VARISCAN OPHIOLITES AND HIGH-PRESSURE METAMORPHISM IN SOUTHERN IBERIA

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ABSTRACT

The Variscan ophiolites in southern Iberia occur both as a thin belt along the boundary between the Ossa-Morena (OMZ) and South Portuguese Zones (SPZ) (Beja-Acebuches ophiolite) and as dismembered, scattered allochthonous klippen on top of lower Palaeozoic sequences within the internal areas of the OMZ. The Beja-Acebuches ophiolite corresponds to a thin amphibolite-serpentinite belt displaying internal lithological organisation including, from bottom to top: metaperidotites (harzburgitic/dunitic) and cumulate pyroxenites, flaser gabbros with trondhjemitic intrusions, amphibolites (locally derived from a sheeted dike complex) and fine-grained greenschists (locally preserving pillowed structures). Deformation structures result from three main deformation phases: D1 (early Devonian) corresponds to high-temperature ophiolite obduction towards N-NE, D_2 (middle Devonian) is related to retrogression during transpressive sinistral shearing to WNW, and finally, D_3 is a more brittle event, and involved sinistral south-westwards thrusting reactivating D_2 structures. The ophiolite is bounded to the north by a thrust that brought OMZ infra-crustal rocks over the ophiolitic sequence; towards the south the ophiolitic complex has been thrust over the SPZ units and is unconformably overlain by a late Devonian flysch sequence. The Beja-Acebuches amphibolites were originally tholeiitic gabbros/dolerites/basalts displaying considerable geochemical variations that range from MORB-type to those transitional to arc tholeiites, suggesting derivation from a back-arc basin oceanic crust.

The internal ophiolitic klippen were emplaced contemporaneously with the obduction of the Beja-Acebuches ophiolite. They comprise small, dismembered tectonic slices that were imbricated within a high-pressure (eclogite/blueschist), early Palaeozoic passive continental margin sequence, and then thrust onto the OMZ. The high-pressure metamorphism was polyphase; early (pre- to syn-D1) eclogite recrystallization is interpreted as reflecting type-A subduction and initial D1-thrusting; late blueschist facies overprinting corresponds to tectonic imbrication related to the nappe emplacement. Ophiolite geochemistry displays wide variations in incompatible element fractionation, ranging from N-MORB type LREE-depleted to LREE-enriched T/P-MORB; contrasting with similar lithologies from the Beja-Acebuches ophiolite, the orogenic (island arc-like) characteristics were not detected in these internal ophiolitic occurrences. The contrasting characteristics of the Ossa-Morena ophiolite types are reminiscent of those already described from other ophiolite belts and suggest that they probably represent different oceanic basins.

INTRODUCTION

The Variscan Belt of the Iberian Peninsula resulted from a continent-continent collision between an Ibero-Aquitanian indentor (Brun and Burg, 1982; Matte, 1986; Burg et al., 1987) and a northern continent (Baltica?, N-America?; Ribeiro et al., 1990; Quesada et al., 1994). Collision has produced, in the frontal areas of the indentor, a crustal scale imbrication in the Ibero-Armorican arc contrasting with oblique convergence along both N and S branches of the arc. Therefore, indentation has produced left-lateral transpression in Iberia and right-lateral transpression in Armorica. It has been proposed (Crespo-Blanc and Orozco, 1988; Fonseca, 1997) that a major ocean, the Rheic ocean, was closed by subduction/obduction towards the inner part of the arc, leaving some remainder ophiolitic slices: the Lizard suture in SW England (northern branch of the Ibero-Armorican arc) and the Beja-Acebuches suture zone (at the southern branch of the same arc) (Fig. 1).

In this paper we review the available geological data on ophiolitic and associated high-pressure allochthonous structures in the SW branch of the Iberian Variscan Chain and make an attempt to integrate them within the proper geotectonic context.

THE BEJA-ACEBUCHES OPHIOLITIC COMPLEX

Regional Setting

The Beja-Acebuches Ophiolitic Complex (BAOC) is a thin amphibolite-serpentinite metamorphic belt occurring between the southern boundary of the Ossa-Morena (OMZ; Iberian Autochthon) and the South-Portuguese Zones (SPZ).

Fig. 1 - Correlation between the Variscan sutures in western Europe (adapted from Crespo-Blanc, 1989 and Matte, 1986). The stippled area correspond to the innermost crystalline nappes, ophiolitic remnants and related root-zones. MCO: Massif Central Ocean; BAOC - RO: Beja-Acebuches Ophiolitic Complex - Rheic Ocean.

This complex comprises a continuous unit (about 1500 m thick) extending from the neighbourhood of Beja (South Portugal; Fig. 2 and 3a) to Acebuches (Aracena - Southwest Spain) (Crespo-Blanc, 1989; Quesada et al., 1994; Fonseca, 1995). Along a geotraverse, from S to N (and top to bottom), we mapped fine-grain greenschists (locally pillowed metabasalts containing chert-like intercalations), amphibolites s.l. (corresponding locally to metamorphosed sheeted dikes or multiple dike intrusions in gabbros), flaser gabbros (metagabbroic cumulates with minor meta-trondhjemitic intercalations), and scattered serpentinite bodies (Fonseca, 1995). The BAOC was first deformed during emplacement towards N-NE (D1; early Devonian), causing mylonitic imbrication and high-T recrystallization of the basal units; this was followed by a D_2 deformation phase (middle Devonian) corresponding to greenschist/lower amphibolite grade, transpressive ductile, sinistral shearing, that partially dismembered the original sequence by juxtaposing different ophiolite units. The ophiolitic complex is bounded on the northeast by a D_3 (more brittle) sinistral thrust which has placed rock units of the OMZ above the BAOC. The OMZ rocks include Precambrian high-grade basement (exposed within the core of antiformal megastructures), and a Cambrian to lower Devonian cover, which were affected by D_1 deformation and coeval regional metamorphism. All these tectonic units were intruded by the Beja Igneous Complex (BIC) (Fonseca, 1995). The BIC is a typical gabbroic layered complex, grading upwards from dominantly peridotitic-gabbroic to anorthositic-gabbroic assemblages (Santos et al., 1990); the BIC hosts xenoliths of several regional tectonic units, (including previously deformed metamorphic rocks from the BAOC; Fonseca and Ribeiro, 1993), and is younger than middle Devonian (Eifelian).

