replace Globotruncana, hindering identification. Moving up section, the pelagic carbonates become pink and reddish; cherty mudstone partings increase, and there is a gradational passage into overlying mudstone and locally developed green radiolarite (Fig 2).

Radiolarites sampled from both the Tchouka and Nerostoma sections have yielded a moderately well preserved fauna, including the diagnostic short-ranging form Pseudodictymitra pseudomacrocephala in both sections. This radiolarian ranges from the Late Albian to mid Turonian (Pessagno 1977). In the light of a Cenomanian - Turonian age for the underlying platform carbonates (see above) the radiolarite is of probable Turonian age.

Flysch Succession

In all three sections the pelagic carbonate and radiolarite passes rapidly upwards into a thick interval (~100m) of moderate to strongly deformed flysch-type deposits (Figs 2 & 3).

Sections through the flysch are well exposed at all localities, particularly in the Tchouka region (Fig 3, log 4). Strong penetrative deformation and chevron folding are developed within the flysch and hence, intact sections are difficult to find. Despite this, the flysch is a generally uniform succession of interbedded poorly sorted sandstones, siltstones and mudstones, with local horizons of pelagic carbonate and radiolarite. At both the Theodoraki and Tchouka sections, brecciated and iron encrusted detached blocks of platform-derived carbonate (up to 3m across) are encountered near the base of the flysch (Fig 3, logs 1 & 4).

The flysch sandstones are typically poorly sorted coarse-to very coarse-grained litharenites, commonly showing evidence of erosive and channelised bases into the underlying sediments. In thin section, these sandstones are rich in lithic fragments set in a iron-rich and calcareous matrix. Clay rims to clasts are common. Lithic fragments include polycrystalline quartz and quartz-mica-schist, possibly of metamorphic provenance, as well as a significant contribution of volcanic and volcaniclastic fragments, including quartz porphyry, chloritic schist, rare very altered lavas, plagioclase and perthite grains. Occasional marble fragments are also present. Monocrystalline and polycrystalline quartz make up to 50% of the grains. The associated siltstones and mudstones are similar in composition, but are noticeably richer in detrital muscovite. Derivation from the subjacent Paikon basement is probable. Baroz (1987) described quartz-mica-schists rich in white mica (phengites) from the Triassic Gandatch Formation of the Paikon Zone. Clasts of this lithology are commonly seen in the flysch.

Within the flysch, localized, pink to dark grey pelagic, ferruginous carbonates are also encountered, again rich in detrital muscovite. Mercier (1968) obtained a Campanian - Maastrichtian Globotruncana fauna from this unit.

The flysch unit is tectonically overlain, at all localities, by thrust slices of Cretaceous platform carbonates (Fig 3, "The Tchouka Imbricates"), which form a fold and thrust imbricate beneath the basal thrust of the Almopias Zone (Eastern Almopias Thrust). Several lines of evidence suggest that these carbonates

