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TECTONIC EVOLUTION OF THE MESOZOIC–CENOZOIC PINDOS OCEAN: GREECE

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ABSTRACT

Over the last few years, we have carried out detailed studies of several areas in Greece: the Pindos Mountains, Argolis Peninsula, the NW Peloponnese and on the Island of Euboea, coupled with reconnaissance elsewhere. Following this work, an overall palinspastic reconstruction of the Mesozoic-Tertiary evolution of a Pindos ocean (Pindos-Olonos and Sub-Pelagonian Zones (Figs. 1,2,3) is now possible. A small ocean was sited between a large Apulian microcontinent to the west (Gavrovo-Tripolitza, Ionian and Pre-Apulian Zones) and a smaller Pelagonian microcontinent to the east (Pelagonian Zone).

Rifting during Late Permian times first detached Apulia from Gondwana, giving rise to a southerly seaway (e.g. Phyllite unit, E. Crete; Fig. 1). Further rifting in the Early to Mid-Triassic (Scythian-Ladinian) developed deep rift basins, accumulating intermediate composition extrusives, volcaniclastics, redeposited carbonates, quartzose clastics and radiolarites (e.g. Vardoussia, Zarouchla). During the Mid-Triassic, 'ammonitico rosso' carbonates accumulated on seamounts (e.g. Megdhovas, W Greece; Asklipion Limestone, Argolis). Continental break-up was complete and sea floor spreading began in the Late Triassic (Carnian-Norian; e.g. Othris, Fig. 2). Basaltic extrusions of rift and marginal ocean basin origin exhibit calc-alkaline affinities (e.g. Zarouchla, N.W., Peloponnese), whilst basalts inferred to represent more open ocean

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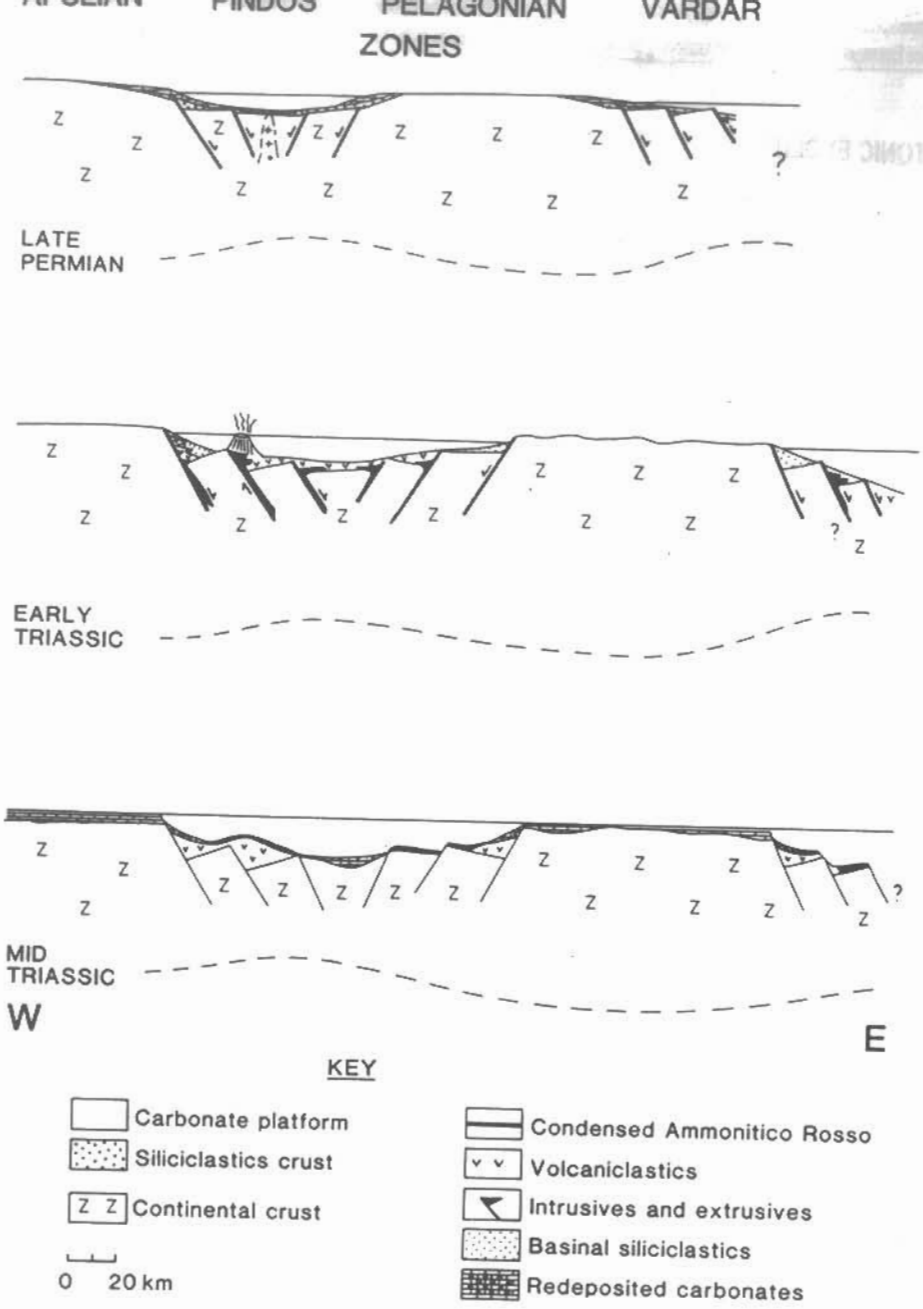

