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Middle to Upper Devonian melanges in SW Spain and their relationship to the Meneage Formation in south Cornwall

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Melange deposits have recently been discovered in SW Spain in the Oceanic Exotic Terrane between the Ossa Morena Zone and the South Portuguese Zone. They occur in tectonic slices of different metamorphic grade where they have been imbricated together in the immediate footwall to the Beja-Acebuches Amphibolites. Debris in the melange includes greywacke, quartzite and amphibolite phacoids and also exotic material such as serpentinite and marble. Available palaeontological dating supports Givetian to Famennian ages for the imbricated sedimentary sequences. The geological setting of the Oceanic Exotic Terrane is analogous to that of the Gramscatho Basin in SW England. This demonstrates that similar processes were operating during the Upper Devonian in both SW England and SW Spain which were linked around the Iberian-Armorican arc.

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Introduction

The Iberian Peninsula has been subdivided into several distinct structural and stratigraphic domains (Fig. 1, Lotze 1945; Julivert *et al.* 1972). The two most southerly domains, the Ossa Morena Zone and the South Portuguese Zone have recently been separated by a new tectonostratigraphic unit, the Oceanic Exotic Terrane (Quesada, in press), which has been defined on the basis of structural and lithological criteria (Oliveira, in press; Silva *et al.* in press; Crespo-Blanc 1989). The Oceanic Exotic Terrane is separated from the Iberian Pyrite Belt and the rest of the South Portuguese Zone by a series of north-dipping, southwards transporting thrust faults and from the Ossa Morena Zone by a belt of high grade amphibolites.

Increasing knowledge of the geology of the S W Iberian Peninsula has reinforced previous hypotheses of a Variscan link between SW England and SW Iberia (Andrews 1982) around the Iberian-Armorican Arc (Matte and Burg 1981; Matte 1986). Detailed field mapping on the external southern limb of the Arc, in the region of Aroche, N W Huelva Province (Fig. 2) has revealed the presence of melanges which lie in a similar structural and stratigraphic setting to that of the Meneage Formation (Barnes 1983) (partly equivalent to the Roseland Breccia Formation of Holder and Leveridge 1986). Both units occur in the footwall to an oceanic suture that is marked by a dismembered ophiolite and both units structurally imbricate sediments that have been dated as being Late Givetian to Early Famennian in age. This contribution focuses on the melange units of the Oceanic Exotic Terrane and how they relate to the established geological framework. It also addresses the wider implications for the development of melanges around the Ibero-Armorican Arc which resulted from similar processes operating in spatially divided areas during the Upper Devonian.

Geological setting

The Ossa Morena Zone and the Oceanic Exotic Terrane are separated by a narrow belt of strongly deformed amphibolites, the BejaAcebuches Amphibolites, thought to represent fragments of an ophiolite (Bard and Moine 1979: Munha *et al.* 1986; Crespo-Blanc and Orozco 1988). High grade granulite facies rocks comprise the internal hanging wall of the Ossa Morena Zone (Crespo-Blanc 1989) and lower grade metasediments of the Oceanic Exotic Terrane the external footwall. Studies to date, mainly within the Portuguese sector (Oliveira *et al.* 1986; Oliveira, in press; Silva *et al.* in press) have established a stratigraphic framework for the South Portuguese Zone (Fig. 3), although melange units have not previously been recognised. On the Spanish side of the border the area is less well studied and here the Oceanic Exotic Terrane is comprised of several contrasting sedimentary facies which have been tectonically imbricated, a process that occurred during regional greenschist facies metamorphism.

All of the formations identified have been strongly affected by three phases of deformation and polymetamorphism that has resulted in fundamental modifications to the original sedimentary deposits. The boundaries between these formations are tectonic in nature and therefore the stratigraphic scheme presented in Fig. 3 is proposed. This differs from previously published schemes such as that compiled by Portuguese workers, which is also shown in Fig. 3 for comparison, in that the Oceanic Exotic Terrane is seen as an imbricated sequence as opposed to a normal time-stratigraphic sequence.

