Δελτίο Ελληνικής Γεωλογικής Εταιρίας τομ. XXX/2, 93-107, 1994
Πρακτικά 7ου Επιστημονικού Συνεδρίου, Θεσσαλονίκη, Μάιος 1994
Bulletin of the Geological Society of Greece vol. XXX/2, 93-107, 1994
Proceedings of the 7th Congress, Thessaloniki, May 1994

EARLY TERTIARY MELANGE IN THE PELOPONNESE (SOUTHERN GREECE) FORMED BY SUBDUCTION-ACCRETION PROCESSES

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ABSTRACT

Early Tertiary mélange, of tectonic origin, is distributed at various localities throughout the Peloponnese, southern Greece, sandwiched between the Gavrovo-Tripolitza Zone carbonate platform below and overlying deep-water allochthonous units of the Pindos zone. Locally large (>1m^3) volcanic blocks in the melange are mainly of basic to intermediate composition, together with intrusive equivalents (dolerites) and abundant volcaniclastics. New analyses of 'stable' elements confirm some form of subduction related geochemical signature. Generally smaller (<1m^3) sedimentary blocks in the mélange include lithologies that can be correlated, both with the Gavrovo-Tripolitza zone below (e.g. sandstones, redeposited limestones with large foraminifera) and with the Pindos nappes above (e.g. pelagic and redeposited limestones, quartzose sandstones and radiolarian cherts). The matrix was entirely derived by fragmentation of these two tectonic units. Competent igneous lithologies are preserved as relatively large equant blocks, whereas the less competent sediments experienced layer-parallel extension on all scales, giving rise to phacoidal-shaped blocks. Our favoured interpretation is that the mélange began to form as an accretionary prism, related to eastwards subduction of the Mesozoic Pindos Ocean in the Early Tertiary. Volcanic basement highs were preferentially off-scraped. Later, the subduction trench collided with the Gavrovo-Tripolitza passive carbonate margin to the west, emplacing the accretionary complex westwards over the collapsed margin and resulting in additional incorporation of foredeep sediments as blocks and further tectonic mixing of the melange.

INTRODUCTION

The purpose of this paper is to give field descriptions and interpretations of important an igneous-sedimentary mélange forming scattered outcrops in the Péloponnese of Southern Greece (Fig. 1; Degnan, 1992). The mélange is sandwiched between the Gavrovo -Tripolitza Zone below, interpreted as part of the passive margin of Apulia and the Pindos nappes above, sediments that are interpreted as Triassic to Eocene deep-water facies formed within a Pindos oceanic basin to the east (Fig. 2) (Fleury, 1980; Robertson et al., 1991). The Gavrovo- Tripolitza Zone existed as a passive margin from Triassic to Early Tertiary, while the Pindos nappes formed in an oceanic basin to the east that rifted in the Early-Mid Triassic (Green, 1982; Robertson et al., 1991; Degnan, 1992). During the Early Tertiary,

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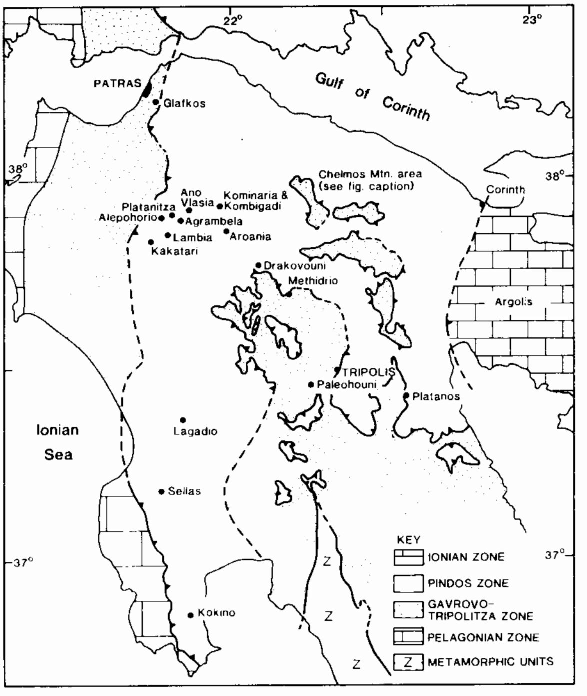

Fig.1: Outline tectonic map of the Peloponnese, showing mélange locations mentioned in the text. Note: the following additional locations mentioned in the text are in the immediate vicinity of Chelmos Mountain-Zarouchla, Feneoss, Foura, Arboynas, Likoria and Elatophyton.

the Pin-dos oceanic basin began to close, resulting in imbrication and thrusting of the deep-water sedimentary units over the Apulian continental margin (Fleury, 1980, Degnan, 1992). An important outstanding question is the setting and mechanism of this basin closure. The mélange unit considered here is interpreted as a dismembered accretionary prism, that developed in response to eastward subduction of oceanic crust within the Pindos Oce-an basin in the Early Tertiary, prior to collision with Apulia to the west.