Fig. 1 Reconstruction of the rift history of the Pindos ocean. The sections refer to areas north and south of the Parnassos platform unit.

seamounts and oceanic crust are mainly of within-plate and mid ocean ridge-type (e.g. Avdella Melange, Pindos Mtns; Agrilia lavas, Othris). The calc-alkaline character is probably an artifact of crustal contamination, and does not necessarily reflect contemporaneous subduction, for which there is little evidence regionally.

Both the Apulian microcontinent and the opposing Pelagonian microcontinent were offset by a series of major transform faults (e.g. Sperchios, Kastaniotikos). These exerted an important influence on passive margin sedimentation and Tertiary emplacement (Fig. 3).

The passive margin of Apulia is represented by the Pindos-Olonos nappes. Proximal slope units were mainly concealed by overthrusting, whilst more distal units are excellently exposed within a huge imbricate fan that dominates the Pindos Mountains south of the Metsovo 'corridor'. Facies analysis reveals overall trends of increasingly more distal deposition towards the east (e.g. N E Peloponnese). Proximal platform edge and slope units are, however, locally exposed in the east, but only where large-scale, Early Tertiary out-of-sequence thrusting has taken place (e.g. E of Tripolis; E Peloponnese; eastern Koziakas unit; Central W Greece).

The opposing passive margin of the Pelagonian microcontinent is best preserved in Othris (e.g. Meterizia Fm.), but elsewhere was mainly destroyed due to Late Jurassic and early Tertiary thrusting. Rift and passive margin units are now mainly preserved as blocks within Late Jurassic melange (e.g. Pagondas Complex, Euboea; Vourinos melange).

Spreading during the formation of the Pindos ocean separated a large carbonate platform, the Parnassos Zone from the Apulian margin, where it remained isolated from tectonic deformation until early Tertiary time (Fig. 3). The western margin of the Parnassos platform is represented by the Vardoussia units. In the SE a