Ages for the rocks on both sides of the border are loosely constrained due to a paucity of suitable material. However, in Portugal poorly preserved palynomorphs have yielded Frasnian to Famennian ages (Oliveira *et al.* 1986) for rocks within the Ferreira-Ficalho Group (Fig. 3) which outcrops along the northern border of the Oceanic Exotic Terrane along strike from the study area (Fig. 1). On the Spanish side spores have been extracted from rocks within the study area (Lake *pers. comm.)* and these give a late Givetian to early Frasnian age for one of the formations identified (Fig. 3, La Giralda Formation). No other dates have been extracted from the Oceanic Exotic Terrane in Spain.

Lithological descriptions

Several different rock types are distinguished but in general terms these can be viewed within two separate categories: bedded sediments and melange.

(a) The bedded sediments

Two formations, the Puerto Canon Formation and La Giralda Formation, are identified. The Puerto Canon Formation outcrops on the northern limb of the Los Ciries Antiform (Fig. 2) and consists of a relatively immature assemblage of intercalated coarse grained arenites and thin horizons of dark coloured mudrock and lighter coloured silt. The arenites have a high volcanic component, indicated by polymetamorphic quartz grains that can be up to several millimetres in diameter, and igneous fragments which are supported within a matrix of phyllosilicate minerals. The relationship of this formation with the structurally underlying formations remains uncertain, although deformation by only one obvious set of structures and the relatively immature nature of the sediments has led to the suggestion that the boundary between them was originally (or might be) unconformable (Crespo-Blanc 1989).

The La Giralda Formation outcrops both to the north and south of the Los Ciries Antiform (Fig. 2). This is a flysch dominated unit composed of arenites and fine grained siltstones intercalated, on various scales from several metres to several centimetres, with black shales and slates together with minor tuffaceous horizons. The

