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TECTONIC AND SEDIMENTARY EVOLUTION OF THE WESTERN PINDOS OCEAN: N. W. PELOPONNESE, GREECE

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ABSTRACT

An integrated sedimentological, structural and geochemical study of imbricated Mesozoic facies of the Pindos Zone indicates that they represent the passive margin of a Mesozoic Tethyan ocean basin situated east of an Apulian microcontinent. Emplacement in the Early Tertiary produced a regularly ordered thrust stack that can be restored to show original facies patterns. Sediments of Late Triassic to Early Tertiary age record base-of-slope to abyssal plain settings, which became progressively more distal eastwards. Axial siliciclastic sediment supply from the north also played an important rôle particularly during continental break-up in the Late Triassic. Intermediate and basic-extrusives occur locally, as tectonic-sedimentary mélange and as coherent units, at the base of some thrust sheets. Analyses of "immobile" elements suggest compositions intermediate between mid ocean ridge basalts (MORB) and island arc tholeiites (IAT). This crust was preserved as small units within a subduction-accretion complex related to eastward subduction in the Early Tertiary. Subduction eventually led to collision and emplacement of ocean crust and sediments over the subsided continental margin of Apulia.

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The Pindos isopic zone of western Greece (Fig. 1) consists of a series of tectonically repeated deep-water sedimentary sequences (Pindos Group; Fig. 2) (Aubouin et al. 1970; Fleury, 1980; Thiebault, 1982; Green, 1982). These lithologies represent continuous sedimentary input into a deep marine environment, from Late Triassic to Early Tertiary times. The sediments are dominantly turbiditic, with detritus derived from a carbonate platform to the west, within the Gavrovo-Tripolitza Zone, and/or from a metamorphic terrane located further north, based on palaeocurrent data. Early Tertiary (Alpine) deformation has resulted in the Pindos Group deep-water sediments being thrust westwards onto the Gavrovo-Tripolitza carbonate platform. The resultant structure is a series of stacked, highly imbricated thrust slices, which display characteristic thin-skinned fold and fault features. A base-of-slope setting is inferred for the westerly, structurally lower sediment sheets, whereas clast size variation, sedimentary structures and facies distribution indicate more outboard deposition for the structurally higher units located further east. Comparisons with modern ocean basin sequences suggest that a passive margin existed along the eastern margin of Apulia from the Late Triassic (Norian) to Late Cretaceous (Maastrichtian), as outlined below.

Stratigraphy and facies

The structurally lowest unit in the Pindos thrust stack is a tectono-sedimentary mélange, comprising blocks of igneous (basalt, andesite and hyaloclastite) and sedimentary (sandstone, mudstone and limestone) origin within a pelitic matrix, which displays layer-parallel-extension features. Unpublished geochemical data show that extrusives exhibit features of both VAB (Volcanic Arc Basalt) and MORB (Mid Ocean Ridge Basalt) when plotted on stable element discriminant diagrams (Pearce, 1980).

Jurassic (Toarcian-Tithonian) (De Wever 1989). Notable thickness variations exist and are explained in terms of palaeogeographic position and variable degrees of tectonic disruption. In general, the member thins towards the west, towards the passive continental margin of Apulia. Indeed, at some localities near the western margin, radiolarite is completely absent and the Late Jurassic interval is characterized by thick reworked reefal limestone (e.g. at Kakotari). This facies is defined as the Kakotari Member. Debris flows also form massive beds up to 4m thick within the Aroania Member in more outboard positions, that are still within 8km of the present Pindos thrust front. These debris flows are channelised and contain limestone clasts that are identical to those within the Kakotari Member; the two units are therefore correlated. At three localities (Aroania, Kombigadi and Platanitz), basalts, tuffs and volcaniclastic conglomerates, of apparently Late Jurassic age are found within the Aroania Member. Interbedded ribbon radiolarites exhibit pronounced manganese enrichment. Mn and trace-element analysis of these cherts and of associated siliceous mudstones (unpublished data) suggest a combined hydrothermal and hydrogenous origin for the enriched metal component. These features may relate to a period of renewed crustal extension, associated with off-axis volcanism and hydrothermal activity. Elsewhere (e.g. Solinari, S.E. Peloponnese), calpionellid-bearing limestones are found above ribbon radiolarites of the Lesteena Formation (Thiebault 1982), suggesting a relative lowering of the carbonate compensation depth (CCD) in latest Jurassic to earliest Cretaceous time.