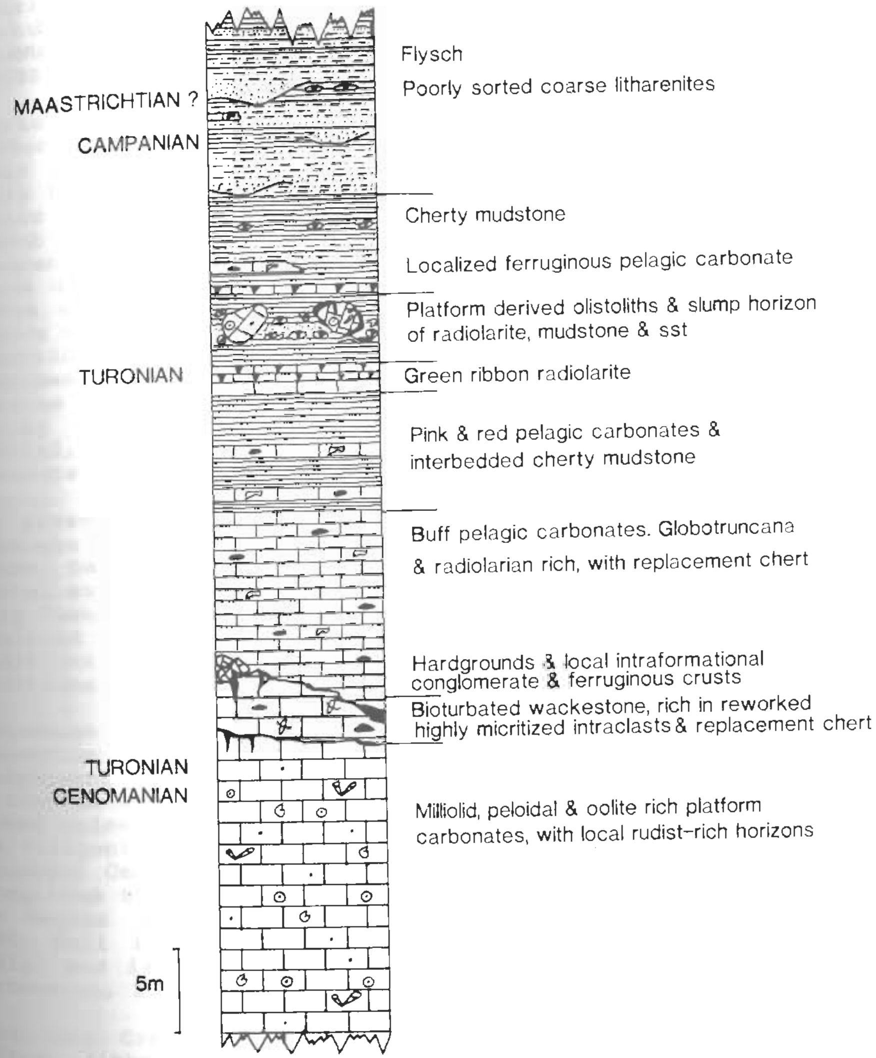

FIG. 2 COMPOSITE LOG. TOP PAIKON PLATFORM

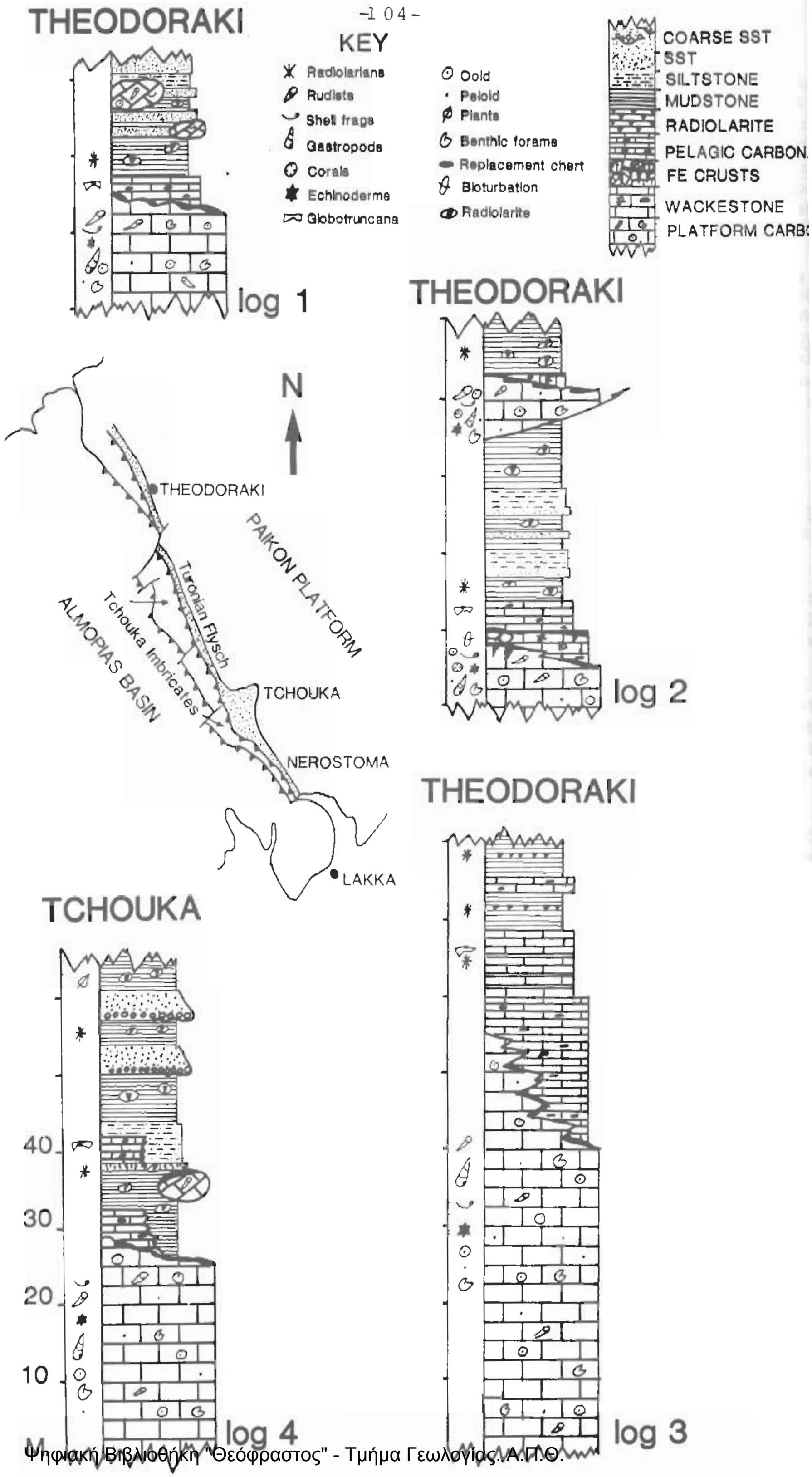

FIG. 3. SEDIMENTARY LOGS OF TOP PAIKON PLATFORM

are facies and age equivalents of the platform carbonates that yielded a well preserved fauna of Albian to mid Turonian age. Specifically, the stratigraphy described above is structurally repeated towards the west, with an iron encrusted platformal top, again overlain by pelagic carbonates and locally flysch. The most easterly preserved lavas and radiolarites of the Almopias Zone structurally overlie the "Tchouka Imbricates" (Fig 1b & c).

DISCUSSION OF SEDIMENTATION

We interpret the carbonate platform to flysch transition in terms of crustal extension and rapid subsidence of the entire western margin of the Paikon Zone in Late Cenomanian to Turonian times. Within 10m, shallow-marine platform carbonates gave way to basinal pelagic carbonates, with Globotruncana and radiolarites. The highest level of the platform records a depositional hiatus, accompanied by reworking and bioturbation of the sediment by bottom dwelling fauna. The presence of a hardground is indicated by the extensive development of ferruginous crusts on the upper surface of this unit, which is assumed to represent prolonged non-deposition. The local development of intraformational conglomerates at this horizon is consistent with extensional collapse of the platform. The overlying pelagic carbonates record further deepening, with local redeposition of platform-derived material, followed by radiolarite deposition, possibly below the carbonate compensation depth (CCD).

The presence of detached limestone blocks, derived from the carbonate platform and channelised sediments (with an inferred Paikon basement source), indicates subsidence, break-up and crustal extension of the Paikon Zone during the Late Cenomanian - Early Turonian. The Campanian-Maastrichtian pelagic carbonates and localized radiolarite within the flysch show that deep-water conditions persisted throughout this time and that neritic conditions were not re-established as suggested by Mercier (1968).