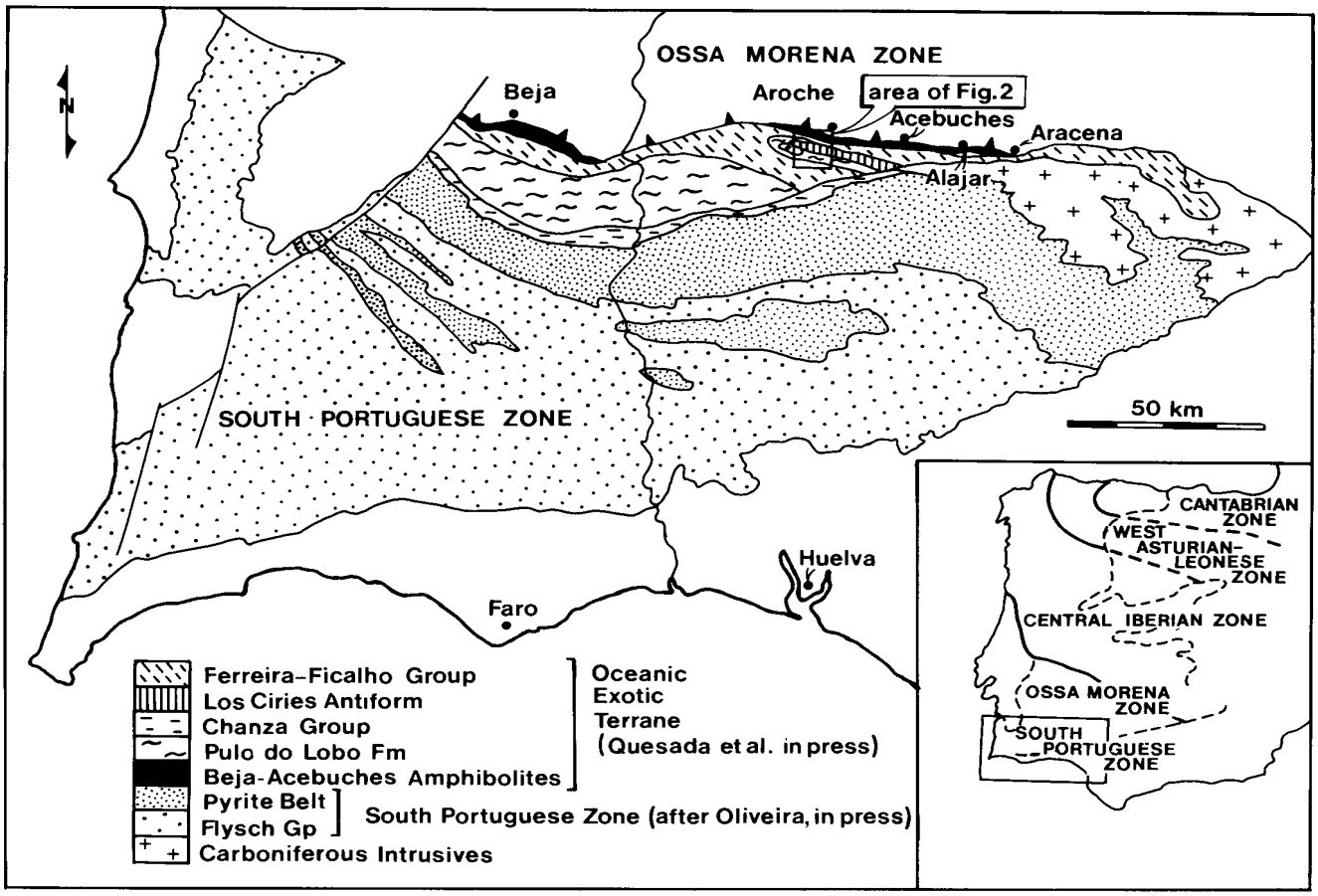

Figure 1. Location and outline stratigraphy of the study area.

formation is sedimentologically mature, the arenite horizons being composed mostly of quartz with accessory feldspar and opaque minerals. Heavy minerals assemblages are generally composed of zircon and tourmaline. Graded bedding is a common feature although its use to determine the predominant facing direction is complicated by the deformation which has severely disrupted the beds by folding, thrusting and considerable repetition of the sequence.

Recent palynomorphs recovered from black slates (Lake *pers. comm.)* places this formation within the late Givetian to early Frasnian stages. Sparse spore abundance in the sediments, together with the maturity of the deposits indicates they may have had a relatively distal source.

(b) The melanges

Two distinct formations are identified to the south of Aroche and a further one is considered that lies along strike from Aroche outcropping to the south of Alajar (Fig. 2). These are the Peramora Mélange Formation, the Cumbres de Los Ciries Formation and, further to the east, the Alajar Formation.

(i) The Peramora Mélange Formation is well exposed in the hinge of the Los Ciries Antiform and along river sections that cut perpendicular to strike (Fig. 2). It consists of a chaotic mixture of isolated lenses, or phacoids, and exotic debris that includes amphibolite blocks, greywackes and some quartzites preserved within a fine grained recrystallised matrix composed of actinolite, plagioclase and hornblende with accessory quartz, epidote, clinozoisite and opaque minerals. The blocks range in size from small pebbles of amphibolite (Fig. 4B) up to large (20m wide, strike length unknown) fragments of a sheeted dyke complex. In the Los Ciries Antiform the phacoids vary in composition from small (<200mm) fragments of chert to large (> 10m) blocks of amphibolite. The latter are generally lenticular in shape but many smaller blocks retain an angular shape around which the external foliation is deflected. The amphibolite blocks often possess an internal foliation that is distinct from the enclosing regional schistosity and in some cases (Fig. 4C) they preserve an original igneous texture. Fig. 4C illustrates a block that is subrounded and preserved within a recrystallised matrix that is dominated by fine grained phyllosilicates. Along river sections that cross the boundary between the melange and the Beja-Acebuches Amphibolites (Fig. 2) the phacoids once again vary in size from small pebbles (Fig. 4B) to large blocks metres in diameter. The example in Fig. 4B clearly shows a small amphibolitic clast preserved within a fine grained matrix. Thin section analysis shows that the matrix consists of smaller crystals of actinolite, plagioclase, hornblende, quartz, phyllosilicate and opaque minerals. Other exposures along the river sections display lenticular clasts, up to 150mm long, of bedded material which have their long axes orientated parallel to the regional schistosity and have been strongly flattened within it. These latter clast types are rare and in the majority of cases signs of an earlier sedimentary history are not preserved. Quartzite phacoids range in size from small pebbles a few centimetres in length to large metre length phacoids. They vary in colour from white through to black and invariably their matrix is recrystallised.