NOMENCLATURE AND GEOLOGICAL SETTING

Mélange is loosely defined as "a mappable, internally fragmented and mixed rock containing a variety of blocks, commonly in a pervasively deformed matrix" (Silver and Beutner 1980). This term is applicable to mixed rock units of a sedimentary, diapiric and/or tectonic origin (Raymond, 1984). Within the study area, outcrops in the Peloponnese conform to the above loose definition of mélange. These include extrusive and hypabyssal igneous rocks, debris flows, turbiditic sandstones and various sedimentary rocks. In this paper we use the term mélange simply as a non-genetic field term for pervasively mixed rocks. Melange of Early Tertiary age was already reported from a number of localities in the Peloponnese (De Wever 1975, 1976a, b, Richter and Lensch 1977, 1989, Pe-Piper and Piper 1984, 1990). Richter and Lensch interpreted the igneous rocks in terms of a Lower Cretaceous ophiolite, while Pe-Piper and Piper (1990) presented geochemical data and postulated formation in a back-arc basin related to southwestward

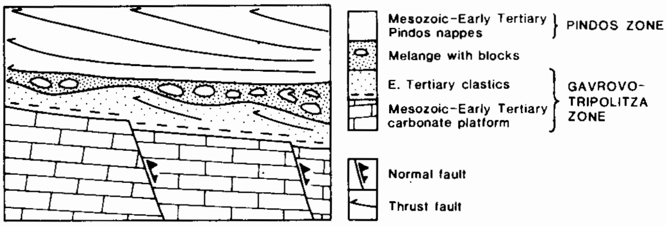

Fig.2: Tectono-stratigraphy of the mélange. In most cases the melange is underlain by the Gavrovo-Tripolitza Zone carbonate platform and overlain by deep-water sediments of the Pindos nappes.

subduction of Palaeotethys. However, any tectonic interpretation is critically dependent on understanding the tectono-stratigraphy and field relations of individual outcrops, and for this reason more detailed descriptions are given here.

DESCRIPTION OF OCCURRENCES

The mélange is located in the northern, central and southern Peloponnese, areas that are described in turn below (Fig. 1).

Northern Peloponnese

Drakovouni

The most extensive mélange outcrop is at Drakovouni (De Wever, 1975). In this area (Figs. 1,3) Upper Eocene flysch of the Tripolitza Zone is in depositional contact with underlying Tripolitza Zone carbonate platform rocks. The flysch is coherent for approximately 50m, then bedding becomes severely disrupted, forming a "broken formation", as defined by Hsü (1974), and then continues upwards into a chaotic pelitic unit (Fig. 3) containing matrix-supported blocks of sandstone. Locally, neritic carbonate overthrusts

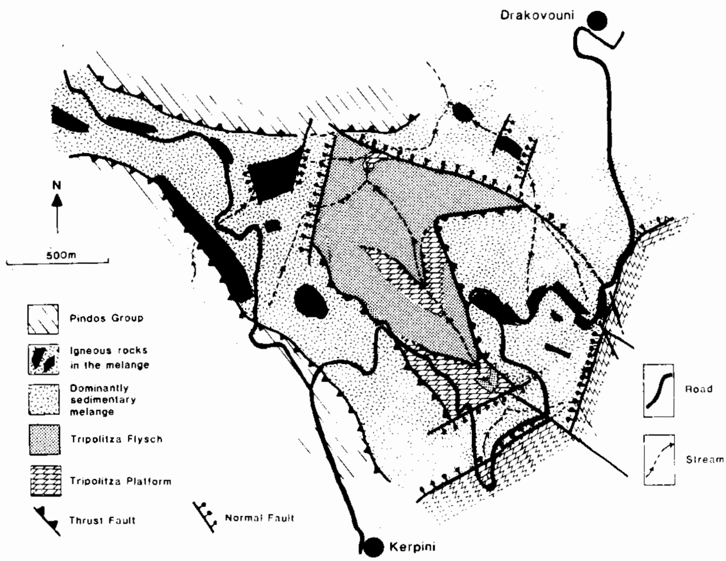

Fig.3: Geological map of the mélange at Drakovouni, northern Peloponnese. Note the occurrence of igneous rocks within the mélange.

Tripolitza flysch. Other faults (e.g. south-eastern mélange boundary) are high-angle normal faults throwing the mélange against Tripolitza Zone carbonates. Locally, radiolarian cherts of the Pindos Zone overlie the mélange. This confirms that the mélange is located between flysch of the Tripolitza Zone below and the Pindos nappes above.

The Tripolitza flysch grades into the mélange, which is 50-100m thick. In the upper part of the mélange, a 20m-thick horizon consists mostly of sheared pelite, sandstone and matrix-supported conglomerate, lithologically similar to units exposed in the uppermost part of the Tripolitza Zone succession.