Subsidence of the eastern margin of the Pelagonian Zone in Cenomanian - Turonian times can also be documented, with the local development of an intraformational conglomerate and a brief period of clastic sedimentation, deeper-water carbonate deposition and a marked pulse in Cretaceous transgression westward (landward) over the Pelagonian Zone (Sharp et al. 1991 and unpublished data). An important Cenomanian - Turonian extensional event is also widely recognized throughout continental Greece, the Peloponnese and in the Aegean (Fleury 1980, Thiébault 1982, Maillot 1973, Harbury 1986, Hall 1988, Clift 1990, Robertson 1990a, Robertson et al. 1991), and is typically reflected in subsidence, redeposition of carbonates, local unconformities and the deposition of flysch.

This Late Cretaceous subsidence may reflect a regional Eastern Tethys lithospheric extensional event (Hall 1988), locally expressed by the genesis of ophiolites in the Axios Zone (e.g. Euboea, Robertson 1990a, Argolis, Clift & Robertson 1990, Sporades, Jacobshagen & Wallbrecher 1984) and more generally in the Eastern Neotethys (e.g. Troodos, Robertson 1990b). Importantly, this inferred extensional subsidence considerably pre-dates the onset of regional compressional deformation of the Hellenides in the Early Tertiary.

THE ALMOPIAS - PAIKON EARLY TERTIARY CONTACT

Mercier (1968) defined the Paikon to Almopias zone contact as a region of extensive reverse faulting, with the Cretaceous carbonates of the Paikon Zone being thrust westward across lavas and radiolarites of the Almopias Zone (Mercier 1968, Mercier and Vergely 1971, IGME Edessa sheet). Mercier also recognized that the Paikon Zone forms a vast anticlinal dome of post Late Cretaceous age, the axis of which trends 320° . The core of the anticline is formed of older, Triassic sediments, overlain by younger units towards the east and west (Fig 1b & c).

Our work along the western margin of the Paikon Zone, and along the Ghramoss river valley, cutting the main Paikon massif (Fig 1b) supports Mercier's (op. cit.) structural trend of the anticlinal axis and thrust faults (320° - 140°), but indicate eastward, rather than westward thrusting.

Structural Evidence

Shear-sense indicators and asymmetrical folds along this contact indicate SW to NE movement (Fig 4), with the radiolarites and lavas of the Almopias Zone being thrust over the Cretaceous carbonates of the Paikon Zone, resulting in folding, thrusting and imbrication of the platform carbonates beneath. A thick imbricate of platform carbonate is well developed along the entire length of the Almopias - Paikon thrust contact ("The Tchouka Imbricates", Fig 1 & 4). These carbonates were previously believed to conformably overlie flysch (Mercier 1968).

Where we have carried out detailed mapping along the Almopias - Paikon thrust contact in the Theodoraki, Tchouka and Nerostoma regions (Fig 4), the iron encrusted platform carbonate - pelagic limestone - flysch sequence, described above, forms an excellent marker horizon, allowing large-scale structures in the area to be mapped. At all three localities, a SW to NE movement sense can be demonstrated, including large-scale fold and thrust structures. Minor, later, SW-directed reverse faults are also present.

Fold styles are dominantly of chevron and locally box fold-type (e.g. Nerostoma region). Fold axial trends vary along the contact between 190° - 100° , but cluster between 120° and 140° at all localities (Fig 4). Reverse and thrust faults follow the same trend, and are commonly offset by perpendicular tear faults. Smaller-scale folds within the pelagic carbonates are characterized by strain-slip cleavage, again trending between 120° and 140° , with reverse slip movement towards the NE. Strong layer-parallel-extension is developed within the flysch, with sandstone and pelagic limestones showing early tectonic extension, followed by chevron and box folding.