Radiolarite sedimentation of the Lesteena Formation was succeeded by the deposition of the thickest Pindos Group formation, the Lambia Formation (Fig. 2). This comprises four stratigraphic members. The lowermost one is a pink silt grade, to micritic limestone, the Paos Member. This shows evidence of redeposition and hemipelagic derivation. Deposition of the Paos Member was coeval with localised deposition of a unit dominated by siliciclastic turbidites, the Klitoria Sandstone Member (Premier Flysch). This is generally thin (<15m), and is often composed of several fine- to medium-grained sandstone packages, with interbedded limestones.

A new stratigraphy is introduced here for the structurally overlying successions in the NW Peloponnese, which conforms to internationally accepted usage (Hedberg 1978, Fig. 2). Formal definitions will be given elsewhere.

The oldest preserved coherent sedimentary successions are siliciclastic turbidites of the Priolithos Formation (Le Détritique Triassique), dated as Late Triassic (Carnian) (Fleury 1980). These rocks are generally fine- to medium-grained sandstones with mudstone intercalations, and show Bouma sequences, sole markings, and internal sedimentary structures indicative of turbidites. Thicknesses vary from 0-40m due to depositional processes (e.g. channelisation) and/or related to structural emplacement.

Overlying the Priolithos Formation is the Drimos Formation (Calcaires de Drimos), composed of turbiditic and hemipelagic limestones, with local radiolarian cherts and dolomites. The presence of Halobia sp, other pelagic bivalves and conodonts indicates a Late Triassic (Carnian) to Early Jurassic age for this unit (Flament 1973). Thickness varies widely across the basin, from 75-110m in the more proximal, westerly units, to ca. 40m in the distal, easterly outcrops. There are also along strike thickness variations, especially in the west, that are inferred to represent an originally irregular seafloor topography.

Overlying the Drimos Formation is the Lesteena Formation. This comprises three members. The oldest is the Kastelli Mudstone Member (Pelites de Kastelli), which is mainly composed of varicoloured mudstone, 15-25m thick. Diagnostic fauna are not present, but the stratigraphic position suggests an Early Jurassic age for this member. There is a very high competency contrast with the adjacent units, and as a result the unit was commonly sheared-out during emplacement. Ribbon bedded cherts of the Aroania Member overlie the Kastelli Member (Fig. 2). This is an important lithologic unit within the Lesteena Formation that has been dated as Early to Late

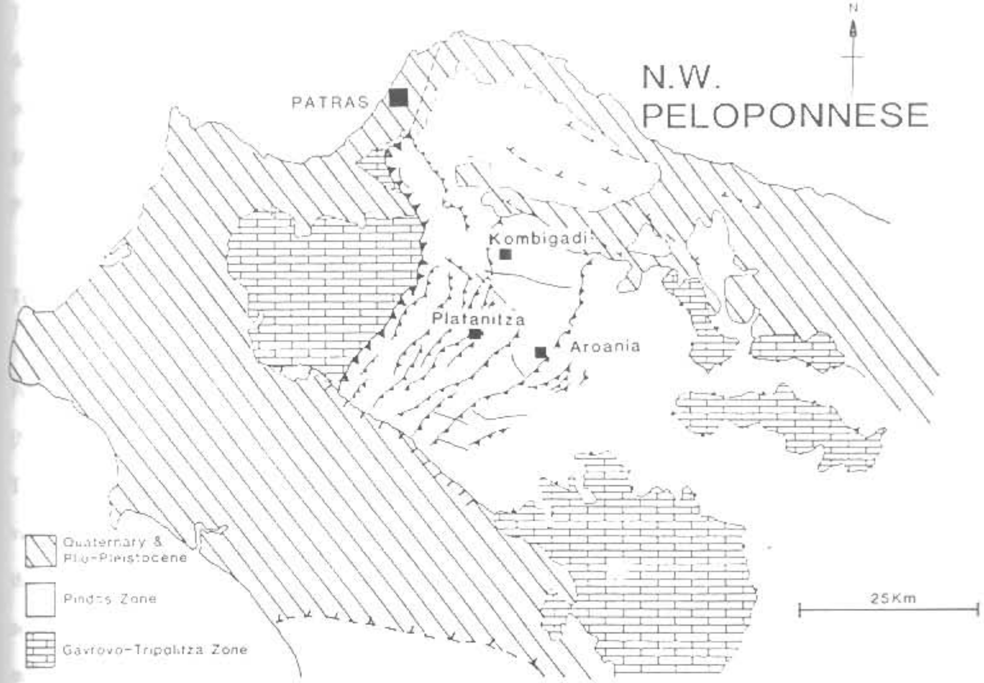

Fig. 1 Outline structural map of the N.W. Peloponnese.