Above is a horizon, approximately 30-40m thick, in which clasts are found floating in a phacoidal pelitic matrix. The clasts range from gravel-grade to 30 x 30 x 10m, but are generally of decimetric size. Most are phacoidal in shape, but many large (metre-scale) extrusive igneous blocks are also present. The extrusives are purple/violet to black and aphyric and sometimes contain calcite-filled amygdales. Most blocks are rounded and some are pillowed. Cracks, possibly inter-pillow interstices, are infilled with pelagic sediment. Calcite, of inferred hydrothermal origin, and celadonite are also present within some cracks. Blocks of pyroclastic tuff, lava breccia and lava conglomerate are also seen directly below Pindos Zone radiolarian chert in some cases.

Within an important fault-bounded outcrop, dolerite can be traced westwards with continuity into basalt, depositionally overlain by tuff and volcaniclastic conglomerate. The eastern boundary of the dolerite is a high-angle, NNE-SSW - trending normal fault, down-throwing limestone bearing pelitic sediment of the mélange against igneous rock. This sediment is itself downfaulted further east against flysch typical of the Gavrovo-Tripolitza Zone. The coarse igneous lithology consists of a green-weathering rock with randomly orientated phenocrysts of feldspar, up to 3x 1cm in size. Passing upwards, grain size becomes progressively smaller. Green (1982) describes a sill of dolerite north of the Gulf of Corinth (near Moschophyton), intruding *Halobia*-bearing carbonate rocks with chilled margins. Chilled margins were not observed at Drakovouni, but it seems likely that the dolerite represents another high-level sill.

Large phacoids (greater than $5m^3$) of sedimentary lithologies are found in the mélange and these comprise: i) limestone with black cherts (latest Cretaceous); ii) similarly-sized blocks of pelagic limestone (undated); iii) large irregular blocks of platform-derived, sub-angular, to sub-rounded matrix-supported conglomerate, containing *Alveolina* and *Nummulites* (Eocene); iv) a block of shallow-marine limestone, heavily recrystallised, with a neritic fauna (undated).

Other sedimentary blocks are mostly <15 cm in size and include:

i) *Halobia*-bearing black micritic limestone; ii) 1-2cm-scale alternating bands of green and purple siliceous, fine-grained limestone; iii) black chert; iv) grey micrite; v) blue-grey calcareous grainstone with micrite; vi) red and yellow hydrothermally stained jasper with distinctive "wavy" mm-scale laminations; vii) green vitreous chert; viii) Sub-angular quartzose breccia; ix) recrystallised calcareous, gravel-grade limestone breccia; x) dark, bituminous limestone; xi) hard, dark grey siliceous calc-grainstone.

Central Peloponnese

Although smaller than the Drakovouni outcrops, mélange is also known in the central Peloponnese, as follows:

Methedrio

Near the village of Methedrio (Fig. 1) a flat-lying thrust sheet of radiolarian-bearing cherts of the Pindos Group (U. Jurassic) overlies flysch of the Gavrovo-Tripolitza Zone (Early Tertiary). Between the two is melange composed of igneous and sedimentary lithologies. Many of the rock bodies have slickensided surfaces, indicating dominant transport towards the west. Sedimentary lithologies include matrix-supported conglomerate (with clasts of neritic limestone, micritic limestone and black chert), phacoids of sandstone (rich in mica and carbonaceous fragments) and isolated blocks of recrystallised grainstone carbonate, all within a sheared pelitic matrix. Disrupted beds of volcanic breccia are present, with clast sizes up to 3 x 2cm. Some of the clasts are highly vesicular. Extrusive igneous blocks are mostly dark and aphyric (some possibly being pillow lava), while amygdaloidal violet and purple lithologies are also present.

Lagadio

Pink micritic limestones of the Pindos nappes overlie flysch of the Gavrovo-Tripolitza Zone (Fig 1). The contact is poorly exposed, but isolated blocks of igneous rocks and conglomerate crop out near the thrust contact. The largest in situ igneous block (2 x 2 x 1m) is purple amygdaloidal lava. Several other blocks occur downslope in recent screes.

Southern Peloponnese

Mélange also crops out in the Southern Peloponnese (Fig. 1), as follows:

Sellas

East of Kyparissia, volcanic lithologies, interpreted as being related to the mélange, are found at the base of a Pindos thrust sheet, between the villages of Sellas and Krioneri (Figs. 1, 4). Highly altered blocks of lava are present in a sheared red mudstone matrix, or within pyroclastic tuff. Near Sellas, the extrusives resemble pillow lavas, with rims of hydrothermal calcite and celadonite including zeolites and fresh interiors. The total observed lava thickness is >3m. Clear contacts are not seen with the underlying lithologies, which are fine - to medium-grained turbiditic sandstones with abundant mica and plant fragments. This lithology is correlated with the Tertiary Pindos flysch. Thus, the lava is interpreted as being located at the base of Pindos thrust sheets. Above the mélange, sheared green and red pelite, then micrites and grainstones (some *Halobia*-bearing) are seen. The presence of red cherts in the limestones allows the sequence to be assigned to Late Triassic units of the Pindos nappes. By contrast, Pe-Piper and Piper (1990) suggested these igneous lithologies were located stratigraphically below Jurassic radiolarite. Relationships at Sellas suggest a Mid and/or Late Triassic age for the extrusives.