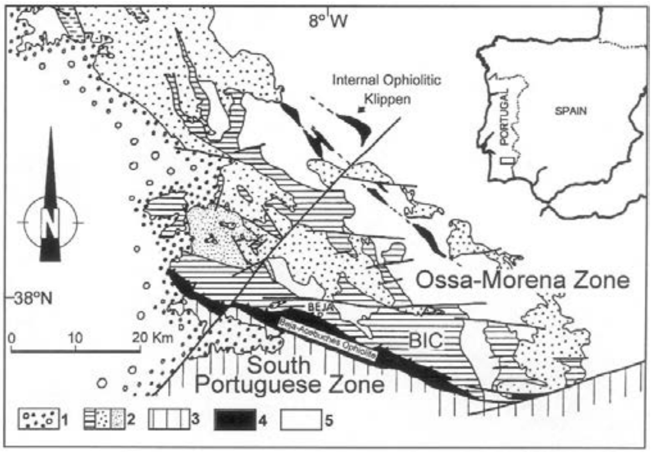

Fig. 2 - Simplified geological map of the Variscan Suture Zone (Portuguese branch) after Fonseca (1995); 1 Tertiary cover; 2- Beja Igneous Complex; 3- Undivided South Portuguese Zone; 4- Ophiolitic sequences; 5- Undivided Ossa-Morena Zone.

Tectonothermal evolution

The igneous rocks of the BAOC underwent intense Variscan deformation and metamorphism (Andrade, 1983; Munhá et al., 1986; 1989; Fonseca and Ribeiro, 1993; Quesada et al., 1994; Fonseca, 1995; 1997). Original textures and mineralogy have been, in some places, almost completely destroyed. This, together with the disruption of the original lithologic sequence, render difficult recognising the original ophiolitic lithological sequence. Metamorphic grade within the ophiolite (s.s) is variable, increasing very fast both northwards and along the (ESE) strike direction towards the central part of the belt. Metamorphic conditions range from typical greenschist-amphibolite facies transitional assemblages developed in metabasalts, through amphibolite facies, to low-pressure granulite facies metagabbros (Quesada et al., 1994). Metamorphic textures are dominantly nematoblastic and display the deformational history of

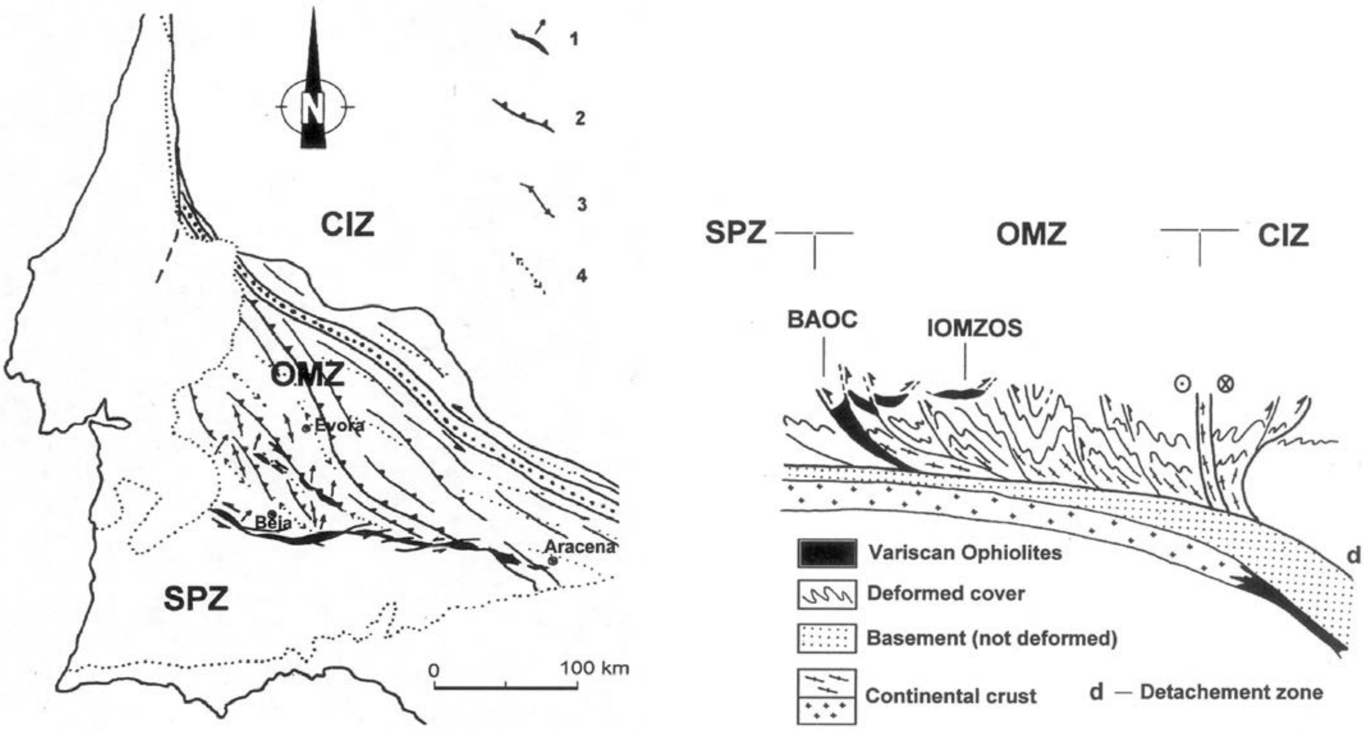

Fig. 3 - **a**- Schematic structural map of SW Iberia - OMZ; 1- Variscan Ophiolites: arrows represent D_1 stretching lineations and sense of shear; 2- D_2 thrusts; 3- D_1 fold axis; 4- D_2 fold axis. **b**- Deep structure of the SW Iberian Variscan Fold Belt (Ossa-Morena Zone) (adapted from Araújo et al., 1998).

the BAOC; three phases of deformation are recorded and preserved in the footwall rocks of the BAOC. These three phases are responsible for the present dismembered configuration of this geodynamically important suture between the OMZ and SPZ.

The first phase of deformation - D_1, well identified at all scales, is associated with the basal rock units of the ophiolitic sequence (including granulite/amphibolite facies dikes in gabbro, flaser gabbros with associated plagiogranites, and serpentinized ultramafics). The presence of σ-type asymmetric tails on retrograded recrystallized grains of brown hornblende from dikes in gabbro indicates northwards thrust shear. This agrees with the presence of a macroscopic mylonitic cleavage with associated stretching lineation indicating shear towards N-NNE. D_1 thrusts are mainly sub-horizontal or gently dipping to the south (Figs. 3a and 3b). This deformation phase (D_1) is related to the obduction and emplacement of the ophiolite upon the crystalline footwall of the N-S Serpa-Brinches Antiform in the OMZ and affects both the Precambrian basement and its Cambrian cover (Fonseca, 1995).