(ii) The Cumbres de Los Ciriers Formation (Fig. 2) is essentially a monotonous sequence of quartz-mica schists, or phyllonites, intercalated with minor discontinuous horizons of quartzite and slate and all these lithologies have been extensively modified by polyphase tectonism and metamorphism. The intensity of the deformation has obliterated any indication of the sedimentary history and nowhere are sedimentary structures preserved. The fine grain size and mineralogy of the rocks indicates that they were probably originally mudstones deposited in a basinal or starved marginal environment.

This formation is included as a mélange unit because it contains phacoids of exotic debris although these are generally smaller and less abundant than in the Peramora Melange. They range from blocks that have a basic geochemistry to small clasts of quartzite. The strike-parallel rafts and trains of quartzite and slate may represent large phacoids that are disrupted remnants of an original stratigraphy.

(iii) The Alajar Formation outcrops along strike from the above named formations (Fig. 1). Criteria used for its definition are a matrix of fine grained schist enclosing variably sized phacoids of very pure quartzites that are strongly attenuated parallel to strike rare occurrences of exotic phacoids that include serpentinite and marbles. The massive quartzites are almost pure quartz with minor and variable amounts of feldspar (plagioclase and orthoclase), muscovite and biotite mica. The colour of the quartzite lenses is usually white to grey although occasionally black quartzites are found, sometimes associated with pyrite mineralisation. These massive quartzite bodies do not display any recognisable sedimentary features such as graded bedding or flow direction indicators and probably represent dismembered fragments of mature, well sorted units. Because they are more erosion resistant than the surrounding matrix the quartzite phacoids or "fish" form positive features across the hillsides and this makes them easy to see in three dimensions. Their size varies considerably from thin centimetric quartz ribbons to phacoids that are greater than 30m in strike-parallel length, the larger ones being generally sigmoidal in shape while the smaller ones are disc-shaped with either stubby or pointed noses.

Rare, isolated blocks of very exotic material (Kühner *pers. comm.*) are particularly important in considering the derivation of the sediments comprising this formation. Three particular occurrences are noted. The first is a block of serpentinised ultramafic material measuring some 30-50m parallel to strike and with a width of up to 10m. It consists of an homogenous dark green, soft serpentinite. The block is wrapped around by the regional foliation. A thin continuation of material that has been highly attenuated and altered to talc can be followed laterally for several tens of metres but is eventually lost after some 40m. This may be the equivalent to a similar unit with ultramafic bodies found to the west in Portugal (P. Forben pers. comm.).

Along strike from this ultramafic phacoid is a unit of dark grey material previously identified by IGME (1983) as an outlier of the Beja-Acebuches Amphibolite. Investigation revealed that the outcrop in fact consists of fragmented blocks of a similar nature to the Peramora Mélange Formation. It is bounded on its northern border by a c.10m wide zone of light coloured mylonites that form a thrusted contact, parallel to the regional foliation.

The third occurrence of exotic material is exposed along strike from the massive quartzites described earlier. It consists of blocks of marble which contain within them phacoids of quartzite completely enclosed within the marble matrix. The matrix is multicoloured ranging from white to black and grain size varies from fine to coarse. Thin section analysis shows that serpentine occurs as a fracture filling mineral. Chlorite is also present as a late stage mineral forming from the alteration of fine grained argillaceous material. These blocks can be correlated with marbles found in the adjacent hanging wall granulite facies rocks of the Ossa Morena Zone.