Kokino

West of the village of Kokino, turbiditic pelites, siltstones and subordinate sandstones, corre-lated with the Tertiary Pindos flysch, are tectonically overlain by over 20m of volcanic rocks and volcaniclastics below the Pindos basal thrust. The lowermost 12-15m of these extrusive rocks are relatively intact. Pillow lavas include minor hyaloclastite filling interpillow interstices. There is also evidence of sills, with

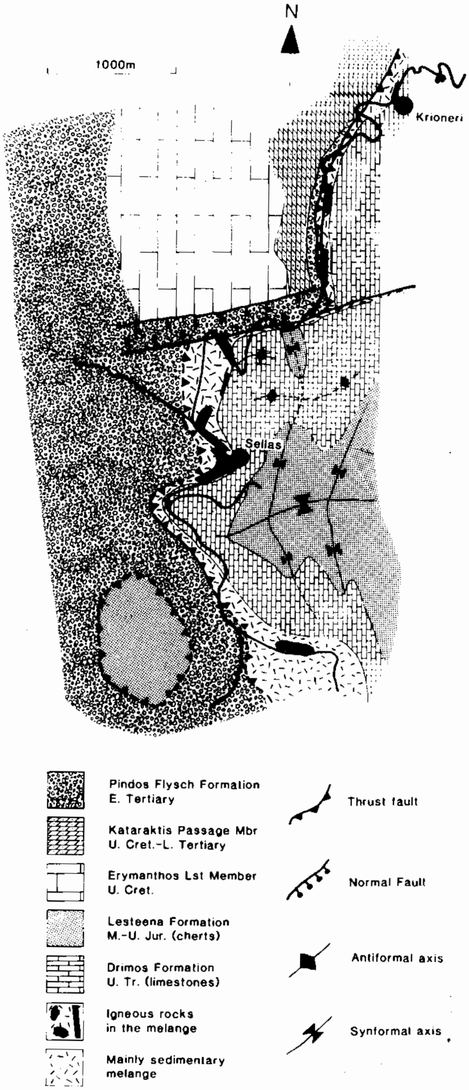

Fig.4: Geological map of the mélange at Sellas, southern Peloponnese. Note the setting of the mélange between Tertiary sediments of the Pindos flysch and overlying Triassic Limestones of the Pindos nappes.

well-defined cooling joints, that are intruded into extrusives.

Above the volcanic sequence, a sheared horizon of lava breccia is overlain by volcaniclastic muds. Pink *Halobia*-bearing, thin-bedded limestones are found towards the top of the breccia and intercalated within the pelite. These limestones were deposited coevally with the volcaniclastics, rather than being sheared-in. Above the purple volcaniclastic muds, regularly bedded *Halobia*-bearing hemipelagic and calciturbiditic beds of Middle-Upper Triassic age are found. The calciturbidites are of coarse arenite to gravel size and contain reworked basalt in minor quantities. Several interbeds (up to 10s of cm thick) are almost totally composed of locally derived volcanic breccia; these are present between volcaniclastics and a Middle-Upper Triassic Pindos succession.

Palaeohouni

This mélange crops out on the main Kalamata to Tripolis road and in a stream-cut to the south (Fig. 1). The mélange is located below the Pindos nappes, locally represented by mid Cretaceous radiolarian chert. The contact is marked by sheared tuff and mudstone. This mélange includes undated volcanics and overlies pelites and sandstones of the Tripolitza Zone. In a stream-cut, sub-rounded to rounded volcaniclastic conglomerates of cobble size are found within a green volcaniclastic pelitic matrix, intercalated with a 30-40 cm-thick layer of black aphyric lava. Volcaniclastic mudstones and siltstones above exhibit parallel lamination and scoured channeled bases, indicating that they are not inverted. On the north side of the road and further downstream, loose blocks of purple-blue, slightly vesicular, aphyric lava are found, sometimes with celadonite and hydrothermal calcite. Spheroidally weathered lava blocks, often seve-rely degraded, are also locally observed.

Eastern Peloponnese

In addition, mélange is known in the Eastern Peloponnese (Fig. 1). Approximately 15 km SE of Astros, near to the village of Platanos, shales and sandstones of the Tripolitza Zone are overlain by blocks of lava and radiolarian-bearing cherts and mudstones, at the base of a mid-Cretaceous Pindos unit that is thrust over shales and sandstones of the Tripolitza Zone. Near the road, aphyric non-vesicular (spheroidally weathering), amygdaloidal lava is observed, forming an approximately 10m long x 3-4m-wide zone. This is interpreted as a tectonic slice at the base of a Pindos thrust sheet. The main mélange outcrop further south comprises degraded lavas overlain by radiolarian cherts of the Pindos nappes. There is evidence of metasomatic alteration along joint planes in the form of patchy silicification.