Also affected by D_1 are felsic to intermediate metavolcanic gneisses, that are tectonically imbricated within the ophiolitic sequence. Microscopically, the felsic to intermediate metavolcanites show quartz porphyroclasts with σ-type asymmetrical tails indicating northwards shearing. These lithologies are interpreted either as highly deformed frontal arc felsic rocks (obducted together with the BAOC on top of the OMZ), or as supracrustal OMZ lithologies (Fonseca, 1995).

The second phase of deformation D_2 can be identified essentially on the topmost units of the ophiolitic sequence (greenschist facies metabasalts and amphibolites s.l.). Kinematic indicators, which include shear bands and rotated porphyroclasts of hornblende, are very abundant, being particularly well-developed in the amphibolitic unit where well-preserved shear bands show a sinistral component with thrust movement towards the WNW. In the metabasalt unit, this shearing is related to a strong mylonitic foliation, subhorizontal or gently dipping to the ESE, and to a stretching lineation, indicating NW-wards movement. It is considered that these events represent late pulses of the ophiolite emplacement (Fonseca and Ribeiro, 1993; Fonseca, 1995). During these events, WNW-ESE sinistral faults and lateral ramps have dismembered and pulled apart the original structures. The lateral ramps are responsible for juxtaposing rocks of very different metamorphic grades.

All these structures have been reactivated by D_3 sinistral SW-wards thrusts and associated WNW-ESE cleavage, becoming more brittle towards the late stages.

Magmatic affinities and geotectonic setting

Petrographical and geochemical features of the BAOC were described in detail by Quesada et al. (1994). These data indicate that the BAOC amphibolites were originally tholeiitic gabbros/dolerites/basalts. The BAOC geochemistry displays several peculiar features, some of which are indicative of orogenic magmatism and other which are more typical of ocean floor basalts. Thus, the fractionation trends ($FeO^{(t)}$, TiO_2, $FeO^{(t)}/MgO$; Fig. 4a) and the high Zr/Nb (21 - 35) ratios are characteristic of the latter; yet, LILE/HFSE ratios and LILE contents range up to much higher values than in typical MORB, suggesting calc-alkaline affinities. Indeed, some Beja-Acebuches amphibolites almost mimic the geochemical characteristics of calc-alkaline island arc basalts (Fig. 4b; Table 1); together with the remaining samples, they demonstrate that the BAOC trace element chemistry is transitional between that of ocean ridge and orogenic basalts (Fig. 4b). This transitional geochemical pattern is widely accepted as a typical feature of back-arc basin basalt geochemistry (e.g., Saunders and Tarney, 1991), strongly suggesting derivation of the BAOC from a back-arc basin oceanic crust (Quesada et al., 1994).

THE INTERNAL OMZ OPHIOLITIC SEQUENCES

Brought up by detailed study of the BAOC, several ophiolitic sequences have been recognized in the OMZ (IOMZOS, Internal OMZ Ophiolitic Sequences; Araújo et al., 1993). Ophiolitic fragments occur as tectonic imbrications within a volcano-sedimentary mylonitic sequence, which has been thrust northwards above the autochthonous Upper

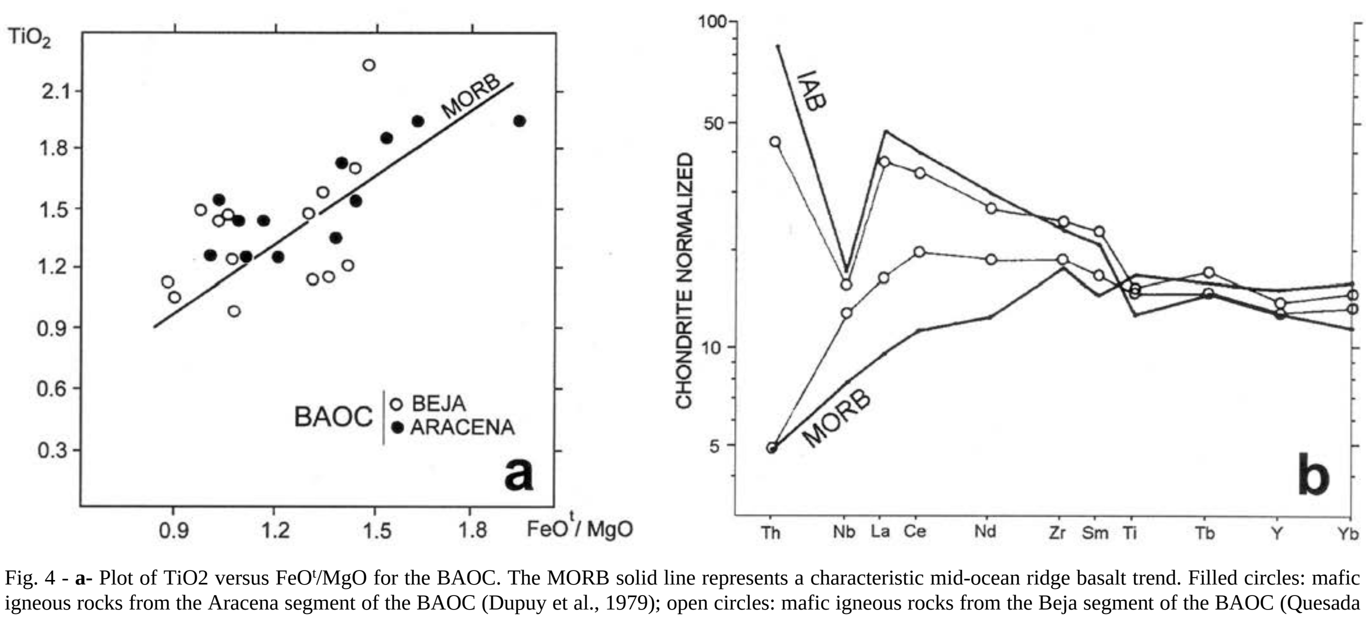

Fig. 4 - **a-** Plot of TiO2 versus FeO^t/MgO for the BAOC. The MORB solid line represents a characteristic mid-ocean ridge basalt trend. Filled circles: mafic igneous rocks from the Aracena segment of the BAOC (Dupuy et al., 1979); open circles: mafic igneous rocks from the Beja segment of the BAOC (Quesada et al., 1994). **b-** Comparison of chondrite-normalized incompatible element abundance patterns for BAOC mafic igneous rocks, mid-ocean ridge basalts (MORB) and island arc basalts (IAB), (after Quesada et al., 1994).