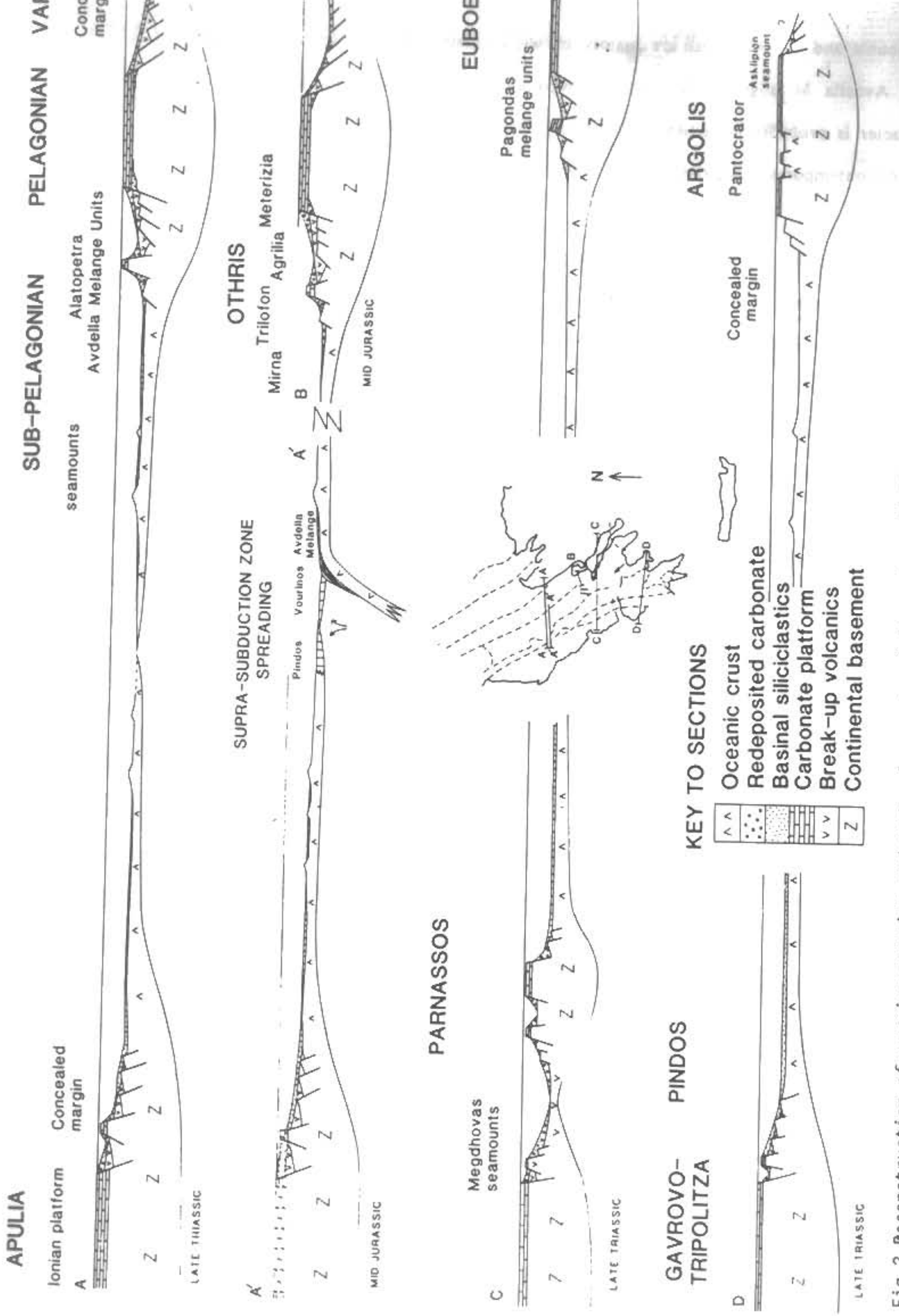

Fig.2 Reconstruction of passive margins and mode of genesis of Jurassic ophiolites within the Pindos ocean. Lines of sectio[n] shown in the inset outline of Greece. Note the origin of the ophiolites as fore-arc complexes generated by spreading above a westwards-dipping subduction zone.

palaeogeographical transition is preserved between the Parnassos platform and the Vardoussia slope units. Further north this is obscured by high-angle neotectonic faulting. The basin that intervened between the distal Apulian margin (Pindos-Olonos nappes) and Vardoussia/Parnassos Platform was floored by Triassic oceanic and/or transitional crust and deep-sea sediments (Kerassia-Milia units). The Parnassos platform was terminated by transform faults to the north (Sperchios) and to the south (Corinth). The eastern margin of Parnassos is concealed by Pelagonian nappes that were overthrust in early Tertiary time. The Olympus unit, now structurally underlying the Pelagonian Zone, apparently originated as another carbonate platform within the Pindos ocean (Fig. 3).

The Pelagonian microcontinent was capped by a carbonate platform after final continental break-up in the Late Triassic (e.g. Kastoria area, Fig. 2). The Pelagonian microcontinent extended northwards into Yugoslavia, but probably terminated southwestwards, in the south Aegean area. There, the Pelagonian basement was rifted to form a series of small platforms and intra-platform basins (Pantokrator and Adhami Limestones, Argolis). Various parts of the Pelagonian platform subsided at different times, for example, in the Toarcian in Argolis, Oxfordian in Beotia and Kimmeridgian on Euboea.

The Beotian 'Zone' is re-interpreted as part of the Pelagonian Zone that exhibited a contrasting subsidence history, relative to the adjacent Pelagonian carbonate platform. The inferred thrust contact separating the Beotian 'Zone' from the Pelagonian Zone is a neotectonic extensional fault zone, related to the Gulf of Corinth graben system (i.e. Aliki, Elopia area).