Geochemical analysis of samples taken from the Peramora Mélange Formation has confirmed its "oceanic" nature. The Beja-Acebuches Amphibolites have tholeiitic affinity (Munha *et al.* 1986) and provide the most obvious source for the amphibolitic blocks found in the mélange. Although the source region for the quartzite debris is not known it may have been derived from the adjacent Ossa Morena Zone. The basic chemistry of this unit, its high concentration of amphibolitic debris and the green/blue tinge to fresh outcrop have led previous workers (Munha *et al.* 1986; Crespo-Blanc 1989) to group it with the Acebuches Amphibolites, as a part of the complex with "oceanic affinity".

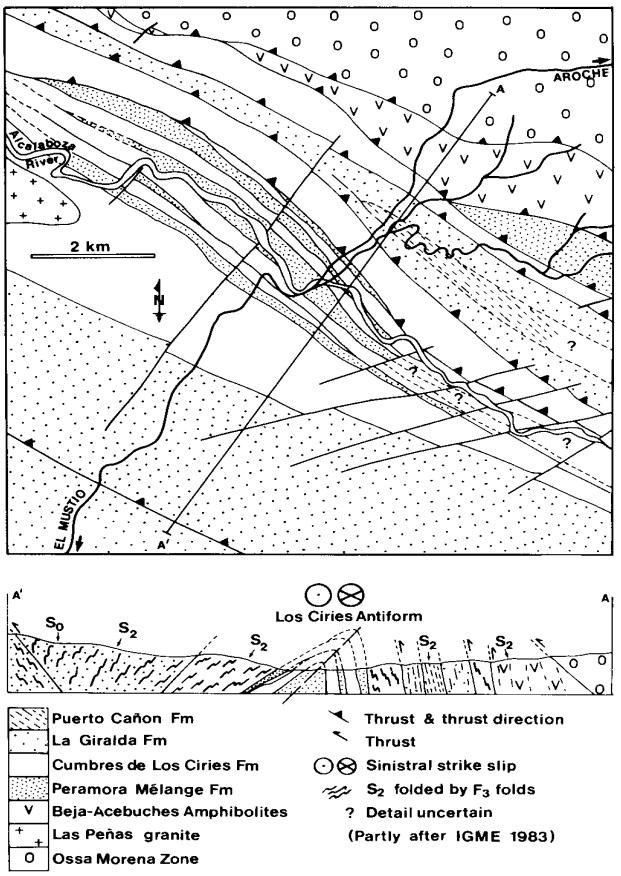

Figure 2. Schematic geological map of the study area which is ' located on the boundary between the Ossa Morena Zone and the Oceanic Exotic Terrane. The structure is dominated by strike-parallel faults bounding tectonic horses. The cross section across line A-A' demonstrates pre-D3 imbrication. The Los Ciries Antiform is overturned to the north showing anomalous vergence. It may be related to a blind backthrust.

Structure

Three phases of deformation are recorded in the footwall rocks of the Oceanic Exotic Terrane (Table 1). Structural mapping along road and river sections has identified a folded imbricate thrust stack, especially well seen within the Los Ciries Antiform (Fig. 2), which consists of horses of the Cumbres de Los Ciries Formation and the Peramora Mélange Formation. They are juxtaposed along knifesharp tectonic contacts that are strongly welded with individual slices being up to 20m in width. The imbrication pre-dates the F3 folding as can be clearly seen in the cross section in Fig. 2. This figure also shows that the whole area is dominated by thrust tectonics with thrust slices of the different formations being faulted together.

Earlier deformation in the Cumbres de Los Ciries Formation and the Peramora Mélange Formation occurred within a ductile regime that was accompanied by D2 sinistral shear. Kinematic indicators, which include shear bands and rotated porphyroclasts of feldspar, are abundant in both units and are especially well developed in the Cumbre de Los Ciries Formation on the southern boundary of the Beja-Acebuches Amphibolites where well preserved shear bands show clearly the sinistral sense of shear (Fig. 4D).

