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RIFT-DRIFT-SUBDUCTION AND EMPLACEMENT HISTORY OF THE EARLY MESOZOIC PINDOS OCEAN: EVIDENCE FROM THE AVDELLA MELANGE, NORTHERN GREECE

G. Jones* and A. Robertson**

ABSTRACT

The Early Mesozoic Avdella Melange of the Pindos Mountains, northern Greece, maps out as a regionally extensive thrust sheet sandwiched between Late Mesozoic deep-water sediments below and the Pindos ophiolite units above. Igneous and sedimentary successions have been measured in large blocks and locally intact thrust sheets. These include Mid-Late Triassic basic-intermediate extrusives and intrusives, of MORB and WPB type interpreted as basement to melange sedimentary successions. Mid Triassic to Mid Jurassic age sediments comprise carbonates of platform, platform margin and redeposited type; also highly quartzose and heterogeneous volcanic-derived turbidites, radiolarites and shales. Mid-Late Jurassic sediments include ophiolite-derived clastics, locally with clasts of boninite-type extrusives, interbedded with radiolarites. The Avdella Melange was formed in response to westward-directed subduction of the Early Mesozoic Pindos ocean during Mid-Late Jurassic time, culminating in collision and emplacement eastwards over the Pelagonian Zone. The igneous-sedimentary units within the melange record four stages of development: i) Mid Triassic rifting; i) Late Triassic-Early Jurassic spreading; iii) Early-Mid Jurassic intra-oceanic subduction; iv) Late Jurassic emplacement. The Avdella Melange has counterparts in the Vourinos area to the east and elsewhere in the Sub-Pelagonian Zone further to the north and south.

INTRODUCTION AND GEOLOGICAL SETTING

The purpose of this short paper is to describe and interpret igneous and sedimentary units which are present within the Avdella Melange, a complexly tectonised unit which crops out extensively below the Pindos ophiolite in northern mainland Greece (Fig. 1). In the Greek area, lithologies that document the initial rift and spreading history of Early Mesozoic ocean basins are usually found as deformed remnants within such melanges (Robertson et al., 1991; Smith, 1993). Melanges are typically highly chaotic rock assemblages, created by sedimentary and/or tectonic processes (e.g. Raymond, 1984). Nevertheless, within most melanges, relatively coherent components may be still be recognised; e.g. large detached blocks or thrust sheets with coherent sedimentary successions. Much useful information concerning tectonic settings can be derived by combining field mapping, with biostratigraphical, sedimentological and igneous petrological work on the varied lithologies

* Department of Earth Science, University of Leeds, Ledds LS2 9Jt, U.K.
** Department of Geology and Geophysics, The Grant Institute, University of Edinburgh, West Mains Road, Edinburgh EH9 3JW, U.K.

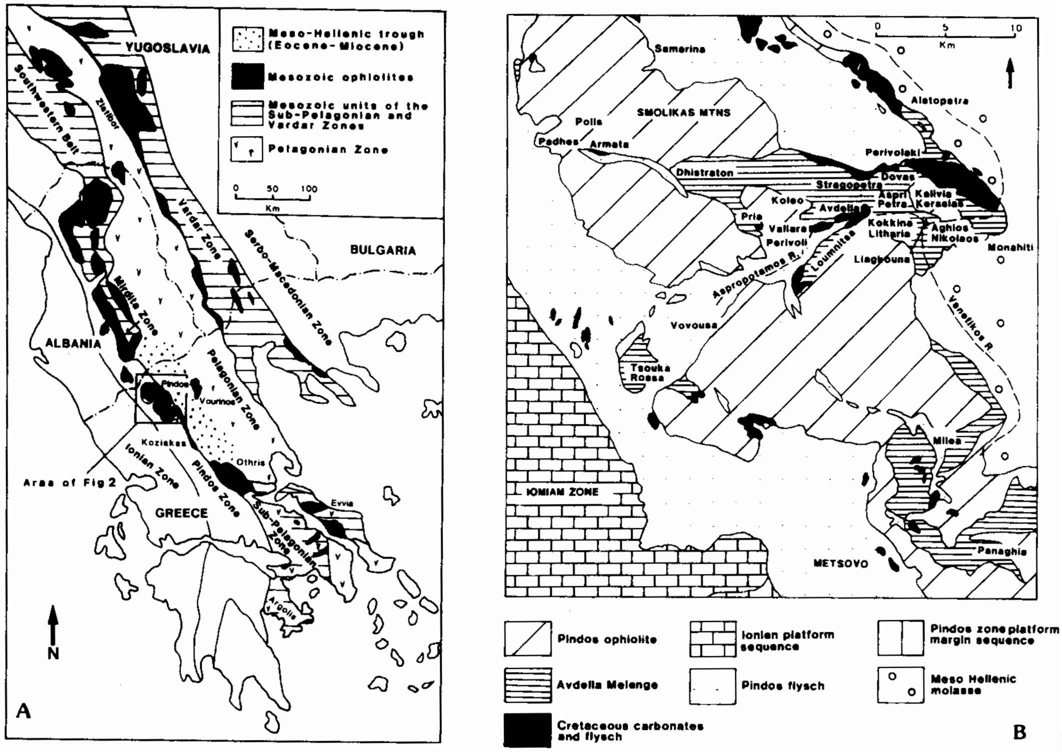

Fig. 1a: Location of ophiolites and melange belts to the W. and E. of the Pelagonian Zone in Greece, Albania and former Yugoslavia.
Fig.1b: Locality map for the Avdella Melange.

present, and the results of such analysis on the Avdella Melange are summarised below. In addition, evidence from comparable sub-ophiolite melange units elsewhere in Greece, will be taken into account (Fig. 1).