Other localities

The mélange is also widely exposed in the area around Chelmos Mountain (Fig. 1). From the village of Arboynas, SE towards Likoria and east towards the head of the Elatophyton valley, an elongate mélange zone is present. This mélange lies directly above Eocene platform carbonates of the Tripolitza Zone. The uppermost Tripolitza Zone dolomitic limestones have been heavily tectonised (e.g. near Arboynas). The presence of this horizon, generally 20-30m thick, indicates that the Pindos thrust sheets were locally emplaced directly onto the Gavrovo-Tripolitza platform. Such intense fracturing and alteration of the platform rocks may have been a consequence of tectonically induced high pore pressure. The mélange here is 6-10m thick, and consists of green pelite with a phacoidal fabric, subordinate flysch-type sandstone, red chert and red pelite. Blocks of calciturbidite are present up to 15 x 10 x 10m. In the SE of the mélange zone an approximately 100m-long outcrop contains abundant rounded blocks of purple amygdaloidal lava. Similarly, at the head of the Elatophyton valley, a small outcrop of purple amygdaloidal pillow lavas is again present. The mélange is overlain by Jurassic limestones and clasts of Pindos sedimentary units.

Below the village of Elatophyton, the Pindos thrust directly overlies Eocene platform carbonates and debris flows. A chaotic broken formation of Jurassic radiolarian chert is present above. On the eastern side of Chelmos Mountain, 1 km NE of Goura village a poorly exposed 20m^2 outcrop was found, where two types of igneous lithology are exposed. Blocks of purple amygdaloidal lava and light-green aphyric igneous rocks, up to 15 cm in size, are found in a sheared green pelitic matrix; the setting is uncertain as no boundaries can be observed. They possibly represent igneous lithologies of the Pindos Ocean (i.e. they formed in a similar setting to the other igneous components discussed above). An alternative possibility is that the volcanics belong to the basement of the Gavrovo-Tripolitza Zone (i.e. Aghios Ilias Eruptive Formation, De Wever 1975).

Above the village of Likoria, an outcrop is present consisting of 2m-thick blocks of lava-breccia and tuff. This outcrop is situated just below the Pindos basal thrust and is overlain by Jurassic cherts. The northern boundary of the outcrop is a south-dipping lateral ramp of Tripolitza Zone carbonates.

Elsewhere in the northwestern Peloponnese there are numerous other localities where relatively small bodies of mélange are found sandwiched between the Pindos thrust sheets. These include Glafkos, Agrambela, Kakotari, Lambia, Aroania and Krinofta (Fig. 1).

Contrasting setting of Jurassic cherts and volcanics

In the NW Peloponnese, igneous rocks are depositionally overlain by Upper Jurassic radiolarian cherts of the Pindos nappes (e.g. at Aroania and

Kombigadi; Degnan 1992). Elsewhere, depositional contacts cannot be proven due to intense deformation. For example, volcanic blocks are also found below Jurassic radiolarian cherts, between Platanitsa and Ano Vlasia (Fig. 1). Where depositional contacts are not confirmed, the igneous lithologies could instead represent mélange lavas entrained along the base of the Pindos nappes.

IGNEOUS LITHOLOGIES

With the exception of the feldspar-phyric rocks at Drakovouni, all the igneous lithologies of the mélange are fine-grained and aphyric. Some are vesicular, or contain calcite-filled amygdales. Lithological associations and scarce normal contacts with fossiliferous units suggest the extrusives are mainly of Mid and/or Upper Triassic age. The rocks are here simply classified as a) basalt/andesite and b) dolerite. These rocks all have been severely affected by hydrothermal and weathering processes. Major-element geochemistry is unreliable as many elements, particularly MgO, CaO and alkalis are mobile, and for this reason trace-element studies have been carried out (Pe-Piper and Piper, 1990; Degnan, 1992). These analyses confirm that many of the extrusives are tholeiitic, and further suggest that parental members are WPB to MORB, but with a strong subduction related overprint.

STRUCTURE OF THE MELANGE

The mélange is dominated by a pelitic matrix, within which various sedimentary and igneous blocks are found. The most obvious aspect of the mélange is layer-parallel extension. This takes the form of sets of subpa-rallel shear bands at approximately 60° to one another, to create criss-crossing arrays of shear zones (10s of cm to several m wide) containing rhombohedral units (Fig. 3a). On a smaller scale (mm to a few cm), anastomosing fabrics are seen within pelite, forming a cleavage that is parallel to one or other of the main sets of shear bands.

Within the sheared matrix, variably sized blocks include matrix- supported conglomerate, sandstone, pelagic and/or calciturbiditic limestone and igneous lithologies (mainly extrusives). The blocks of sandstone and limestone are either rhombohedral, or with slightly sigmoidal borders (Fig. 5a). Such lenticular bodies are generally symmetrical. Upper and lower bounding surfaces are almost exclusively bedding planes to either a single bed, or a series of beds. Bedding planes are usually parallel to the dominant shear zones in the pelite. Frontal and rear surfaces of component blocks are orientated at about 60° to bedding.