Table 1 - Representative whole rock analyses of Beja-Acebuches (BAOC) and Internal Ossa-Morena Zone Ophiolites (IOM-ZOS)

	--- BAOC[1]---		IOMZOS							
Rock type[2]	**B**	**A**	**G**	**G**	**G**	**B**	**B**	**B**	**B**	**B**
SiO2 wt%	49.08	51.02	46.74	46.44	47.92	46.64	46.90	48.46	46.87	46.42
TiO2	1.46	1.49	1.35	1.47	1.44	1.06	2.15	1.92	2.44	1.65
Al2O3	14.98	17.23	18.06	16.18	14.60	17.05	14.55	14.81	14.50	20.95
Fe2O3^t	10.53	8.65	11.41	12.55	11.46	10.02	12.85	12.36	13.44	11.69
MnO	0.17	0.14	0.18	0.20	0.21	0.17	0.22	0.20	0.19	0.16
MgO	9.03	8.04	6.96	8.02	8.26	8.18	6.83	6.09	6.32	4.70
CaO	12.01	9.51	11.50	11.62	12.21	12.38	13.57	11.26	11.29	7.04
Na2O	3.44	3.84	2.34	2.17	2.37	2.79	1.19	3.18	2.95	3.44
K2O	0.19	0.82	0.07	0.21	0.23	0.25	0.17	0.36	0.76	1.44
P2O5	0.08	0.05	0.13	0.12	0.13	0.09	0.21	0.27	0.30	0.30
L.O.I.	1.30	0.70	0.88	1.06	0.87	1.22	0.92	0.70	1.05	3.03
Cr ppm	300	200	335	339	858	380	145	76	29	330
Ni	-	-	153	174	128	125	68	47	27	126
Ba	32	265	25	39	118	90	247	97	206	528
Nb	5	6	3.7	3.8	3.9	2.1	8.1	16	17	21
Hf	2.6	3.7	1.8	1.9	2.1	1.7	3.7	3.7	4.5	4.2
Zr	108	137	65	69	73	55	137	149	177	182
Y	28	30	21	24	26	21	39	24	37	24
Th	0.2	1.8	0.27	0.28	0.32	0.15	0.56	1.12	1.33	2.0
U	0.2	1.0	0.09	0.09	0.10	0.06	0.23	0.32	0.54	0.6
La	5.1	11.7	3.67	3.55	4.21	2.26	7.88	12.8	16.3	22.9
Ce	16	28	10.0	9.97	11.5	6.90	20.4	30.1	38.0	47
Nd	11	16	8.31	8.65	9.60	7.14	16.9	18.7	25.0	26
Sm	3.19	4.37	2.67	2.77	3.17	2.54	5.17	4.58	6.28	6.00
Eu	1.28	1.34	1.03	1.14	1.17	0.98	1.83	1.36	2.48	2.20
Gd	-	-	3.76	4.06	4.52	3.28	6.28	4.62	6.84	-
Tb	0.70	0.80	0.68	0.74	0.84	0.67	1.24	0.85	1.29	1.00
Dy	4.6	4.8	4.10	4.62	5.09	4.09	7.43	4.90	7.67	-
Ho	-	-	0.87	0.96	1.05	0.86	1.55	0.98	1.51	-
Er	-	-	2.66	2.96	3.27	2.58	4.61	2.95	4.44	-
Yb	2.75	3.06	2.46	2.74	2.94	2.33	4.17	2.59	3.60	2.62
Lu	0.42	0.48	0.36	0.41	0.44	0.47	0.62	0.38	0.52	0.43

Analyses by ICP-MS (except BAOC : XRF+INAA) at Activation Laboratories Ltd. (Canada)
(1) - see Quesada et al. (1994); (2) - B: metabasalt; A: amphibolite; G: metagabbro

Proterozoic/Lower Paleozoic OMZ sequences along with the BAOC emplacement (OMZ D1 deformation event). Deformation and greenschist/amphibolite facies metamorphic recrystallization made these ophiolitic sequences incomplete, but quite often they still preserve a typically sequence including (from base to top): ultramafic cumulates (metadunites and metapyroxenites), mafic cumulates (flaser-gabbros which, towards the top, display pegmatoidal structures and show abundant dike intrusions) and metabasalts with chert intercalations; in some occurrences, metabasalts are overlain by pelitic schists interpreted as pelagic metasediments.

Recent geochemical data (Pedro et al., 1998) support the field observations: all the studied samples have tholeiitic affinities. Mafic rocks of the internal OMZ ophiolites have incompatible element ratios (Ti/Zr = 108 ± 17, Zr/Nb = 18 ± 7, La/Nb = 1.0 ± 0.1) and relatively flat REE patterns (La/Sm_{CN} = 0.83 ± 0.16, La/Yb_{CN} = 1.00 ± 0.26; Fig. 5; Table 1), which define an anorogenic geochemical signature identical to the N/T-MORB type (Sun et al., 1979).

In contrast to the BAOC, an orogenic geochemical signature was not detected in any of these ophiolitic occurrences. This feature suggests either a) that these ophiolites correspond to a more mature evolutionary stage within the BAOC back-arc basin, or b) that they represent altogether different type of oceanic crust (Araújo et al., 1993; Fonseca, 1995). Indeed, the contrasting characteristics of the Ossa-Morena ophiolite types are reminiscent of those already described from other ophiolite belts (Betts Cove vs. Bay of Islands ophiolites - Newfoundland by Coish et al., 1982; Gullfjellet and Lykling vs. Solund and Stavfjorden og Skalvaer ophiolites - Norwegian Bergen Ophiolites by Furnes et al.,1982) and suggest that originally they represented distinct oceanic basins.

HIGH PRESSURE METAMORPHISM

Variscan high-pressure metamorphism in the OMZ was first reported by Fonseca et al. (1993). High-pressure metamorphic assemblages were recognized in mafic metavolcanites which represent tectonic slices and/or dikes into early Cambrian marbles and late Proterozoic (pelitic and siliceous) metasedimentary sequences. Glaucophane/omphacite-eclogite and blueschist facies metamorphism gave rise to the development of variable amounts of garnet, omphacite, glaucophane and paragonite in mafic rocks (Fig. 6a). The high-pressure metamorphism was polyphase (Fonseca et al., 1993; Moita, 1997) as indicated by the development of blueschist facies assemblages overgrowing on previously retrogressed eclogites (Fig. 6b).

Textural relations and garnet compositional zoning (Table 2) indicate that early (pre- to syn-D_1) prograde metamorphism evolved from glaucophane-rich to omphacite-rich eclogite facies assemblages. Still during D_1 deformation, garnet+omphacite were successively replaced by barroisite and symplectitic Na-actinolite + Na-plagioclase + clinozoisite + paragonite (Table 2), but these decompressional assemblages are seen to be overprinted (locally) by glaucophanitic amphibole (Fig. 6) and Na,Fe^{3+}-rich clinopyroxene porphyroblasts (Table 2), before (syn- to late-D_2) general retrogradation to the greenschist facies (actinolite + chlorite + epidote + albite).