In the Theodoraki region, the Almopias - Paikon thrust contact is marked by a spectacular tectonic melange up to 10m wide. This unit consists of blocks of recrystallized platform carbonates set in sheared flysch, and thrust imbricated with lava and radiolarite of the Almopias Zone. Further south, at both the Tchouka and Nerostoma localities, the thrust contact is marked by strongly deformed and recrystallized pelagic limestone, immediately tectonically overlain to the west by lavas and radiolarite. Rare slivers of flysch are encountered locally between these two units but are commonly thrust out.

At all three localities small-scale reverse faults, trending 120° - 140°, are developed, with displacements towards the SW of up to 1m (e.g. Theodoraki region). These faults locally cut earlier developed folds and thrusts, and possibly relate to the regional westward-directed compression and tightening of the Axios Zone.

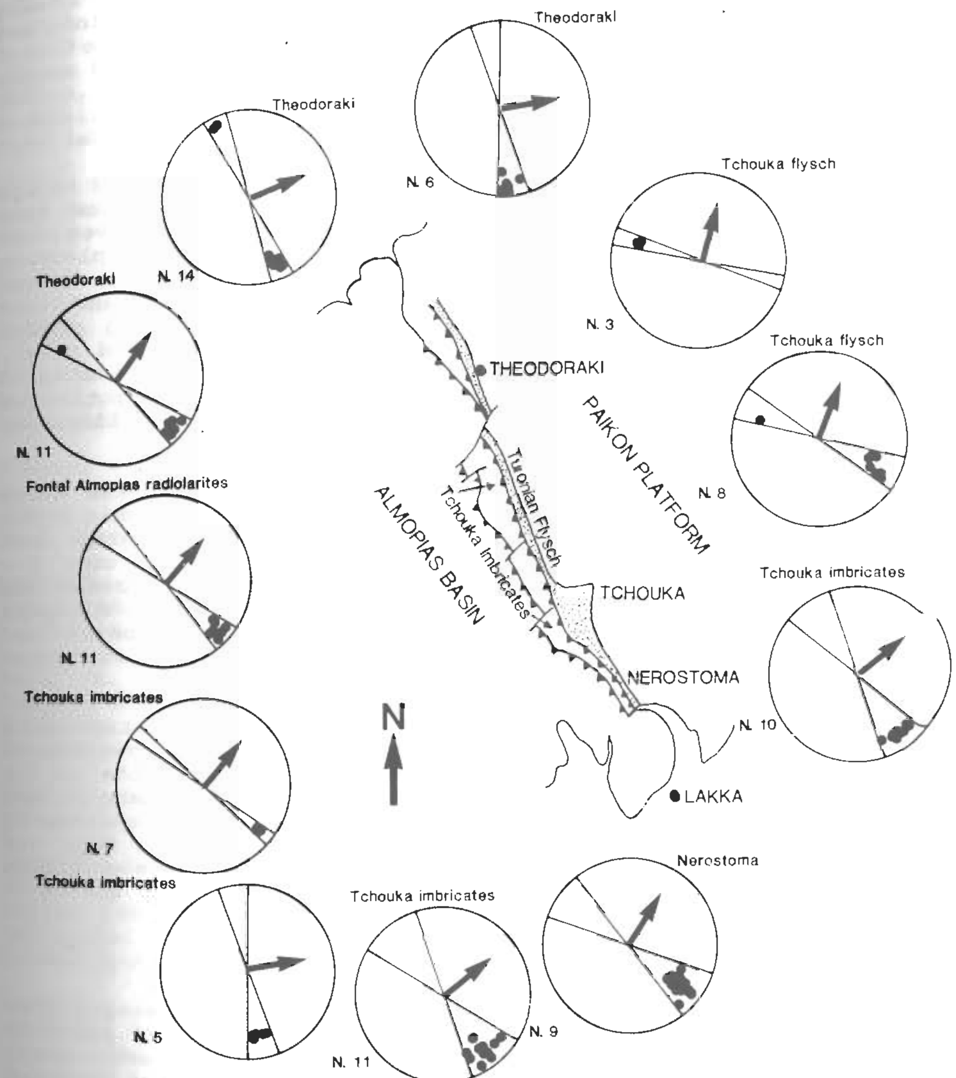

FIG. 4. ALMOPIAS – PAIKON EARLY TERTIARY CONTACT.
FOLD AXIAL TRENDS & FACING DIRECTION (95 readings).