Within the Drakovouni mélange, a block consisting of several limestone beds, with bedding-parallel chert horizons, was observed in the pelitic matrix. Normal faults are seen to dissect the beds into phacoidal shapes. Bedding-parallel slip is developed along several bedding planes, with displacement transferred to lower bedding planes via normal faults that cut across bedding. The normal faults are orientated at approximately 60° to the dominant shear zones, while bedding planes are parallel to it. There is thus clear field evidence that the phacoidal structures formed by layer-parallel extension of competent rocks and that the extension continued until a chaotic unit was formed (Fig. 5 b,c).

By contrast, blocks of extrusives and debris flows in the mélange are often rounded, rather than phacoidal. The rounding of igneous rocks is interpreted to be the result of physical abrasion during tectonic transport.

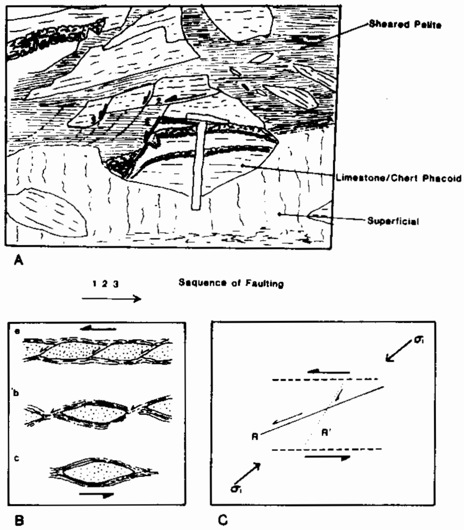

Fig.5a): Field sketch of a limestone/chert phacoid in the mélange at Drakovouni showing clear evidence of formation of blocks in sheared matrix by extension according to the Riedel shear model. 1, 2, 3 indicate the relative timing of three minor faults. A thin chert bed is downthrown in the hangingwall of fault 1 while drag folds are present in the footwall. Fault 2 is parallel to the main shear movement, with top to the west. Faults represented by 3 propagate into the pelite, where they are refracted due to competency contrast. Note that the youngest faults are at a relatively higher angle to the shear bands than the ideal R fracture, in the competent limestone, but flatten listrically in the matrix; b) illustrates the development of competent bed boudinage (after Needham 1987), leading even-

Conversely, the rounding of debris flow blocks is a reflection of competency (determined by cementation) and the shape and size of component clasts.

At several sites, beds of cleaved pebbly, mudstones form an integral part of the mélange. These beds are considered to represent cohesive mud-dominated debris flows that formed in a foreland basin ahead of an orogenic wedge and were later incorporated into the mélange. Such pebbly mudstones were observed in a flysch sequence at Alepohorio, Megdovas (north of the Gulf of Corinth) and at other localities in mainland Greece along the Pindos front. Within these pebbly mudstone beds there is no preferred alignment of the long axis of clasts (length: width ratios of at least 3:1). However, south of Chelmos, and at other locations in mainland Greece, pebbly mudstones constitute part of a mélange in which clasts show a preferred alignment of long axes. Debris flows rarely show well developed clast imbrication, especially where large volumes of pelitic matrix are present and this indicates that pebble alignment can be used as a kinematic indicator. In general (e.g. Drakovouni), we have observed that the long axes are parallel to the transport direction of the over-riding Pindos thrust sheets (i.e. westwards).

Development of the mélange fabric

The dominant planes of shear bands are orientated approximately parallel to the transport direction of the overlying Pindos thrust sheets. Blocks of bedded rock with similar competencies are often roughly the same size. The spacing of the main shear zones appears to have exploited original bedding planes. Large blocks developed between widely spaced shear zones, while smaller blocks formed between less widely spaced shear zones. The geometry of the shear zones (i.e. the dihedral angles of the two subsets) corresponds to the Riedel shear model, whereby a series of secondary fractures develop at an angle to a major through-going shear (Needham 1987, Fig. 5c). The angles of the secondary fractures were controlled by the internal angle of friction of the particular lithology being fractured (a measure of the resistance to movement, itself particular to an individual lithology). The normal faulting observed in the field, which created layer-parallel extension, was developed in the R direction of the Riedel model (i.e. as a synthetic fracture of the main shear zone). The R1 direction is also the orientation of the second sub-set of shears present in the pelitic matrix. Minor shears are also found in the pelite, which could correspond to the R' and P directions.

Extensional features (e.g. small-scale layer-parallel faulting) are found in the mélange, rather than structures indicative of shortening, despite the regionally compressional stress regime. Tensional stresses were developed between the over-riding, highly competent Pindos thrust sheets above and the Gavrovo-Tripolitza platform below. These two major units behaved as rigid bodies relative to the rheologically weak mélange which effectively acted as a lubricant. Highly distributed strain in the matrix accommodated friction-induced stresses between the blocks.