Detailed analyses of the associated felsic, pelitic and carbonate metamorphic assemblages are precluded by almost complete retrogradation. However, the preservation of aragonite (identified by XRD) in marbles, garnet+Na-amphibole in dacitic metavolcanites and kyanite inclusions within garnet in metapelites (Moita, 1997), coupled with estimated equilibria of ~8 kbar/~580ºC from relict garnet + plagioclase + biotite + phengite assemblages in felsic gneisses (Pedro, 1996), indicate that high-pressure metamorphism also affected these lithologies.

Mineral chemistry and thermobarometric data allowed the characterization of a generalized clockwise P-T-t path for high-pressure metamorphism (Fig.7). The main metamorphic path involved initial heating and compression from 450-500ºC/10-12 kbar to ~650ºC/14-16 kbar (eclogite facies) followed by cooling and decompression through 600-500ºC/11-6 kbar (barroisitic stage) to about 400-500ºC/4-5 kbar (greenschist/epidote-amphibolite facies symplectites). Late sequential recrystallization of zoned (glaucophane → barroisite; see Fig. 6b) Na-amphibole and jadeite-poor clinopyroxene implies development along a secondary clockwise P-T-t path (Fig. 7), suggesting renewal of burial before exhumation.

Geochemical data discussed by Pedro (1996) and Moita (1997) (see Table 3) indicate that the mafic eclogite protoliths were derived from tholeiite basaltic magmas. The analysed samples have REE patterns ranging from dominantly LREE-depleted to slightly LREE-enriched, similar to those of most mid-ocean ridge basalts; however, in contrast to MORB suites, the OMZ mafic eclogites have relatively low Ni contents (mostly < 50 ppm) and display variable

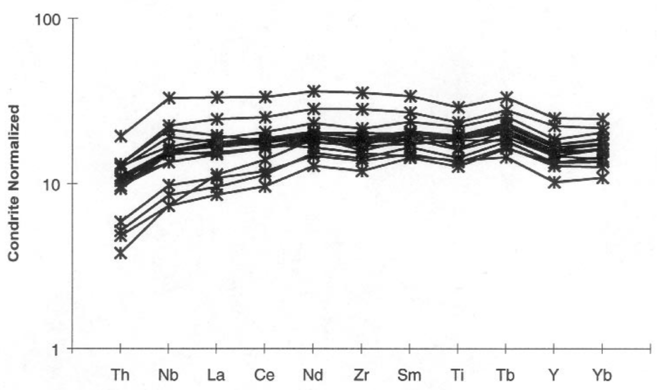

Fig. 5 - Representative chondrite-normalized incompatible element abundance patterns for the Internal Ossa-Morena Zone Ophiolitic Allochthonous Klippen - IOMZOS mafic igneous rocks (Pedro et al., 1998; see Table 1). Normalizing values after Sun and Hanson (1976), Sun and Nesbitt (1977) and Sun et al., (1979).

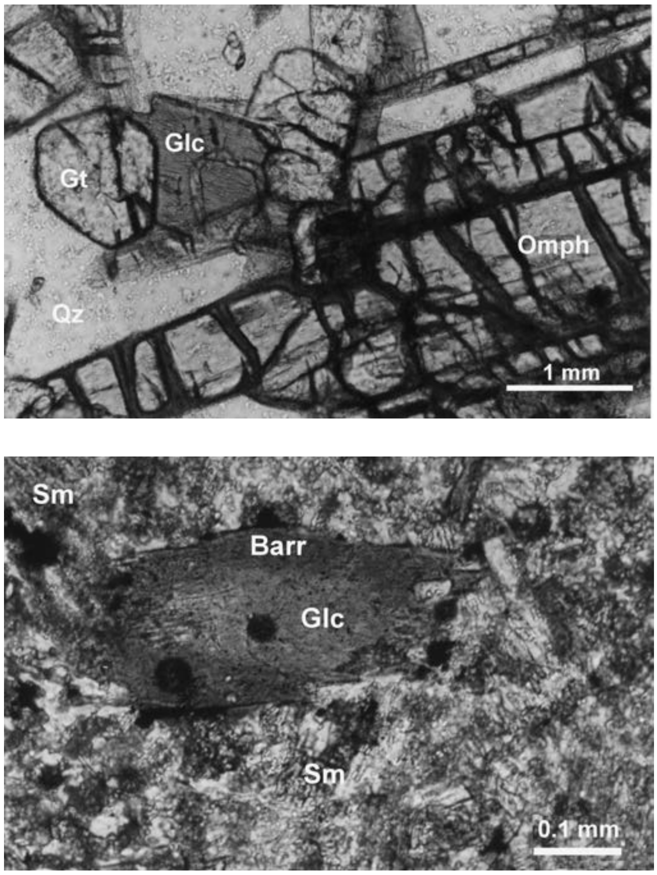

Fig. 6 - Photomicrographs of typical textures of OMZ eclogites. **a-** Omphacite eclogite (Glc-glaucophane; Gt-garnet; Omph-omphacite; Qz-quartz). **b**-Zoned Na-amphibole porphyroblast overgrowing on retrogressed eclogite (Glc-glaucophane core; Barr-barroisite rim; Sm-symplectitic matrix).

Table 2 - Representative clinopyroxene, garnet and amphibole analyses for Ossa-Morena eclogites