During the Mid Jurassic (c. 170 Ma), regional compression of the Pindos ocean resulted in initiation of spreading above a westwards-dipping subduction zone (Figs. 2, 3). The Kastoria, Pindos, Vourinos, Othris, Euboea, Iti, Attica and Argolis

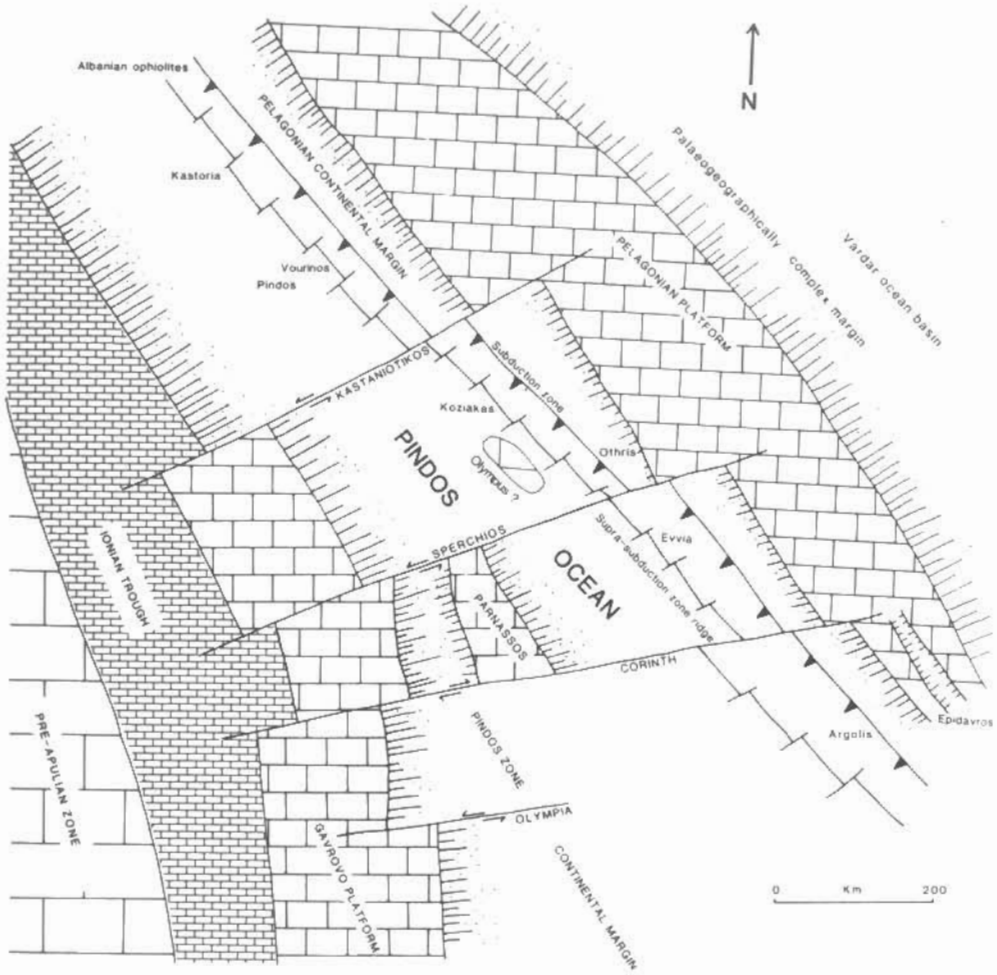

Fig. 3 Palaeogeography of the Pindos ocean in mid Jurassic time (c.a. c. 170 Na). Note the role of transform faults, the location of Parnassos as an off-margin carbonate platform, and the mode of genesis of the ophiolites by spreading above a westwards-dipping subduction zone.

ophiolites were then generated. Each of these ophiolites preserves different parts of a fore-arc complex. MORB-type ophiolites (e.g. Othris; Migdalitsa, Argolis) represent fore-arc basement. Island arc tholeiites and high magnesian andesites (e.g., e.g. Aspropotamos Complex, Pindos, Aegina) preserve distal fore-arc crust and mantle generated by supra-subduction zone spreading. A back-arc spreading axis is preserved in the Vourinos ophiolite. Supra-subduction spreading apparently decreased in effect southwards, from Albania towards the south Aegean.