MELANGE GENESIS AND EMPLACEMENT

In the southern Peloponnese, the mélange is found below Triassic rocks of the Pindos nappes. Similarly, in the west of the Pindos Zone, the stratigraphically lowermost sediments are of Triassic age, while many of the more easterly outcrops have basal thrust detachments located beneath Cretaceous units, or more rarely, below Jurassic radiolarites. Thus, the basal Pindos thrust appears to downstep in the transport direction, from below Cretaceous limestone in the east, to below Upper Triassic sandstones in the west. Possible explanations for this are:

a) The Pindos basal thrust cut down stratigraphic section in the transport direction (Fleury 1980). This assumes that the Pindos sediment formed on thinned continental crust and stratigraphic horizons were deposited as a layer-cake succession;

b) The Triassic formations were largely deposited on Middle Triassic transitional crust, while overlying Jurassic radiolarian cherts were also deposited upon younger oceanic crust further east. During Tertiary compression, MORB crust was entirely consumed in an east-dipping subduction zone, while thin remnants of chert and the bulk of the Cretaceous and Early Tertiary formations were off-scraped and incorporated into an accretionary wedge. The basal detachment was located at the sediment/igneous interface and therefore propagated into progressively older stratigraphic horizons, as older parts of the basin were deformed further west.

c) A foredeep formed on the oceanic crust as the accretionary wedge advanced westwards. The western edge of this downwarp developed east-dipping extensional faults. Thus, the propagating basal thrust was transferred from higher to lower stratigraphic horizons across a thrust plane flat, breaching a normal fault.

Model b) is preferred (Fig. 6), as it solves the problem as to what otherwise happened to the inferred oceanic basement in the east and because it fits well with models of present-day subduction (e.g. Westbrook

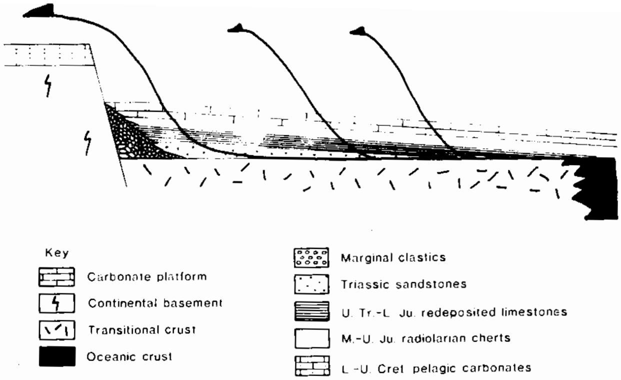

Fig.6: Preferred explanation of the observation that the basal Pindos detachment apparently cuts downsection in the direction of transport. In this case the sediments accumulated on oceanic crust of younger age towards a spreading axis to the east. Thrusting proceeded from east to west, thus the basal detachment propagated into the interface of progressively older sediment above the oceanic crustal basement. The inferred setting was that of a subduction/ accretion complex.

1982).

The rare inclusion of volcanic lithologies in the mélange could have resulted from frontal accretion of raised volcanic edifices on the floor of the Pindos Ocean basin; these were scraped-off into an accretionary complex, while most of the oceanic crust was subducted. This would account for the mélange locally being without igneous rocks and adequately explains the presence of lavas beneath Upper Jurassic radiolarian cherts at Aroania (Fig. 1), where surrounding lithologies are of Upper Triassic and Lower Jurassic age. The presence of mélange with or without igneous rocks intercalated within the Pindos thrust stack indicates that thrusting must have taken place prior to emplacement onto the Tripolitza platform. Most of the mélange is made up of pelite admixed with sedimentary lithologies, including debris flows. These represent turbidite deposits, detached blocks ("olistoliths") and debris flows shed, both off the advancing Pindos thrust sheets and from the collapsed Gavrovo-Tripolitza carbonate platform. Similar debris flow lithologies, that are relatively undeformed in comparison to those of the mélange, are also found in the west at Alepohorio (Fig. 1), where lack of deformation is consistent with a setting in which the Pindos thrust sheets did not over-ride sufficiently far westwards to induce mélange formation (Fig. 7).

REGIONAL TECTONIC SETTING

In the past a number of workers believed that the floor of the Pindos basin represented tectonically thinned continental crust within a rift setting, in which no true oceanic crust was formed (Aubouin 1959, Dercourt 1964, Fleury 1980). An intra-continental setting was also suggested for other Neotethyan basins, including the Hawasina basin in Oman (Bechennec 1987, Bechennec et al, 1990) and the Triassic to Middle Jurassic basin represented by extrusives and deep-water sediments of the Antalya Complex in SW Turkey (Waldron 1984, Dercourt et al., 1986). However, in the Pindos Zone a number of lines of evidence suggest that actual spreading took place to form true oceanic crust: i) deep-water continental margin/oceanic-type sediments are present; ii) tholeiites are considered to have formed in an oceanic setting, including some MORB-type basalts (Pe-Piper and Piper 1990; Degnan, 1992) and iii) backstripped subsidence curves (Green, 1982; Thiebault, 1982) indicate geological settings comparable to present-day passive margins bordering oceanic basins (e.g. NE Atlantic).