Reconnaissance westwards as far as the Ghramoss River, which cuts the main Paikon massif (Fig 1b & c), indicates that the entire western Paikon margin is dominated by NE-directed folding and thrusting. This is particularly well exposed at the base of the Cretaceous carbonate platform on the road to Khromni. Infolded thrust slices of pelagic carbonates and flysch are also encountered along the dip slope forming the entire western margin of the Paikon massif.

DISCUSSION OF STRUCTURE

Large-scale NE-verging thrusts developed at the Almopias - Paikon Zone contact in the Early Tertiary. The eastern Almopias Zone (Krania unit, Mercier 1968) was thrust eastwards over the Cretaceous margin of the Paikon Zone, imbricating the platform carbonate beneath it, and the entire western margin of the Paikon Zone was folded and thrust towards the east. Shear and fold structures within the eastern Almopias Zone (Krania unit) show a similar eastward directed movement (I. Sharp, unpublished data). Jurassic granitic intrusives in the Krania unit are also sheared towards the east, as is particularly well exposed along the new road to Theodraki. Again at this locality late-stage, small-scale, SW-directed reverse faults cut the earlier trend.

The dominantly NE movement sense of the eastern Almopias units over the western Paikon Zone opposes thrust derivation of the Almopias ophiolitic units (Mavrolakkos and Krania units) and fragments of the Serbo-Macedonian Zone from the east over the Paikon Zone in the Early Tertiary, as proposed by Godfriaux and Ricou (1991). In contrast we suggest that the Almopias "ophiolites" were already located between the Pelagonian and Paikon Zones during the Cretaceous, and now form an imbricated "pop-up".

In our structural model, the western Almopias ophiolitic units (Mavrolakkos unit, Mercier 1968) were folded and thrust westwards during collision in the Early Tertiary, together with the entire eastern margin of the Pelagonian Zone (Vergely 1984, Sharp et al. 1991). One regional effect of the Almopias units ramping westwards over the Cretaceous margin of the Pelagonian Zone was large-scale eastward directed thrusting at the Almopias - Paikon Zone contact in the east.

CONCLUSIONS

1. New facies, structural and radiolarian age data indicate that the western margin of the Cretaceous Paikon carbonate platform underwent a major depositional hiatus, followed by extensional collapse and subsidence during Late Cenomanian - Early Turonian time. This regional extensional event was associated with ophiolite genesis elsewhere in the Axios Zone (Eubeoa, Argolis, Sporades).

2. New field mapping of fold and thrust geometry indicates eastward directed thrusting of the Almopias Zone over the Paikon Zone during the Early Tertiary. Full-scale collision appears to have resulted in the expulsion of Almopias Zone ophiolitic units both westwards onto the Pelagonian Zone, and eastwards onto the Paikon zone.

REFERENCES

Baroz, F. Bébien, J. & Ikenne, M. (1987). An example of high-pressure low-temperature metamorphic rocks from an island-arc: the Paikon Series (Innermost Hellenides, Greece). J. Metamorphic Geol. 5, 509-527.

Bébien, J. Baroz, F. Capedri, S. & Ventureli, G. (1987). Magmatismes basiques associes a l'ouverture d'un bassin marginal dans les Hellénides internes au Jurassic. Ofioliti, 12, 53-71.

Clift, P. (1990). Mesozoic/Cenozoic sedimentation and tectonics of the Southern Greek Neotethys (Argolis Peninsula). Unpub Ph.D Thesis. University of Edinburgh, U.K.