On the northern limb of the Los Ciries Antiform rocks of La Giralda Formation were also affected by early ductile shearing (Fig. 2) with formation of a pervasive slaty cleavage, sheath folds and incipient transposed bedding. Fold axial planes have been rotated into sub-

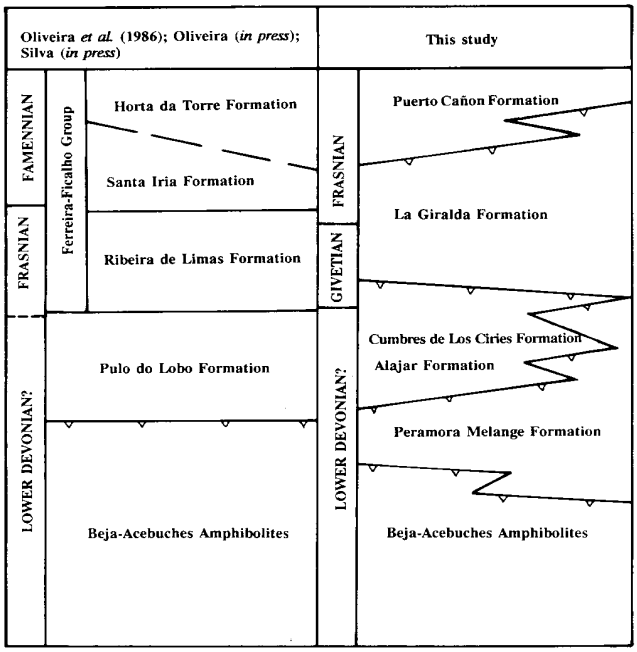

Figure 3. Comparison of the time stratigraphic column compiled by previous workers in the Portuguese sector with the proposed scheme for the study area. The former implies normal boundaries between the formations of the Oceanic Exotic Terrane whereas the latter adopts a structural approach.

Table 1. Summary of the structural and metamorphic features seen in the Beja-Acebuches Amphibolites, the Peramora Melange and the Cumbres de Los Ciries Formation.

STRUCTURE	METAMORPHISM
D1 - Spaced pressure solution cleavage, S1.	MS1 - Amphibolite facies in the Beja-Acebuches Amphibolites.
D2 - Spaced pressure solution cleavage. S2. - Sinistral shear bands - Imbricate thrust stacking.	MS2 - Greenschist facies in the Peramora Melange and Cumbres de Los Ciries - Retrogressive greenschist facies in the Beja-Acebuches Amphibolites.
D3 - Large scale open-tight chevrorn folding. - Weak S3	

Table 2. Tectonostratigraphical comparison between the SW Iberian Peninsula and SW England.

SW IBERIA	SW ENGLAND
Oceanic Exotic Terrane	Gramscatho Basin
South Portuguese Terrane	Dartmouth Antiform
	Trevone Basin
	Culm Basin

parallelism with the regional foliation and once again there is abundant evidence for sinistral movement. On the southern limb of the Los Ciries Antiform the main feature of deformation within La Giralda Formation is the development of two spaced pressure solution cleavages that have both been folded by a later D3 event. This last phase of deformation resulted in open to tight folds, normally verging towards the SW, and also to regional thrusting on varying scales which is responsible for considerable repetition within the sequence.

The main structural feature of the Puerto Canon Formation is the presence of tight mesoscopic folds with steep fold axial planes and sub-horizontal fold plunges. Folding strongly affected the fine grained muddy and silt horizons and resulted in a bedding parallel slaty cleavage. Extensional boudinage displaces the fine grained muddy beds and indicates that a component of sinistral shear accompanied folding.

Metamorphism

Microprobe analysis of minerals from the Peramora Melange Formation shows that the matrix assemblage is dominated by actinolite, plagioclase (composition An_{40}-An_{60}), chlorite, and opaque minerals. The amphibolite clasts found in the mélange are conversely composed principally of hornblende and plagioclase. Secondary actinolite also occurs in the clasts overgrowing the earlier hornblende phase. This indicates that there was a phase of amphibolite metamorphism, as seen in the clasts, that was followed by a phase of prograde upper greenschist facies metamorphism, as seen in the matrix (Table 1). The simplest explanation to account for this would be to derive the amphibolite clasts from an amphibolite facies metabasite source prior to the prograde metamorphism of the matrix.