		AUBOIN, 1959	DERCOURT 1973 FLEURY 1975	DEGNAN 1990		
CENOZOIC		Flysch du Pinde		PINDOS FLYSCH Fm		
CRETACEOUS	Upper	Couches de Passage		Katarraktis Passage Mbr		LAMBIA Fm
		Calcaires en Plaquettes		Erymanthos Limestone Mbr		
	Lower	Premier Flysch de Pinde	Marnes Rouge	Paos Limestone Mbr Klitoria Sandstone Mbr		
JURASSIC	Malm	Les Jaspes a Radiolaires	Calcaires a Calpionelles	Kakotari Limestone Mbr	Aroania Chert Mbr	LESTEENA Fm
	Dogger		Radiolarites			
			Pelites de Kastelli		Kastelli Mudstone Mbr	
	Lias	Les Jaspes et Calcaires a Halobia	Calcaires de Drimos	DRIMOS Fm		
TRIASSIC	Upper					
			Le Detrique Triassique	PRIOLITHOS Fm		

Fig. 2 Stratigraphy of the Pindos Zone in the N.W. Peloponnese. A new stratigraphy is introduced to conform with international usage.

A metamorphic terrane is indicated from the petrography, but presently available palaeocurrent data are ambiguous. By contrast, ophiolitic material has been reported from equivalent Early Cretaceous clastic facies in the Pindos Zone of central and northern Greece. A potential source for these sediments would be ophiolites that were emplaced onto the Pelagonian Zone in the Late Jurassic (e.g. Jones and Robertson 1990). However, further south the Pindos basin may have been wider (e.g. Argolis), such that and any coarse-grained ophiolitic material was not able to reach the western part of the ocean basin represented by the Pindos Zone.

From the Lower Cretaceous to the Maastrichtian, redeposited carbonate and pelagic limestone were laid down. These facies comprise the Erymanthos Member (Calcaires en Plaquette). The precise thickness of this unit is difficult to ascertain due to structural complexity, but it is considered to be at least 100-400m, with thinner successions in structurally lower units towards the east. The hemipelagic and redeposited material was derived from the Gavrovo-Tripolitza carbonate platform to the west, as evidenced by decreasing grain size and bed thicknesses in structurally higher thrust sheets towards the east. Palaeocurrent indicators (e.g. convolute and ripple cross-lamination) also support this provenance.

The youngest member within the Lambia Formation is a transitional facies, the Katarraktis Passage Member (Couches de Passage). This was deposited diachronously from latest Maastrichtian to Palaeocene (Fleury 1980) and marks a change from purely carbonate deposition to an environment with increasing clastic input. The base of this member is locally defined as the first appearance of sandstone, and/or by the presence of a prominent marker horizon comprising black replacement chert, ca. 10 m thick. The Katarraktis Passage Member has been dated as straddling the Mesozoic-Cenozoic boundary (Fleury 1980). Above this the member mainly comprises thin- to medium-bedded siliciclastic turbidites with mudstone interbeds. In general, bed thickness is highly variable.

The youngest formation of the Pindos Group is the Pindos Flysch Formation (Flysch de Pinde, Fleury, 1970). This is Palaeocene at the base, but with deposition continuing into the Eocene (Tsoflias 1969). The thickness is variable, often being greatest in structural synforms. Palaeocurrent data indicate a metamorphic provenance, supplied axially from a northerly source.

Tectonic development of the Pindos Ocean

Permo-Triassic break-up of Gondwana led to genesis of a Mesozoic Tethyan ocean (Neothethys) which narrowed to the west (Robertson and Dixon 1984). Early-Mid Triassic rifting is evidenced in western Greece by extensive volcanism and volcaniclastic deposition. By the Carnian a passive margin had been established on the eastern edge of Apulia, as oceanic spreading was initiated (Fig. 3). The Pindos ocean lay between the Pelagonian microcontinent and Apulia (Smith 1977). In marginal areas final continental break-up was accompanied by siliciclastic deposition from the uplifted flanks of the Apulian margin in the west. There then followed a period of thermal contraction and subsidence of the margin, which is assumed to have coincided with a time of spreading within the Pindos Zone (i.e. Late Triassic-Early Jurassic).

In the mid-Jurassic westwards-dipping subduction apparently began within the Pindos ocean basin and ophiolites were created in a supra-subduction zone setting (e.g. Pindos, Vourinos; Jones and Robertson 1990). In the Peloponnese, there is evidence for extensional processes in the ?Late Jurassic Aroania Chert Member (Lesteena Formation), as noted above. During the Late Jurassic it is inferred that ophiolites were emplaced eastwards onto the Pelagonian Zone (Fig. 1), when a subducting trench collided with the passive margin to the east (Jones and Robertson 1990). However, these tectonic upheavals in the east had little effect along the opposing, westerly margin of the Pindos ocean, where sedimentation continued unabated, except that radiolarian deposition gave way to carbonates as the CCD was lowered. This was probably due to some form of interplay between biogenic productivity, eustatic sea-level fluctuations and tectonics. The subsequent Early Cretaceous (Berriasian) input of siliciclastics (Klitoria Sandstone Member) may reflect eustatic sea-level fall (Green 1982), but otherwise carbonate input continued throughout Cretaceous time.