TECTONO-STRATIGRAPHY

The north Pindos Mountains comprise an Early Tertiary thrust stack (Fig. 2) in which the Avdella Melange forms a coherent thrust sheet that consistently underlies the Pindos ophiolitic units, which include oceanic crustal (Aspropotamos Complex) and mainly mantle (Dramala Complex) units, which locally possess a metamorphic sole (Loumnitsa Unit; Jones and Robertson, 1990; Fig. 2). Across most of the region, the melange is of "block-in-matrix" type (Fig. 2), mainly composed of basalts and sedimentary rocks, with subordinate metamorphic blocks of lithologies found in the sole. Nevertheless, several areas of melange are dominated by discrete tectonic slices of a single lithology (e.g. basalt). Although not well exposed, the melange matrix is dominated by incompetent sedimentary lithologies, usually shale, marl and sandstone. Sedimentary and/ or igneous contacts are locally preserved within melange blocks, or thrust slices. The melange is generally in the order of 100-500 m thick, reaching a maximum of 1000 m in the type area (NE of Avdella; Jones and Robertson, 1990). The Avdella Melange incorporates the Perivoli Complex, described previously by Kemp and McCaig (1984) around the village of that name, and the Anilion Complex of Lorsong (1977) in the Metsovo region. Fossil evidence previously suggested

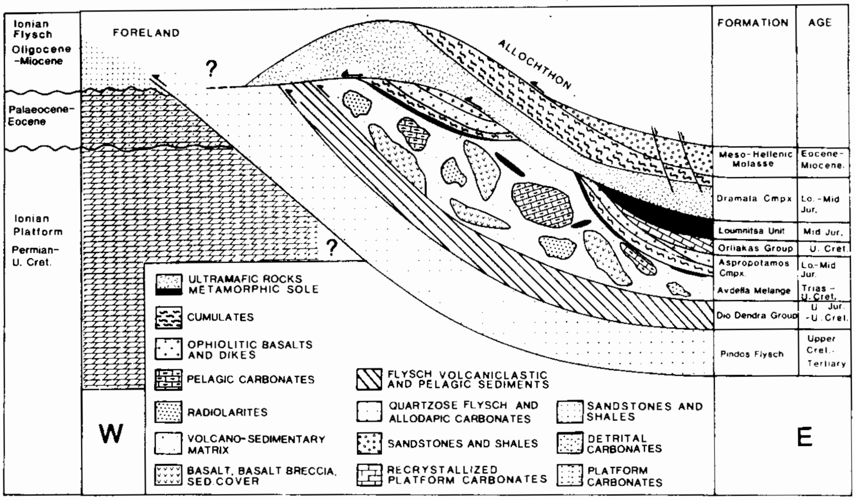

Fig. 2: Tectono-stratigraphic position of the Avdella Melange in the Northern Pindos Mountains. The melange forms a coherent thrust sheet, sandwiched between sedimentary units below and the Pindos ophiolite units above.

a Mid Triassic to Late Jurassic age for the melange sediments (Terry, 1971, 1975; Terry and Mercier, 1973; Jones, 1990). The melange is seen to be transgressed by latest Jurassic (Tithonian) pelagic sediments at one locality (near Milea; Fig. 3; Jones and Robertson, 1990), which confirms a pre-Late Jurassic age of initial melange deformation. The melange is believed to have formed as an accretionary complex within a subduction zone of Early-Mid Jurassic age (Jones and Robertson, 1990). However, further tectonic mixing took place during Early Tertiary rethrusting (Jones, 1990; Robertson et al., 1991). We now go on briefly to discuss each of the major units of the Avdella Melange in turn.

1) IGNEOUS ROCKS

The melange contains a variety of extrusive units, including pillowed and massive lavas, basaltic breccias and hyaloclastites (e.g. NE of Avdella, Figs. 1, 3; Terry, 1971). These lavas occur as blocks (up to 200 m thick) within an extensive matrix, and also as thrust sheets (up to 2 km thick), with little or no matrix (e.g. at Stragopetra, Fig. 1). The extrusives are locally interbedded with, and/or overlain by pelagic carbonates containing Halobia bivalves, indicating a partly Late Triassic age (Terry, 1971). The volcanics in some areas (e.g. NW Avdella/Stragopetra; Fig. 1) are tectonically associated with ?Late Triassic radiolarites and quartzose sandstones, interpreted as originally having formed a local sedimentary cover. The extrusives are mainly highly vesicular, feldspar-phyric basalts, basaltic andesites and andesites. These lavas are highly spilitised, representing zeolite to lower greenschist facies hydrothermal alteration.