The Cumbres de Los Ciries Formation has suffered metamorphism under lower greenschist facies conditions. In this unit the common mineral assemblage is quartz, muscovite, biotite, with chlorite, epidote and spessartine garnet forming minor phases. The metamorphism also appears to be prograde in character.

These prograde metamorphic events may be synchronous with nearby retrogression of the Beja-Acebuches Amphibolites to upper greenschist facies that accompanied sinistral shear across the boundary between the Ossa Morena Zone and the South Portuguese Zone (Crespo-Blanc 1989). The prograde metamorphism could be either associated with subduction related imbrication or collision related imbrication during docking between these two terranes.

Syn-sinistral shearing andalusite, cordierite and garnet are seen as porphyroblasts in rocks immediately juxtaposed against the Beja-Acebuches Amphibolites. They imply a high temperature/low pressure overprint which is interpreted as representing a response to the emplacement of the still hot Beja-Acebuches dismembered ophiolite over the basinal sediments (Crespo-Blanc 1989).

Iberian Pyrite Belt and southern South Portuguese Zone

Previous comparisons of SW England and SW Iberia have tended to emphasise the geology of that part of the South Portuguese Zone which exhibits a less complicated tectono-metamorphic evolution. The stratigraphy and structure of these areas have been described by several authors (Bard 1969; Schermerhorn 1971; Oliveira 1983; Silva *et al.* in press). Their principal features are:

(a) A late Devonian - early Carboniferous extensional phase that gave rise to bi-modal volcanism and extensive massive sulphide mineralisation.

(b) Basin inversion that resulted in SW prograding flysch sedimentation ('Culm').

(c) Continued shortening within a transpressive regime with SW directed transport. Shortening was accompanied by folding and thrusting which reworked the Oceanic Exotic Terrane as the D3 folding phase but is the first recorded event further southwestwards. Kinematic indicators suggest an overall sinistral sense of displacement although there is evidence of local dextral shear in places (eg. Oswin 1986).