	Glaucophane-Eclogite			**---------------------- Omphacite-Eclogites ----------------------**							
sample	**-------- va27.3qi --------**			**------------------ va7c ------------------**					**va7d**	**-----va28-----**	
	Jd	**Gt**	**Gl**	**Jd**	**Gt**		**Gl →**	**Bar →**	**Act →**	**Gl →**	**Cpx**
					core	*rim*	*1^{ary}*	*overg*	*simpl*	*late*	*late*
SiO2	54.84	37.36	57.32	55.63	37.54	38.27	57.07	48.45	54.24	54.95	52.97
TiO2	0.07	0.17	0.00	0.03	-	-	0.02	0.17	0.02	0.05	0.04
Al2O3	9.85	20.66	10.48	10.47	21.55	21.62	12.36	12.92	5.23	9.36	2.20
Cr2O3	0.00	0.07	0.01	0.02	0.08	0.02	0.00	0.03	0.01	0.00	0.00
Fe2O3	3.59	-	3.18	0.58	-	-	2.03	2.66	1.60	5.37	9.48
FeO	3.97	27.72	9.28	4.53	28.09	27.83	7.30	9.59	5.76	12.37	6.33
MnO	0.00	0.49	0.05	0.02	0.41	0.03	0.02	0.05	0.00	0.06	0.21
MgO	6.98	0.72	9.56	8.30	1.11	3.90	11.16	11.37	17.47	7.42	8.01
CaO	12.51	12.05	0.84	13.57	10.98	9.03	1.72	7.73	10.59	1.06	16.48
Na2O	7.16	-	7.01	6.43	-	-	6.70	3.95	1.40	6.93	4.61
K2O	0.00	-	0.02	0.00	-	-	0.02	0.12	0.13	0.03	0.02
Total	98.97	99.24	97.75	99.85	99.76	100.70	98.40	97.04	96.45	97.60	100.35
Σ O	6	12	23	6	12	12	23	23	23	23	6
Si	1.990	3.005	7.917	1.988	2.992	2.991	7.748	6.954	7.643	7.806	1.985
Al^{IV}	0.010	-	0.083	0.012	0.008	0.009	0.252	1.046	0.357	0.194	0.015
Al^{VI}	0.412	1.959	1.622	0.440	2.017	1.982	1.725	1.140	0.512	1.373	0.082
Ti	0.002	0.011	0.000	0.001	-	-	0.002	0.018	0.002	0.005	0.001
Cr	0.000	0.005	0.001	0.001	0.005	0.001	0.000	0.003	0.001	0.000	0.000
Fe^{3+}	0.098	-	0.330	0.016	-	-	0.207	0.287	0.170	0.574	0.267
Fe^{2+}	0.120	1.865	1.072	0.135	1.873	1.819	0.829	1.151	0.678	1.469	0.198
Mg	0.378	0.086	1.968	0.442	0.132	0.455	2.259	2.433	3.670	1.571	0.447
Mn	0.000	0.033	0.006	0.001	0.027	0.002	0.002	0.006	0.000	0.007	0.007
Ca	0.488	1.039	0.121	0.520	0.938	0.756	0.250	1.189	1.599	0.161	0.662
Na	0.504	-	1.878	0.445	-	-	1.764	1.100	0.383	1.909	0.335
K	0.000	-	0.004	0.000	-	-	0.003	0.022	0.023	0.005	0.001
Σ cat	4.000	8.002	15.002	4.000	7.992	8.015	15.041	15.349	15.038	15.074	4.000
T °C		**$490^{(1)}$**				**$460^{(1)}$**	**$635^{(1)}$**				
P kbar		**$11^{(2)}$**				**$10^{(2)}$**	**$15^{(2)}$**				**$4 – 7^{(3)}$**

[1] Ellis and Green (1979) garnet/clinopyroxene (Fet /Mg) geothermometer calibration; (2) Newton (1986) eclogite minimum pressure; (3) albite-clinopyroxenejd10-quartz equilibria at 400 – 600 ºC (Holland and Powell, 1998)

La/Nb (0.7-3.1) ratios, that are similar to geochemical features of continental tholeiites (Dupuy and Dostal, 1984). Closed-system fractional crystallization of MORB magmas could account for the low Ni contents, but it is unable to explain the wide variation observed in the La/Nb ratios; a contribution of the lower Paleozoic continental crust as a wall-rock contaminant to the ascending MORB-type magmas could account for the observed features, resulting in an increase of LREE with respect to high field strength elements during assimilation coupled with fractional crystallization (Thompson et al., 1982). Significantly, garnet-rich/eclogitic metadacites (Table 3) are closely associated with the OMZ mafic eclogites; they might represent contemporaneous anatectic melts from the continental basement or, alternatively, an extreme case of assimilation coupled with fractional crystallization.

Field observations support the geochemical inferences on the nature of the OMZ eclogites. Their occurrence as lens-shaped bodies displaying boudinage in pelitic-siliceous and marble units do indeed suggest that the mafic eclogite protholiths were mainly vein-like bodies intruded into the OMZ's Lower Paleozoic/late Proterozoic epicontinental autochthonous sequences. Accordingly, it is suggested that the most probable tectonic setting would reflect magmatic activity and stretching related to Lower Paleozoic oceanization of the OMZ´s southern passive continental margin.

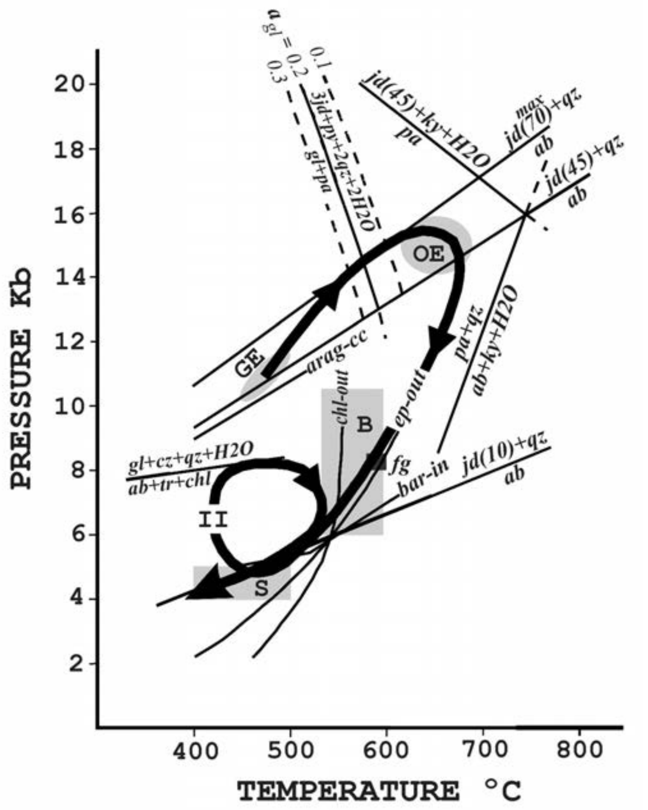

Fig. 7 - P - T - t path summarizing the metamorphic evolution of Ossa-Morena Zone eclogites. Stages: **GE**- glaucophane-eclogitic; **OE**- omphacite-eclogitic; **B**- barroisite-amphibolitic; **S**- Symplectitic greenschist/albite-amphibolite; **II**- late glaucophanitic overprint. Shaded areas indicate typical P-T metamorphic conditions evaluated for OMZ high-P allochthonous units from mineral chemistry (Pedro, 1996; Moita, 1997; see Table 2) and appropriate geothermobarometer calibrations (**GE**, **OE**- Ellis and Green, 1979, Newton, 1986; **B**- Brown, 1977, Graham and Powell, 1984, Kohn and Spear, 1990; **S**- Brown, 1977, Maruyama et al., 1983; ***fg***- felsic gneiss - Perchuk and Lavrenteva, 1983, Hodges and Crowley, 1985). ***bar-in***: barroisite stability field (Ernst, 1979); ***ab+tr+chl=gl+cz+H2O*** (Maruyama et al., 1986) and ***chl-/ep-out*** (Apted and Liou, 1983; Maruyama et al., 1983) represent greenschist-blueschist and greenschist-amphibolite facies transitional reactions; ***arag- cc*** equilibrium from Johannes and Puhan (1971). Other reaction curves have been calculated using the computer program THERMOCALC v2.7 (Powell and Holland, 1988; Holland and Powell, 1998).