Geochemically, the volcanic rocks of the Avdella Melange are of within plate (WPB), transitional to Mid Ocean Ridge Basalt (T-MORB) and normal Mid Ocean Ridge Basalt (N-MORB) types (Jones and Robertson, 1990; Jones, 1990). The MORB-type lavas are sometimes associated with metalliferous sediments, interpreted as hydrothermal precipitates mixed with mainly fine-grained terrigenous sediment (Robertson and Varnavas, 1993).

Intrusive rocks are not common in the melange, but include medium to coarsely-crystalline basic sills (up to 1.2 m thick), which locally intrude clastic and pelagic sedimentary sequences (e.g. at Kokkina Litharia, Fig. 1). These intrusives are generally ophitic gabbros and dolerites. Small (<100 m^2) blocks of gabbroic rocks within the melange have been identified as parts of a dismembered sheeted dyke complex (e.g. at Aspri Petra; Kostopoulos, 1989; S. of Samarina; Jones, 1990; Fig. 1), and have a MORB chemistry. Dyke swarms of WPB to MORB transitional-type are also found intruding interbedded volcanics and sediments that occur above volcanic basement (at Tsouka Rossa; Fig. 1). In addition to these basic rocks, serpentinite is locally seen within the

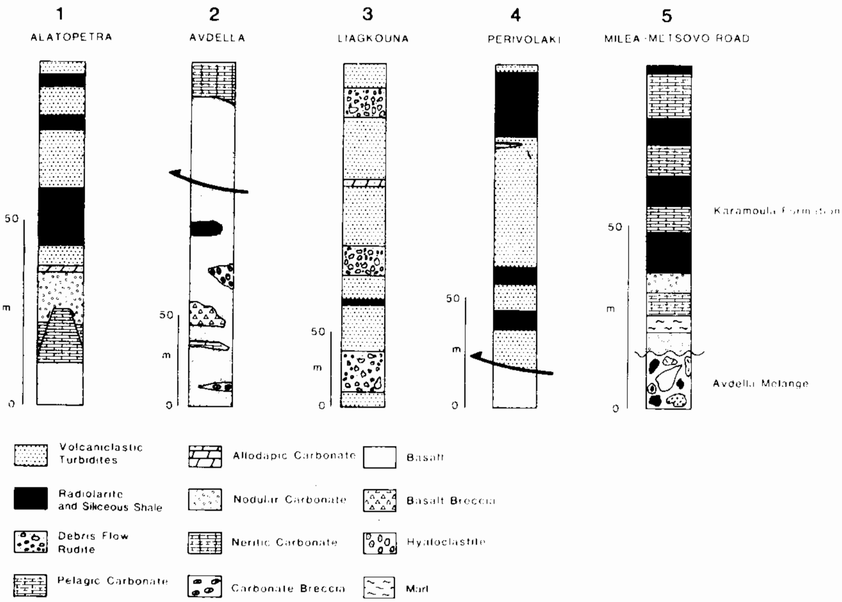

Fig. 3: Generalised stratigraphic columns of coherent melange sedimentary successions. See Fig. 1 for locations. Note that Log 5 shows the Avdella Melange transgressed by a Late Jurassic-Early Cretaceous sequence at Milea.

melange, as folded blocks interthrust with other units (e.g. Perivoli, Milea; Fig. 1). Serpentinite is also found along faulted contacts, forming zones tens of metres thick.

2) SEDIMENTARY ROCKS

A wide variety of sedimentary rocks are present within the Avdella Melange. They occur as: i) detached blocks ("olistoliths"), up to 400 m2; ii) as more extensive thrust-bounded packages; and iii) as a dismembered matrix to the detached blocks. Many of the detached blocks are correlated with units within more complete thrust packages, or are inferred to represent lateral facies equivalents. The following main successions are observed:

A) Mid Triassic to ?Mid Jurassic sequences

The melange contains a variety of sediments of known, or inferred Triassic to Mid Jurassic age. In general, siliciclastic and carbonate sediments dominate and are interpreted as turbidites and pelagic/hemipelagic facies. Shallow-water sediments are also present. Intact conformable successions range in age at least from the Triassic to the Mid Jurassic.

i) Platform and platform margin-type sediments.