During subduction, melanges were formed by accretion in intra-oceanic trench settings (e.g. Pagondas Complex, Euboea; Avdella Melange, Pindos Mtns; Iti Mtns.) These melanges mainly comprise within-plate and MORB-type basalts of rift and/or oceanic origin, deep-sea sediments (e.g. radiolarites), carbonate build-ups and sediments resulting from offscraping and accretion (e.g. volcaniclastic debris flows).

Sub-ophiolite metamorphic soles (amphibolites and greenschists) formed when young, hot, supra-subduction zone mantle was displaced over oceanic basalts, sediments and ophiolitic units beneath (e.g. Pindos, Vourinous, Euboea, Iti Mtns.).

Eastwards emplacement of the ophiolites onto the Pelagonian microcontinent took place when the subduction trench collided with the passive margin to the east. In the Pindos and Vourinos ophiolites, mantle fabrics of both early, ductile and later, brittle origin, indicate displacement towards the northeast. Folds in the amphibolites and greenschists of the metamorphic sole of Euboea (i.e. at Pilibn) mainly indicate eastwards transport. High-level, brittle deformation (thrust and folds) in Othris confirm northeastwards emplacement of oceanic crust and margin sediments onto the Pelagonian platform. Prior to neotectonic rotation, the Migdhalitsa ophiolite (Argolis) and related sedimentary units were emplaced towards the southeast over the Pelagonian units. Regionally, these ophiolites were emplaced over a Late Jurassic (Kimmeridgian) fore-deep, generated by inferred flexural subsidence of the

Pelagonian platform (Vourinos melange; Potami Fm., Argolis). The Late Jurassic-Early Cretaceous 'Beotian flysch' is accordingly reinterpreted mainly as clastic facies shed into a foreland basin, prior to ophiolite emplacement (e.g. Levadia area).

The Pindos ocean in Greece was not entirely closed during the Late Jurassic emplacement of ophiolites, but remained open at this stage as a small remnant basin, undergoing mainly pelagic carbonate deposition. However, the ocean basin was sutured further north, in Yugoslavia and Albania. The eastern margin of the remnant basin was mildly deformed in the Early Cretaceous, related to much more severe tectonism of the Vardar and Almopias zones to the east. During the Late Cretaceous, carbonate platforms (e.g. rudist reefs, Orliakas Mtns, Pindos) with slope deposits (e.g. calciturbidites, Krapa Hills, Vourinos) were re-established along the eastern margin of the Pindos basin (Pelagonian Zone). Carbonate deposition also continued, unabated along the western margin of the Pindos basin (Pindos Zone) and on the off-margin Parnassos platform.

Terrigenous flysch began to be deposited in the Late Cretaceous along the western margin of the Pindos basin, related to sealevel change and/or tectonics. This was followed by activation of an easterly-dipping subduction zone in the Early Tertiary (Palaeocene-Eocene). Subduction/accretion is documented by the development of a unit of debris flows, siliciclastic turbidites and detached blocks ('Beotian units') that is sandwiched between the NE margin of the Parnassos platform below and the overlying Pelagonian nappe (Levadia area). Also associated with this eastwards subduction, the Olympus carbonate platform was apparently thrust beneath the Pelagonian Zone, resulting in the genesis of blueschists. Further west, oceanic and/or transitional crust of the remnant Pindos ocean was subducted, leaving only occasional thin units depositionally underlying Late Triassic deep-sea sediments (e.g. Solinari, S W Peloponnese). The subduction eventually impinged on the eastern passive margin of Apulia; flexural subsidence, combined with hinterland uplift and erosion then gave rise to deposition of the Eocene Pindos flysch, within an early foreland basin. The emplacement of the overriding thrust stack was influenced by earlier Mesozoic palaeogeography (e.g. NE Parnassos margin, Levadia area). In the NW Pindos Mountains thrusting towards the SW was also associated with NE-trending refolding and formation of the Perivoli corridor. Suturing was followed by collapse and initiation of the Mesohellenic molasse basin in the Oligocene, and further westwards transport of the thrust stack over Apulia, reflected in the development of the Ionian flysch, as a younger foreland.

Finally, it should be noted that other units, of Late Cretaceous-Early Tertiary age along the eastern margin of the Pelagonian Zone (e.g. Euboea, E. Argolis) were derived independently, from oceanic basins and margins in the Vardar Zone to the east.

Acknowledgments

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