The Late Mesozoic-Early Tertiary closure of Neotethys in the Hellenides is reflected in a westward migration of orogenic effects with time. In the study area, the Pindos Zone of the Peloponnese, a transition from calciturbidite and pelagic carbonate sedimentation to terrigenous turbidite deposition occurred, which is considered to represent a sea-level fall (Maastrichtian) and/or the earliest possible tectonic influence. By the Early Tertiary (Palaeocene-Eocene), prevailing compressional tectonics had initiated detachment of the Pindos Zone sediments from their volcanic substratum, above an easterly-dipping subduction zone to form the tectono-sedimentary mélange. The remaining Pindos oceanic crust was consumed, while the deep-sea sedimentary cover was detached to form an accretionary complex. Prior to emplacement of the Pindos thrust sheets onto the Gavrovo-Tripolitza platform, the igneous basement was completely removed except for the small remnants at the base of some thrust sheets, either as coherent successions, or more commonly as mélange, which is comparable with a subduction-accretion complex. However, the presence of carbonate debris flows derived from the Gavrovo-Tripolitza platform suggests that additional material was added to the base of the thrust stack as it was emplaced over the collapsed Apulian continental margin.

By the Eocene the Apulian margin was colliding with the trench, initiating a foreland basin on the subsiding Gavrovo-Tripolitza carbonate platform. Siliciclastics were then deposited in thrust-sheet-top basins. Later, in the Late Eocene-Oligocene time the Ionian foreland basin was generated, as the Pindos Group sediments were emplaced further onto the Apulian margin. During thrusting, the Pindos Group was deformed into a highly imbricated series of thrust slices, in

general striking NNE-SSW and dipping towards the east. Current structural work indicates that "in-sequence" thrusting was dominant and thus the stacking order preserves the palaeogeographic positioning of facies. This makes the area exceptionally well suited for the palaeoenvironmental analysis of Tethyan oceanic facies.

Conclusion

Preliminary results from an integrated study of stratigraphy, facies, structural geology and igneous geochemistry indicate that the Pindos Zone of the NW Peloponnese represents part of the passive continental margin and abyssal plain of a small ocean basin (Pindos ocean), rather than merely an intra-continental rift basin as previously envisaged. The area has great potential for the elucidation of deep-sea pelagic and redepositional sedimentary processes.

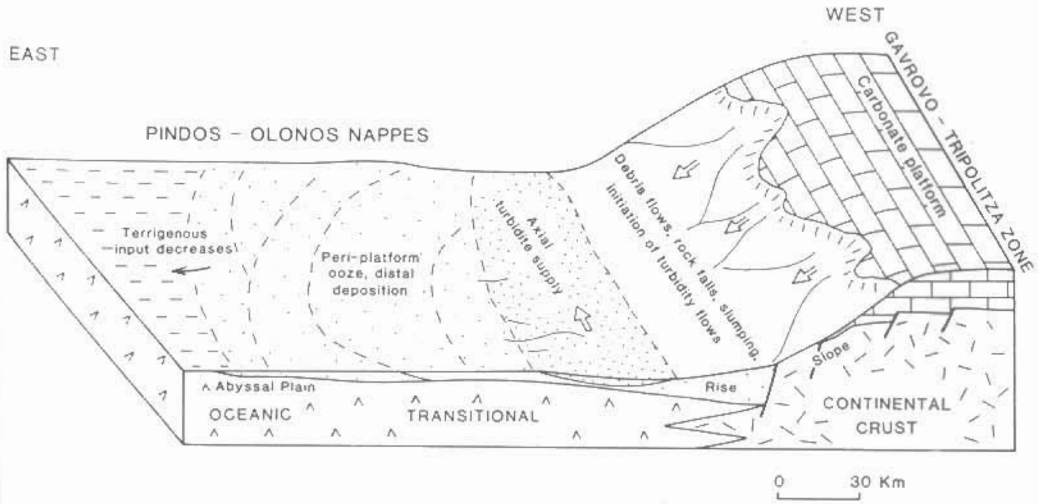

Fig. 3 Simplified reconstruction of the easterly passive margin of Apulia in the Late Triassic, following continental break-up. The Pindos Zone preserves base-of-slope to abyssal plain facies. Slope sediments are obscured by overthrust units, while the platform is represented by the Gabrovo-Tripolitza Zone. Redeposited shallow-water carbonates came from the west, while siliciclastic sediment was introduced axially by turbidites flowing from the north.

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