Shallow-water sediments are comparatively rare in the Avdella Melange, and these are mostly of Triassic age. A fossiliferous detached block of Late Triassic age (near Panaghia; Fig. 1; Brunn, 1956; Pichon and Brunn, 1985) contains current-sorted bioclastic carbonate beds, rich in brachiopods corals, benthic foraminifera, bryozoa and algal stromatolites. Isolated blocks of white fine-grained (Venetikos valley, Aghios Nikolaos; Fig. 1), contain large Megalodontid bivalves of Triassic age. Carbonate blocks, several tens of metres in diameter, also contain localised coral build-ups of presumed Late Triassic age (N. of Samarina; Fig. 1). Although true Jurassic platform-type carbonates are not present in the melange, carbonates of platform and margin-type of this age are found within the metamorphic sole of the ophiolite (Jones, 1990).

ii) Pelagic sediments

Recrystallised red-brown haematitic marls containing ammonites of Mid Triassic (Anisian-Carnian) age (M.K. Howarth, pers. comm., 1990), were discovered at the southern extremity of Kalivia Kerasias (Fig. 1). This succession also contains mildly recrystallised carbonate breccias, forming large (30 m) detached blocks. Laminated micritic carbonates containing thin-shelled bivalves (e.g. Halobia, Posidonia) are common in the melange, and are also described elsewhere in Greece (Brunn, 1956; Bernoulli and Jenkyns, 1974; Green, 1982). Radiolaria, usually recrystallised to calcite, are abundant. Rare benthic foraminifera and shallow-water-derived clasts (e.g. echinoids, or algal fragments) are also locally present. Pelagic carbonates, intercalated with basalts and hyaloclastites, also contain Halobia fragments, and spalled basaltic material, mainly altered volcanic glass. Pelagic carbonates are also found locally (e.g. at Liagkouna; Fig. 1), where cherty porcellaneous Late Triassic limestones form part of a bedded sequence, with overlying ferruginous mudstones, volcanic-rich sediments and radiolarites. Thickly-bedded, fine-grained carbonates with abundant nodules of replacement chert are stratigraphically overlain by thinly-bedded, pink or light grey micritic carbonate (e.g. at Dovas, Fig. 1). These sediments are found in association with a variety of other carbonate sediments, many of which are redeposited. Pink and grey nodular "Ammonitico Rosso" limestones are also present within the melange as detached blocks (e.g. at Avdella; Fig. 1). Lithologically, these rocks consist of grey or pink fine-grained carbonate nodules (up to several cm in diameter), within a haematitic clay-rich matrix.

The melange also contains abundant Late Triassic radiolarian chert, often recrystallised and calcite-veined (Jones, 1990). The radiolarites are commonly associated with manganiferous and ferruginous shales. The radiolarites occur as isolated blocks, as more extensive tectonic slices (usually associated with basalt), and also within conformable deep-water sedimentary successions (e.g. Liagkouna, Figs. 1, 3). These cherts are regularly bedded (2-6 cm thick on average), and generally red-brown, or green. Elsewhere (e.g. at Alatopetra; Fig. 3), intermediate composition extrusives, including resedimented volcaniclastics, exhibit an intact cover of grey condensed carbonates (?Triassic), containing palaeo-extensional faults exhibiting displacements of up to 80 cm. These carbonates are overlain by pink nodular "Ammonitico Rosso" limestones, with hardgrounds, and then by bioclastic calcarenites of Early Jurassic age. A transition into several metres of manganiferous and siliceous mudstones and haematitic shales is followed by Mid? Jurassic radiolarian cherts. These sediments are overlain by, and partly interbedded with, ophiolite-derived clastic turbidite successions.

iii)Redeposited carbonates

Carbonate breccias, mainly comprising clasts of fine-grained carbonates, are abundant within the melange. They are typically clast-supported (e.g. at Dovas; Fig. 1), and adjacent clasts have stylolitic contacts. Clasts locally contain thin-shelled bivalves (e.g. on Stragopetra Mountain, Fig. 1), and are sometimes tectonically associated and/or interbedded with blocks of vesicular purple basalt of probable Triassic age (e.g. at Aspri Petra; Fig. 1). Carbonate breccias and fine-grained carbonate turbidites are locally found cutting volcanic- and chert-rich clastic turbidites (e.g. Liagkouna; Fig. 3). Elsewhere, carbonate turbidites are interbedded with deep-water successions comprising radiolarites, black shales and volcaniclastics of probable Triassic and Jurassic age.

iv) Quartzose turbidites

In several areas, the Avdella Melange contains coherent thrust-bounded turbidite sequences, composed of terrigenous, fine- to medium-grained, carbonate-cemented sandstone and shales, locally up to 150 m thick (e.g. Aspropotamos Valley at Kokkina Litharia; Fig. 1). Calcite-cemented fine rudites and coarse arenites are present as individual beds up to 1.5 m thick, containing clasts of fine- to medium-grained plagioclase-phyric acidic volcanics and intrusives, quartzose schists and other quartzo-feldspathic metamorphic clasts. Redeposited angular to sub-angular clasts of quartzarenite, well-rounded quartz clasts, abundant chlorite and rare epidote grains are seen in the matrix. Siltstones and shales are present as interbeds, and are mica-rich. Plant material is present in hemipelagic shales. These successions generally form part of the melange matrix, but may be found as detached blocks, or intercalated between thrust sheets of basalt. The sediments are not directly dated, but tectonic association with WPB-type extrusives and Halobia-bearing sediments suggests a Triassic age (e.g. at Stragopetra; Fig. 1).