More recently, a near consensus has emerged that basins such as the Hawasina in Oman (Cooper, 1986; Robertson, 1986; Robertson and Searle 1990), Antalya in Turkey (Robertson and Woodcock 1984; Robertson and Waldron, 1990) and the Pindos in Greece (Jones, 1990; Jones and Robertson, 1991; Stampfli et al., 1991) represent transitional domains to oceanic crust proper. Thus, for many, the question is no longer "was the Pindos basin formed on thinned continental crust or oceanic crust?", but "did the Pin-dos basin develop as a back-arc basin, or a Red Sea-type basin?" This que-stion has been discussed at length elsewhere (Robertson et al., 1991, Degnan 1992) and it was concluded that there is no definite evidence that the Pindos extrusives were erupted in a back-arc basin, and a Red Sea-type setting remains a valid alternative. In this case, the geochemistry was affected by crustal melting and/or inclusion of a geochemical component from some earlier unrelated subduction event. In this paper, we simply infer that the Pindos extrusives represent an oceanic setting formed by spreading in Mid-Upper Triassic time.

CONCLUSIONS

The lavas of the mélange were extruded on an irregular seafloor in the Mid and/or Upper Triassic related to the rifting and initial spreading of the Pindos Ocean. They have since undergone weathering and low-grade metamorphism. Dolerite represents intrusive equivalents. These lithologies, together with volcaniclastic rocks, formed the basement to overlying sediments (locally U. Triassic), now represented by the Pindos nappes. Rifting in the Middle Triassic was accompanied by outpouring of tholeiitic lavas of mostly basic-intermediate composition, as seen in the Gavrovo-Tripolitza Zone. Subsequently, spreading took place to form the Pindos ocean basin to the east, which was overlain by Upper Triassic and younger sediments (Fig. 7). During the Early Tertiary the Pindos ocean basin began to close as a result of eastward subduction. Most of the oceanic lithosphere was subducted without trace. However, when the trench began to impinge on the passive margin to the west, now represented by the Gavrovo-Tripolitza Zone, elevated areas of volcanic basement were detached and incorporated into a westward advancing accretionary wedge.

Fragments of the Tripolitza Zone carbonate platform below, and the Pindos Nappes above, were detached and incorporated as blocks within the mélange. The melange matrix was partly derived by mixing of Eocene foredeep sediments of the Gavrovo-Tripolitza carbonate platforms and mainly pelitic lithologies within the Pindos nappes. The basal detachment horizon of the Pindos nappes experienced intense layer-parallel extension, which facilitated mixing of lithologies to produce tectonic mélange.

The mélange is the end-product of a long history beginning with off-scraping from oceanic crust within the Pindos ocean, and ending with final emplacement over the collapsed Gavrovo-Tripolitza carbonate platform to the west. Mélange in the Peloponnese thus provides important insights into tectonic processes in the Hellenides.

ACKNOWLEDGEMENTS

The first author acknowledges receipt of a NERC research studentship,

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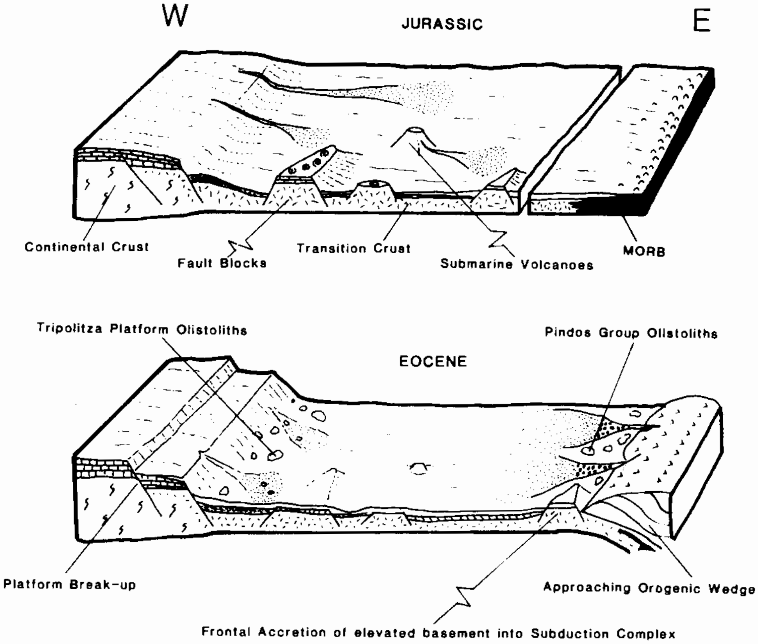

Fig. 7: Model of the genesis and deformation of the western part of the Pindos oceanic basin, a. During the Jurassic, when sediments blanketed an irregular continent-ocean boundary area; b. During the Eocene when Pindos oceanic crust was being consumed in an eastward-dipping subduction zone. Note the development of an accretionary complex in the east, and the destabilisation of the Tripolitza platform in the west as it began to undergo flexurally induced subsidence. The subduction complex was finally emplaced over a collapsed margin to the west.

while the second author's fieldwork was assisted by a grant from the Carnegie Trust for the Scottish Universities. Helpful comments on the manuscript were received from two anonymous referees.

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