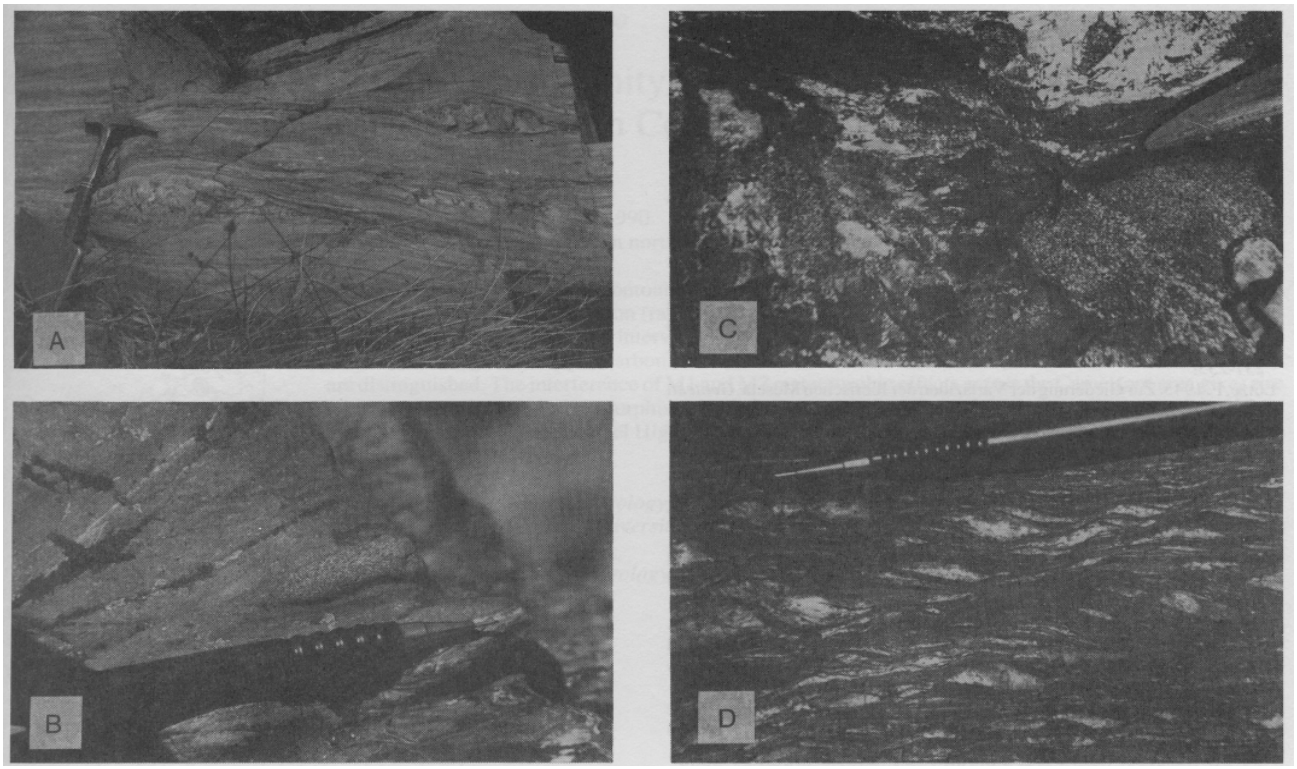

Figure 4. A, Band C. The Peramora Mélange Formation. Blocks within the mélange consist of a choatic mix of lithologies around which the foliation is deflected: (A) shows blocks of greywacke wholly contained within the strong S2 foliation; (B) shows an amphibolite clast within a fine grained pelitic matrix; (C) shows a rounded block of gabbro also contained within a fine grained matrix. D. Shear bands and kinematic indicators demonstrating sinistral shear within the Cumbres de Los Cities Formation. The notebook in (A) is 200mm long, the pencil in (B) and (D) is 140mm long and the pointed hammer head in (C) is 170mm long.

This evolution should be compared with that of SW England north of the Perranporth-Pentewan Line (Table 2).

Discussion

It is now possible to refine the comparisons between S W England and SW Iberia. The Gramscatho Basin is an obvious analogy of the Oceanic Exotic Terrane. Palynomorphs from sediments within the latter range from Givetian to Frasnian in age whilst sediments in the Gramscatho Basin range in age from Eifelian to Famennian (Sadler 1973; Le Gall *et al.* 1985; Wilkinson and Knight 1989). Both the Oceanic Exotic Terrane and the Gramscatho Basin are dominated by turbiditic detritus. Frequent olistostromes show evidence of tectonic instability. The Peramora Melange Formation is typical of the exotic melange deposits associated with obducted ophiolites and can be directly compared with the Meneage Formation (Barnes 1984) in south Cornwall. Indeed the latter formation contains amphibolite rudites with clasts bearing a hornblende-plagioclase fabric and mineralogy (Barnes 1984) which also predates the regional (pumpellyite-actinolite) facies metamorphism (Barnes and Andrews 1981). The suggestion of late Devonian - early Carboniferous obduction of the Lizard Complex (Barnes and Andrews 1986) is mirrored by the late Devonian - early Carboniferous tectono-metamorphic events in SW Iberia probably reflecting collision between the Oceanic Exotic Terrane and adjoining continental massifs. The D1 and D2 events seen in the Oceanic Exotic Terrane are not recorded in the Iberian Pyrite Belt and further south in the South Portuguese Zone.

Notwithstanding the comparisons above, there are also important distinctions to be made between south Cornwall and the Oceanic Exotic Terrane. The style of deformation and metamorphism differs considerably. In SW Iberia thrust slices that record different sedimentary facies and metamorphic grades have been imbricated together and indicate a more complex tectono-metamorphic history, possibly incorporating subduction related events. Subsequently low pressure metamorphism occurred in the sediments in the immediate footwall of the Acebuches Amphibolites, attributed here to a hot metamorphic sole during obduction. No similar metamorphic response is seen in SW England (Barnes and Andrews 1984). The D2 (syn-obduction?) fabric in SW Spain is strongly transpressional with a strike-parallel stretching lineation. In SW England the syn-obduction fabric is conversely shallowly dipping with a weak down-dip stretching.

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