v) Volcanic-derived turbidites

Coherent and disrupted sequences of volcanic-rich turbidites and debris flows ("olistostromes") are a notable feature of the Avdella Melange. However, it is important to note that these Late Triassic-?Mid Jurassic sediments do not contain abundant clasts derived from Pindos ophiolitic mantle and crust, unlike younger deposits described below. Where well-preserved (e.g. at Liagkouna; Figs 1, 3), these turbidites are commonly interbedded with thin siliceous pelagic limestones, radiolarites and siliceous mudstones. The debris flows contain clasts of many Avdella Melange lithologies, including basalts (mainly of WPB-type) quartzo-feldspathic sandstones, chert and pelagic limestone (up to 40 cm in diameter). Thin sections of finer-grained sediments similarly reveal gabbro, dolerite, vesicular phyric basalt, rare pyroxene crystals, brecciated basalt, quartzarenite, pink and grey micritic limestone, chert and calcified chert. Similar turbidites and debris flows are found as disrupted blocks elsewhere in the melange (e.g. E. of Kalivia Kerasias; Fig. 1). Calcareous and siliceous fossil ages suggest that these sediments are generally of Late Triassic to ?Mid Jurassic age (Jones, 1990, Jones et al., 1993), although Late Jurassic sediments have been proven locally (see below).

A remarkable sequence is exposed at Tsouka (Fig. 1), where several dykes (T-

MORB; Jones, 1990) cut pelagic carbonates and recrystallised radiolarites, which are interbedded with, and overlie volcanic basement in this area. Volcaniclastic turbidite sequences are present above these radiolarites, which in this locality contain detached blocks of quartzose siliciclastics and ammonitico rosso-type carbonates. Redeposited carbonate units also cut channels up to 20 m-thick into these sediments. Lava units of WPB-type (Jones, 1990) also occur as intercalations within the turbidite sequences. A folded, but coherent sequence, exposed northeast of Perivolaki Village (Figs.1, 3), is important as it preserves a transition from terrigenous quartzo-feldspathic fine-grained sediments to volcanic-dominated sediments. Towards the top of the succession there are several radiolarite horizons, up to 5m thick, of which the uppermost was dated, using Radiolaria, as being of Late Callovian to Late Oxfordian age (Jones et al., 1993).

b) ?MID-LATE JURASSIC SEQUENCES

Sediments of this age are generally of deep water facies, and are dominated by volcaniclastic turbidites and radiolarites. Extensive (i.e. several hundred m2) turbidite and debris flow sheets interbedded with haematitic, siliceous and manganiferous shales and marls are exposed locally (e.g. at Polis; Fig. 1). Although superficially similar to older volcanic-derived sediments described above, these turbidites are often dominated by serpentinised peridotite with abundant chrome spinels, alongside the gabbro, basalt and radiolarite clasts seen in older deposits.

Derivation of these turbidites from an ophiolitic source is confirmed by the discovery of a basic extrusive clast 2 m in diameter from a debris flow (in the Valiara Valley, northwest of Perivoli; Fig. 1): this is geochemically of boninite series volcanic (BSV) affinities. These sequences show abundant evidence of deformation prior to lithification. Red-brown ribbon radiolarites of Mid to Late Jurassic age are present within these turbidite sequences (e.g. at Alatopetra, Perivolaki, Perivoli; Figs. 1, 3) and as numerous detached blocks elsewhere. These sediments indicate a second major interval of radiolarite deposition, as recognised in central and southern Greece and elsewhere (De Wever, 1989). The radiolarites are bedded on a 5-15 cm scale, commonly recrystallised, and often interbedded with red shales, cherty mudstones and manganiferous mudstones. Soft-sediment structures, including slump folds, are seen particularly in radiolarite horizons (Kemp and McCaig, 1984).

Several blocks of thrust-deformed and folded carbonates are also exposed locally (e.g. Kalivia Kerasias, Fig. 1). These include pink and light-grey thinly-bedded (5-8 cm) pelagic and redeposited limestones with Cladocoropsis algae and red radiolarite interbeds, dated as Callovian-Kimmeridgian. Redeposited Late Jurassic oolitic carbonates also locally contain minor bioclastic debris, including ?Mid-Late Jurassic algae and foraminifera (e.g. at Aghios Nikolaos; Fig. 3).

REGIONAL CORRELATIONS

Most directly comparable with the Avdella Melange is the Vourinos Melange, exposed below the Vourinos ophiolite (Moores, 1969; Zimmerman, 1972; Vergely, 1976, 1977, 1984; Naylor and Harle, 1976; Fig. 1). The Vourinos ophiolite is thought to be continuous with the Pindos ophiolite beneath the Meso-Hellenic Trough, and both were emplaced onto the western Pelagonian margin during the Late Jurassic, essentially as one sheet (Jones and Robertson, 1990). The Vourinos melange is exposed intermittently between the Pelagonian platform and the ophiolite (Fig. 1) and is mostly of greenschist facies (Zimmerman, 1972).