CONCLUSIONS AND GEODYNAMIC EVOLUTION

It is now possible to propose a geodynamic model to explain the evolution of the boundary between the OMZ and the SPZ, which has been considered an important suture zone within the Iberian Variscan Belt (e.g., Bard et al., 1973).

We will first discuss the general polarity of subduction during the high-pressure metamorphic events and ocean closure. From the tectonic and petrological point of view - thrusting in the SW branch of the Iberian Fold Belt to the south and contemporaneous orogenic calc-alkaline magmatism to the NE side of the suture, we favour a period of subduction towards the N or NE (Bard et al., 1973; Santos et al., 1987; Santos et al., 1990). Early eclogite facies metamorphism resulted from northward subduction of the southern continental margin of the OMZ, involving a process of tectonic truncation (subduction erosion) during closure of the Beja-Acebuches back-arc basin (Fig. 8). Eclogite exhumation and subsequent nappe emplacement on top of the OMZ parautochthonous should have taken place shortly afterwards; the resulting tectonic stacking caused renewed burial and late blueschist recrystallization on both the already retrogressed eclogites and OMZ parautochthonous (see Fig. 9). IOMOZS ophiolitic nappes were not affected by blueschist facies metamorphism suggesting that their emplacement would correspond to a relatively late stage in this process. During the final pulses of this event, there was development of tectonic “mélanges” (“Xistos de Moura” and “El Cubito” Formations; Araújo et al., 1998) that cut and bound the OMZ sequences, including both ophiolitic IOMOZS and high-pressure nappe units; these “mélanges” reflect northwards tectonic imbrication post-dating the

Table 3 - Representative whole rock analyses of Ossa-Morena Zone Eclogites

Sample	va7-9[1]	sf15[2]	va31d[1]	sf12b[2]	sf13[2]	va27a[1]
SiO2 wt%	49.44	50.08	50.46	51.73	53.87	65.33
TiO2	1.70	2.30	2.17	2.66	1.86	0.91
Al2O3	13.89	14.21	13.67	14.21	15.53	14.11
Fe2O3[t]	10.37	14.23	13.01	14.23	10.72	6.17
MnO	0.13	0.31	0.21	0.31	0.13	0.06
MgO	6.88	5.72	5.49	5.72	6.29	1.41
CaO	13.46	7.49	9.26	7.49	6.24	2.50
Na2O	2.76	3.10	4.23	3.10	4.75	7.38
K2O	0.09	0.25	0.28	0.25	0.47	0.27
P2O5	0.14	0.29	0.24	0.29	0.13	0.23
L.O.I.	0.84	0.93	0.89	0.25	1.91	0.58
Cr ppm	46	47	39	47	258	1
Ni	45	33	17	33	24	4
Ba	118	241	53	75	269	84
Nb	3.1	4.4	2.9	5.4	2.8	3.9
Hf	2.3	4.3	3.3	4.6	3.5	5.0
Zr	106	158	150	169	126	198
Y	40	43	39	46	57	46
Th	-	0.85	0.6	0.93	0.53	4.0
La	2.3	9.66	8.00	8.92	8.85	15.3
Ce	9.0	24.2	20	21.7	17.9	30.0
Nd	8.0	18.6	15	21.5	13.9	16.0
Sm	2.97	5.63	4.04	6.10	4.64	4.48
Eu	1.22	1.96	1.39	2.10	1.39	1.06
Gd	-	6.46	-	8.14	5.94	-
Tb	0.90	1.41	1.00	1.36	1.38	1.00
Dy	-	7.14	-	8.45	8.40	-
Ho	-	1.77	-	1.79	2.00	-
Er	-	5.36	-	5.27	6.14	-
Yb	3.75	4.80	3.46	4.54	5.59	4.26
Lu	0.58	0.71	0.51	0.67	0.81	0.65
La/Nb	0.7	2.2	2.8	1.7	3.2	3.9

Analyses by (1) XRF+INAA and (2) ICP-MS at Activation Laboratories Ltd. (Canada)

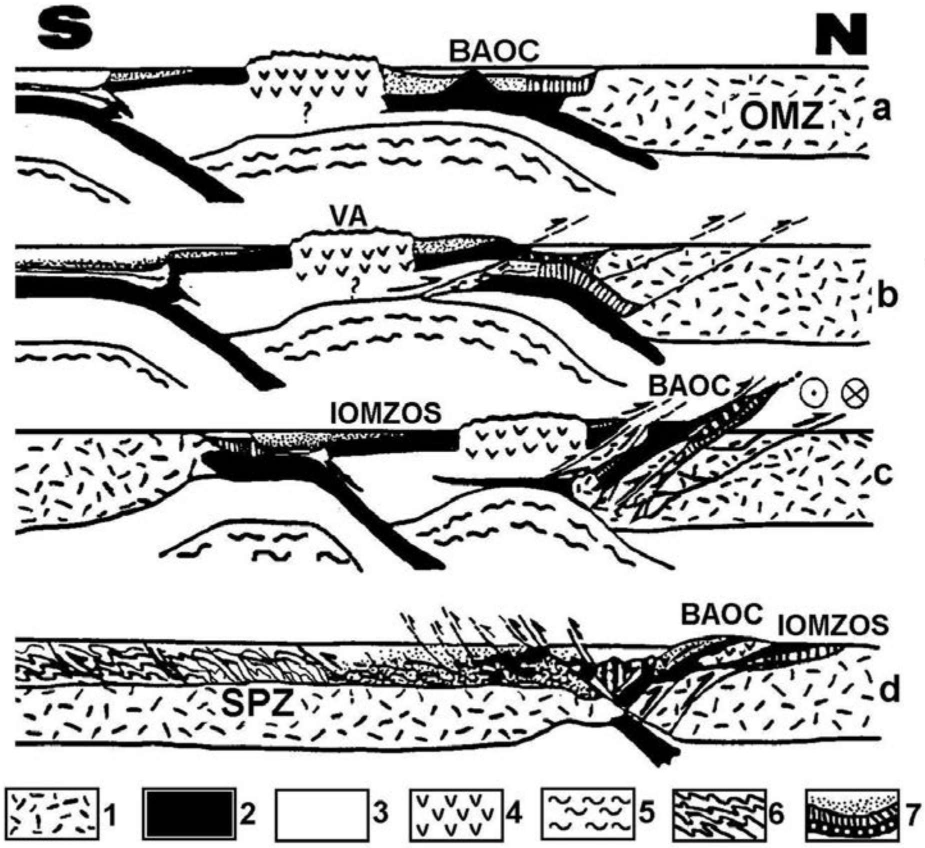

Fig. 8 - Obduction of the BAOC and IOMZOS (ophiolite) units onto the OMZ continental margin from a rear-arc basin (adapted from Dewey, 1976) 1 - continental crust, 2- oceanic crust, 3- mantle, 4- volcanic arc-derived rocks, 5- low-velocity zone, 6- generation of an accretionary prism during polyphase deformation and very-low grade metamorphism in the South Portuguese Zone, 7- OMZ passive continental margin.

nappe emplacement process.