Clift, P. & Robertson, A.H.F. (1990). Evidence of a late Mesozoic ocean basin and subduction-accretion in the southern Greek Neo-Tethys. Geology, 17, 559-563.

Ferrière, J. Bonneau, M. Thiébault, F. & Clement, B. (1991). Regard peripacifique sur une chaine Téthysienne: Les Hellénides. Bull. Geol. Soc. Grèce 25 (1), 33-53.

Fleury, J. (1980). Les Zones de Gavrovo-Tripolitza et du Pindos-Olonos (Grèce continentale et Péloponnèse du Nord). Evolution d'une platform et d'un bassin dans leur cadre structurale. Soc. Geol. Nord. Spec. Publ. 4, 651pp.

Godfriaux, I. & Ricou, L.E. (1991). Le Paikon, une fenêtre dans les Hellénides Internes (Macédoine, Grèce). C.R. Acad. Sci. Paris, t. 313, Serie II, 1479-1484.

Hall, R. (1988). Basement and cover rock history in western Tethys: HT-LP metamorphism associated with extensional rifting of Gondwana. In Audley-Charles, M. & Hallam, A. (eds) Gondwana and Tethys, Geol. Soc. London Spec. Publ. 37, 41-50.

Harbury, N. (1986). The stratigraphy and structural evolution of the SE Aegean. Unpub. Ph.D Thesis, University of London, U.K.

Jacobshagen, V. & Wallbrecher, E. (1984). Pre-Neogene nappe structure and metamorphism of the North Sporades and the southern Pelion peninsula. In: Dixon, J.E. & Robertson, A.H.F. (eds). The Geological Evolution of the Eastern Mediterranean. Geol. Soc. London Spec. Publ. 17, 591-602.

Maillot, H. (1973). Etude faciologiques, sédimentologiques, ebauches d'études stratonomiques et esquentielles de la Formation d'Andritsena (Péloponnèse occidental, Grèce). Thèse 3éme cycle, Université de Lille, France.

Mercier, J. (1968). Etude geologique des zones internes des Hellenides en Macedoine centrale (Grèce). Ann. geol. Pays Hell. 20.

Mercier, J. & Vergely, P. (1984). Carte geologique d'Edessa. IGME Athenes.

Pessagno, E. (1977). Lower Cretaceous radiolarian biostratigraphy of the Great Valley Sequence and Franciscan complex, California Coast Ranges. Cushman Foundation for Foraminiferal Research, Spec. Publ. No. 15, 1-87.

Robertson, A.H.F. (1990a). Late Cretaceous oceanic crust and Early Tertiary foreland basin development, Euboea, Eastern Greece. Terra Nova, 2, 333-339.

Robertson, A.H.F. (1990b). Tectonic evolution of Cyprus: In: Malpas, J. et al. (eds), Ophiolites, Oceanic Crustal Analogues, Proc. Symp. Troodos, 1987. Geol. Surv. Dep., Cyprus, 235-252.

Robertson, A.H.F. Clift, P.D. Degnan, P.J. & Jones, G (1991). Palaeogeographic and palaeotectonic evolution of the Eastern Mediterranean Neotethys. Palaeogeog. Palaeoclimatol. Palaeoecol. 87, 289-343.

Sharp, I.R. Robertson, A.H.F. Dixon, J.E. (1991). Tectonic and sedimentary history of the Eastern margin of the Pelagonian Zone, NE Greece. In: European Union of Geosciences EUG VI, Strasbourg, Terra Abstr., 3, 323.

Thiébault, F. (1982). Evolution géodynamique des Hellénides externes en Péleponnèse méridional (Grèce). Soc. Geol. Nord, Spec. Publ. 6, 574 pp.

Vergely, P. (1984). Tectonique des ophiolites dans les Hellénides internes. Consequences sur l'évolution des régions Téthyiennes occidentales. Thèse. Univ. Paris-Sud, Orsay, France.