It is relatively thin compared to the Avdella Melange, reaching a maximum of 400 m. Mylonitic platform carbonates of the Pelagonian Zone locally pass conformably upwards into interbedded phyllites and tuffs, with occasional rudites (at Zavordas Monastery area; Jones, 1990). These meta-sediments are, in places, intruded by coarse-grained amphibolite-facies gabbroic dykes, which are similarly metamorphosed and sheared. Melange blocks are dominated by marbles, including dark-grey, shallow-water loferitic-type carbonates (Naylor and Harle, 1976) ranging from pebble-grade up to 100 m long. Most of these blocks are enclosed in a matrix and are elongated parallel to foliation. In some cases, carbonates are clearly seen to be interbedded with the matrix. Generally, this matrix consists of light-grey to brown phyllites and meta-tuffs, rich in quartz and chlorite (Zimmerman, 1972). Chemical analysis of matrix phyllites shows both meta-sedimentary and metabasic affinities (Jones, 1990). Other blocks such as radiolarite are extremely rare compared to the volume present in the Avdella Melange (Zimmerman, 1972). Similarly uncommon basic volcanic blocks in this melange have MORB-like chemical affinities (Jones, 1990).

EVOLUTION OF THE PINDOS OCEAN

In the light of the regional setting, the various lithologies of the Avdella Melange document the history of the Pindos ocean in northern Greece (Fig. 4). The following evolutionary stages are inferred:

1) Mid-Late Triassic: rifting

The oldest dated melange sediments are Anisian-Carnian ammonite-bearing pelagic carbonates. Distal quartzo-feldspathic turbidites, associated with alkaline and transitional basalts, were deposited during rifting, by erosion of the exposed metamorphic basement, probably within the Pelagonian Zone. These sediments appear to pass upwards into radiolarites of Late Triassic age. Shallow-water carbonates (e.g. Megalodontid limestones) are interpreted to have formed on the margins of the Pelagonian microcontinent, where widespread platform carbonate deposition was taking place concurrently (Brunn, 1956).

2) Late Triassic-Early Jurassic: sea-floor spreading (Fig. 4a)

The volcanic basement of the Pindos ocean basin preserved in the Avdella Melange represents tectonic settings ranging from a rifted continental margin through to a mid oceanic ridge. In some places, this basement is still preserved beneath sedimentary sequences (e.g. Alatopetra), but mostly it is thrust and sheared along with originally overlying sediments, or totally destroyed. However, local successions record rifting followed by sea-floor spreading, as documented by basic dykes of WPB and transitional to MORB chemistry, intruding Late Triassic pelagic sediments (e.g. at Tsouka Rossa). Elsewhere, N-MORB type volcanics are chemically indistinguishable from volcanics forming the basal units of the Pindos ophiolitic sequences (Kostopoulos, 1989). Late Triassic spreading processes also account for the presence of hydrothermal metalliferous sediments associated with some melange volcanics (Robertson and Varnavas, 1993). Turbidites of Late Triassic to Early Jurassic age, despite lithological similarities with younger (Mid-Late Jurassic) turbidites in the melange (see below), do not contain ophiolite-derived material, but instead contain only material eroded from pre-existing (i.e. mainly Triassic) volcanic basement and cover units. We interpret these turbidites as having formed during spreading of the Pindos ocean. Some of these volcanics formed marginal basement highs and/or oceanic seamounts, as shown by the presence of mainly WPB-type volcanics, and occasional carbonate turbidites as interbeds within Late Triassic deep-water sequences (e.g. at Liagkouna, Loumnitsa). This implies the existence of a rugged sea-floor topography throughout much of Upper Triassic and Lower Jurassic time. Some of the shallow-water blocks (e.g. Panaghia, Samarina) may have developed as carbonate caps to volcanic seamounts.

3) Early-Mid Jurassic: onset of subduction (Fig. 4b)