Recent models for ophiolite obduction in the Variscides (e.g., Matte, 1998) seem to require subduction of the oceanic units to considerable depths before their crustal emplacement; however, there is no evidence for high-pressure metamorphism affecting any of the southern Iberian ophiolites. Low-pressure/high-temperature metamorphism on the BAOC is related to hot emplacement (Quesada et al., 1994) whereas low/medium-grade recrystallization of IOMOZS units reflect high level deformation and early Carboniferous thermal doming (Dallmeyer et al., 1993) in the OMZ.

Dewey's (1976) classical ophiolite obduction model has been successfully applied to the Taitao ophiolite in Chile (e.g., Ramos and Kay, 1992; Nelson et al., 1993; Lagabrielle et al., 1994; Forsythe and Nelson, 1995) which shares several common features with the BAOC. This model would also explain several well-established geological observations in southern Iberia, such as (Fig. 8): a) northwards ophiolite obduction partially coeval with continental OMZ orogenic magmatism implying subduction in the same direction (Fonseca and Ribeiro, 1993); b) the BAOC geochemistry (Quesada et al., 1994) indicating ophiolite emplacement from a rear arc basin onto a continental margin; c) the presence of contemporaneous supra-subduction arc-derived rocks thrust above the BAOC (Quesada et al., 1994); d) the geophysical profiles across the OMZ/SPZ boundary (Matias et al., submitted) which show two high velocity channels reflecting a flake geometry; e) contrasting geochemistry between the Beja-Acebuches and the internal OMZ ophiolites, suggesting derivation from different ocean basins.

Therefore, we propose the following model (see Fig. 8): In pre-Eifelian times, an ocean opened between Iberia and Gondwana (Ribeiro et al., 1990). Northwards subduction of this large ocean resulted in opening of a small back-arc basin and associated intraoceanic arc to the south. Continued subduction (already involving continental margin rocks) produced eclogites and coeval obduction of the ophiolites and the arc-group rocks to the N (early Devonian). This was followed by complete subduction of the ocean situated to the S (in the late Devonian), producing the W-vergent structures of the OMZ and, afterwards, collision of the northern continental OMZ with the southern continental SPZ in the Carboniferous.

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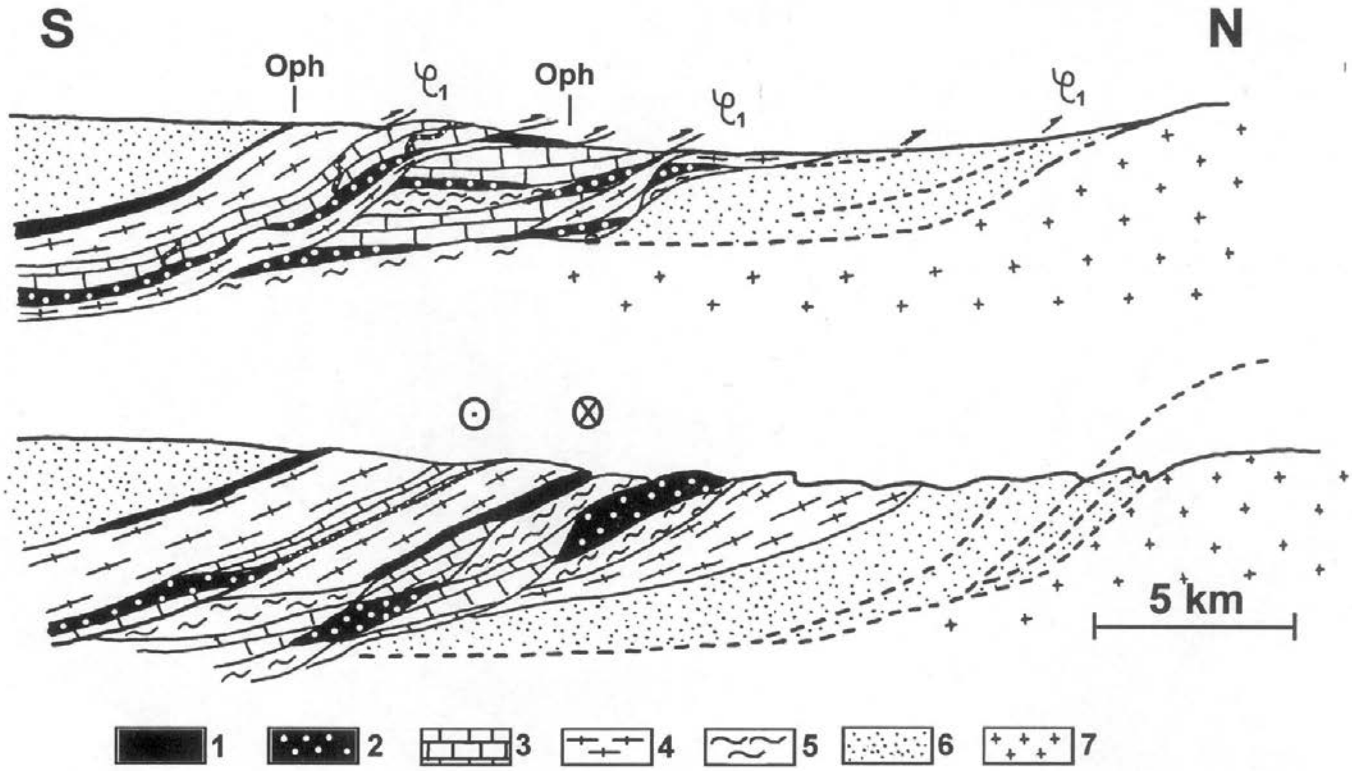

Fig. 9 - Structural section of the OMZ. Interpretation of the sequences: 1- ophiolitic nappes (IOMZOS); 2- mafic eclogites; 3- aragonite-bearing marbles (lower Cambrian); 4- felsic gneisses; 5- late Proterozoic basement; 6- undifferentiated imbricated units (tectonic "mélanges"); 7- undifferentiated Ossa-Morena Zone (para)autochthonous sequences.

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