During this time, essentially passive conditions were maintained near the margins of the Pindos ocean, but more axial areas were beginning to record the first evidence of ocean basin destruction. Taking the marginal areas first, thickly-bedded, fine-grained carbonates (e.g. at Alatopetra) are believed to represent off-margin "high" facies, intermediate between the carbonate platform and more basinal facies. These sediments developed on extended, slowly subsiding, volcanic-basement highs, evidenced by preserved palaeo-extensional faults. It is also possible that these sequences developed on oceanic seamounts (i.e. located further out in the ocean basin). The presence of overlying Ammonitico Rosso-type limestones is indicative of condensed sedimentation on seamounts, probably at depths ranging from 800-1500 m (e.g. Jenkyns, 1980). Ammonitico Rosso carbonates are also common in the Argolis area of southern Greece (e.g. Clift and Robertson, 1989), and also within the Pindos nappes of central Greece (Tsoflias, 1969). Thinly-bedded pink and grey micritic carbonates with replacement chert formed a more distal facies, and may represent redeposited peri-platform ooze, or fine-grained carbonate turbidites. Radiolarites probably formed in the deepest part of the basin (perhaps at several thousand metre depths), and are found interbedded with the volcanic-rich turbidite sequences (e.g. Liagkouna), or associated with carbonate debris flows. Jurassic basinal facies of the melange show evidence of continued deep-water sedimentation. Fine-grained sediments, including red haematitic siltstones and grey and black mudstones are ubiquitous in the melange matrix, together with large volumes of coarser-grained turbidites. Off-margin "high" sequences, found at Alatopetra record subsidence through the CCD in the Mid-Late Jurassic. These sediments are significant, as they preserve a stratigraphy not found elsewhere in the melange. The sequence is comparable to others further south in central Greece, and to the north in Yugoslavia. An interval of manganiferous mudstones and cherty shales passing into ribbon radiolarite marks the end of carbonate sedimentation in these blocks. Manganiferous shales underlying radiolarites are also characteristic of sedimentary sequences of the Pindos Zone in central Greece (Kastelli mudstone: Aubouin, 1959; Fleury, 1980; Baltuck, 1982; Green, 1982). In addition, turbidite units deposited in late Early to Mid Jurassic times (i.e. pre-Bathonian) commonly contain clasts of radiolarite and pelagic limestone, implying that basinal facies were being eroded. In our preferred tectonic model for the region (Jones and Robertson, 1990; Jones et al., 1991) the Pindos ophiolite was formed by spreading above an intra-oceanic subduction zone around this time. In the coherent section exposed at Liagkouna, the Early-Mid Jurassic, approximately corresponds to the time of an influx of coarse-grained detritus, as debris flows and turbidites. These sediments are interpreted as having accumulated in a trench setting undergoing active subduction, where extensive erosion and mass-wasting was also taking place. These sediments contrast strongly with post-Bathonian aged turbidites and radiolarites which contain abundant ophiolitic detritus.

4) Bathonian-Kimmeridgian: emplacement onto a passive margin (Fig. 4c)

The first clear evidence of ophiolite emplacement affecting the basin is the

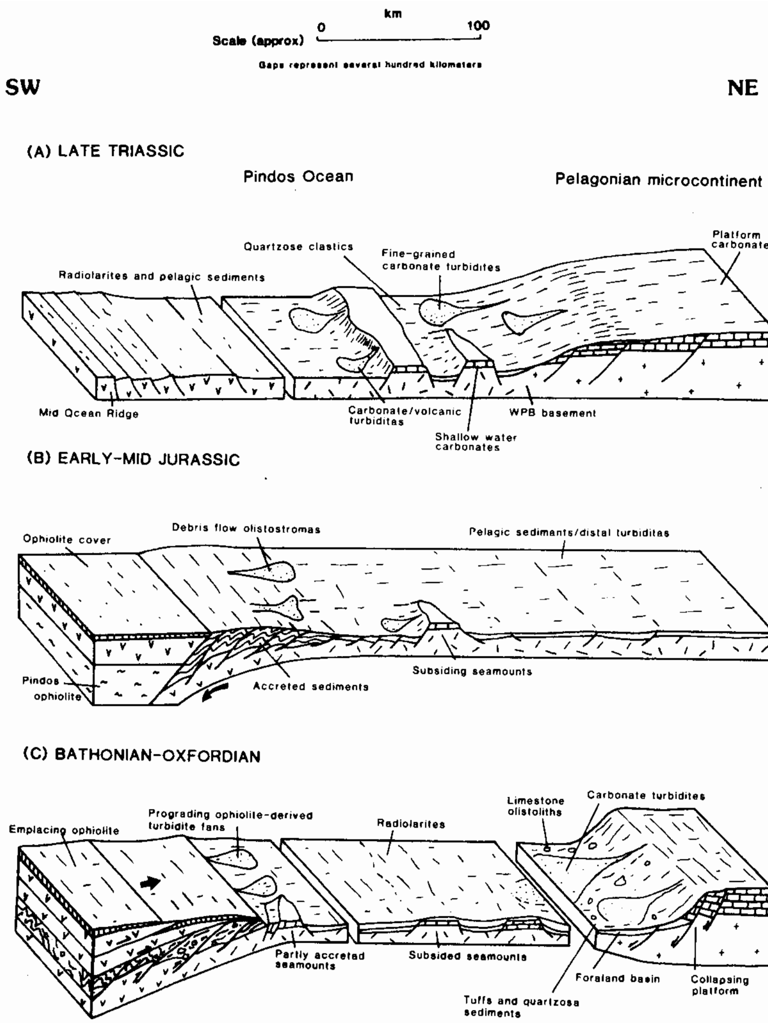

Fig. 4: Reconstruction of the Avdella Melange as a rifted passive margin, bordering a Mesozoic oceanic basin (a), followed by genesis of the Pindos ophiolite above an intra-oceanic subduction zone (b), and finally emplacement of the ophiolite, together with the Avdella Melange, eastwards into the Pelagonian microcontinent (c). Some blocks and thrust sheets in the melange are interpreted as basin margin units (e.g. seamount and basement ridges), while younger (Early and Late Jurassic) sediments accumulated in trench settings related to subduction and later emplacement.

upward passage, at Alatopetra, from radiolarites to ophiolite-derived clastic sediments. The radiolarites range from Bathonian to Kimmeridgian age, as recorded in southern and central Greece (De Wever and Cordey, 1986), although diagnostic fauna were not found in the Pindos Mountains. Further evidence of the effects of ophiolite emplacement is present in the form of thick volcaniclastic turbidites (e.g. at Smolikas), where extensive turbidites contain ophiolitic detritus and radiolarite clasts. The presence of boninite-type extrusive clasts in debris flows implies that these sediments were deposited after

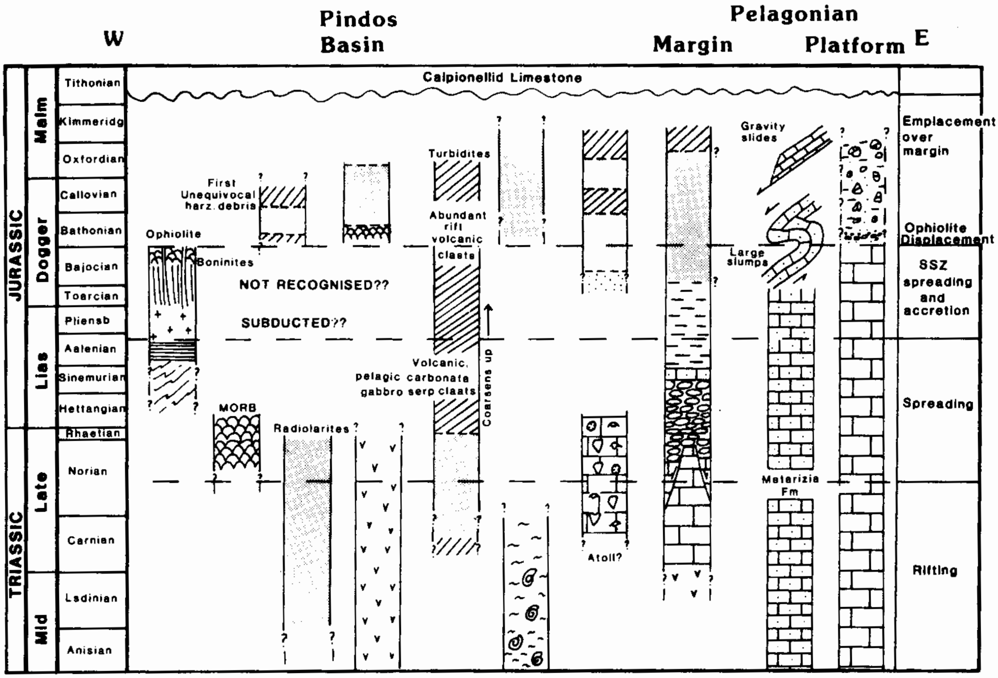

Fig 5: Summary of main Triassic-Jurassic tectonic and sedimentary events in the Pindos ocean.

formation of the Pindos ophiolites, as boninitic volcanics represent the last igneous intrusive event in the known ophiolite sequence (Kostopoulos, 1989; Jones and Robertson, 1990). These turbidites are, thus, thought to reflect submarine erosion of an emplacing ophiolite during Mid-Late Jurassic. This is in agreement with the known Bathonian age of metamorphic sole formation, and therefore with displacement of the ophiolite within the Pindos ocean (Spray et al., 1984). Redeposited carbonates of Late Jurassic age (e.g. at Aghios Nikolaos, Kalivia Kerasias) are locally rich in displaced shallow-water detritus, including ooids. Input of these sediments is thought to have been triggered by collapse of the Pelagonian margin to the east, as a consequence of ophiolite emplacement. However, these sediments could also have been shed from seamounts, either near the continental margin, or further out in the ocean basin. The Vourinos melange is interpreted as the fill of a foreland basin formed within the Pelagonian platform, during collapse related to ophiolite emplacement in the Mid-Late Jurassic. The presence of a conformable transition from platform limestones into phyllites and debris flow conglomerates (i.e. at Zavordas) confirms this setting. This is also supported by the presence of abundant platform-derived blocks, and occasionally interbedded platform carbonates in the phyllites. Other oceanic material present was derived as blocks shed from advancing oceanic crust (e.g. basalts, radiolarites). The matrix is mainly composed of quartzose meta-siltstones, presumably derived from the Palaeozoic basement of the Pelagonian platform. Platform collapse was apparently accompanied by extension-related intrusive and extrusive igneous activity. During or soon after emplacement, the Vourinos melange was overlain by Tithonian aged Calpionellid limestones (Mavrides, 1983). We have chronologically summarised the major tectonic and sedimentary events in the Pindos basin and west Pelagonian margin in Fig. 5, using all evidence discussed above.

CONCLUSIONS

The lithologies of the Avdella Melange can be used to reconstruct the tectonic setting of a Neotethyan ocean basin sited to the west of the Pelagonian microcontinent. In summary, four main tectonic stages are documented: i) Mid Triassic continental rifting; ii) Late Triassic-Early Jurassic sea-floor spreading; iii) Early-Mid Jurassic intra-oceanic subduction and iii) Late Jurassic ophiolite emplacement.

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