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The Ordovician, Silurian and Devonian sedimentary rocks of the Ossa-Morena Zone (SW Iberian Peninsula, Spain)

Las rocas sedimentarias del Ordovícico, Silúrico y Devónico de la Zona de Ossa Morena (SO Península Ibérica, España)

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Abstract

The present paper reviews the Ordovician, Silurian and Devonian sedimentary rocks of the Ossa-Morena Zone of the SW Hesperian (Iberian) Massif in Spain and Portugal. It gives detailed informations on the successions and faunas from the Early Ordovician to the Late Devonian, i.e. during the passive margin development that followed a Cambrian rifting phase and preceded the Variscan orogenic events.

Comparison of the sedimentary and faunal record from the Ossa Morena and Central Iberian zones during the Palaeozoic indicates that both regions were part of the North Gondwanan shelf, characterized by distal (OMZ) and proximal (CIZ) shelf conditions, respectively. This shows that the Badajoz-Córdoba Shear Zone corresponds only to a Variscan shear zone and cannot be considered as the cryptic suture of a Palaeozoic ocean.

Keywords: Palaeozoic, Ossa-Morena Zone, Hesperian Massif, Variscan Belt, Stratigraphy, Palaeogeography.

Resumen

Se revisa el registro sedimentario del Ordovícico, Silúrico y Devónico de la Zona de Ossa Morena del Macizo Hespérico (o Ibérico), referido esencialmente a la parte española, pero complementado con algunos datos portugueses. Se analizan en detalle las principales sucesiones y fósiles coetáneos al desarrollo del margen pasivo que sucede a la etapa de rifting cámbrica, y que a su vez precede al ciclo orogénico varisco.

La correlación del registro sedimentario y paleontológico paleozoico, entre las zonas de Ossa Morena y Centroibérica, revela que ambas formaron parte de la periferia del norte de Gondwana, pero tipificando ambientes distintos: plataforma marina proximal (en el caso de la Zona Centroibérica) frente a palataforma distal (Zona de Ossa Morena). Consiguientemente, la banda de cizalla Badajoz-Córdoba debe de interpretarse como una falla transcurrente varisca, y no como la sutura críptica de algún océano paleozoico.

Palabras Clave: Paleozoico, Macizo Hespérico, Zona de Ossa Morena, Cadena Varisca, Estratigrafía, Paleogeografía.

1. Introduction

The subdivision of the Hesperian (= Iberian) Massif into six "zones" differing in their stratigraphical, structural and/or metamorphic characteristics was proposed originally by Lotze (1945). It was later modified slightly by Julivert *et al*. (1972, 1974) who combined Lotze's Galician-Castilian and Luso-Alcudian zones into a single Central Iberian Zone. The resultant fivefold subdivision has been accepted almost unanimously, but some controversies still persist for the precise location of some zone boundaries, especially the northern boundary of the Ossa-Morena Zone. The "classical" boundary, traced along the Los Pedroches Batholith in the E, and the Portalegre-Ferreira do Zêzere Thrust in the W, has been questionned by several authors (see Robardet, 1976; Robardet and Gutiérrez-Marco,

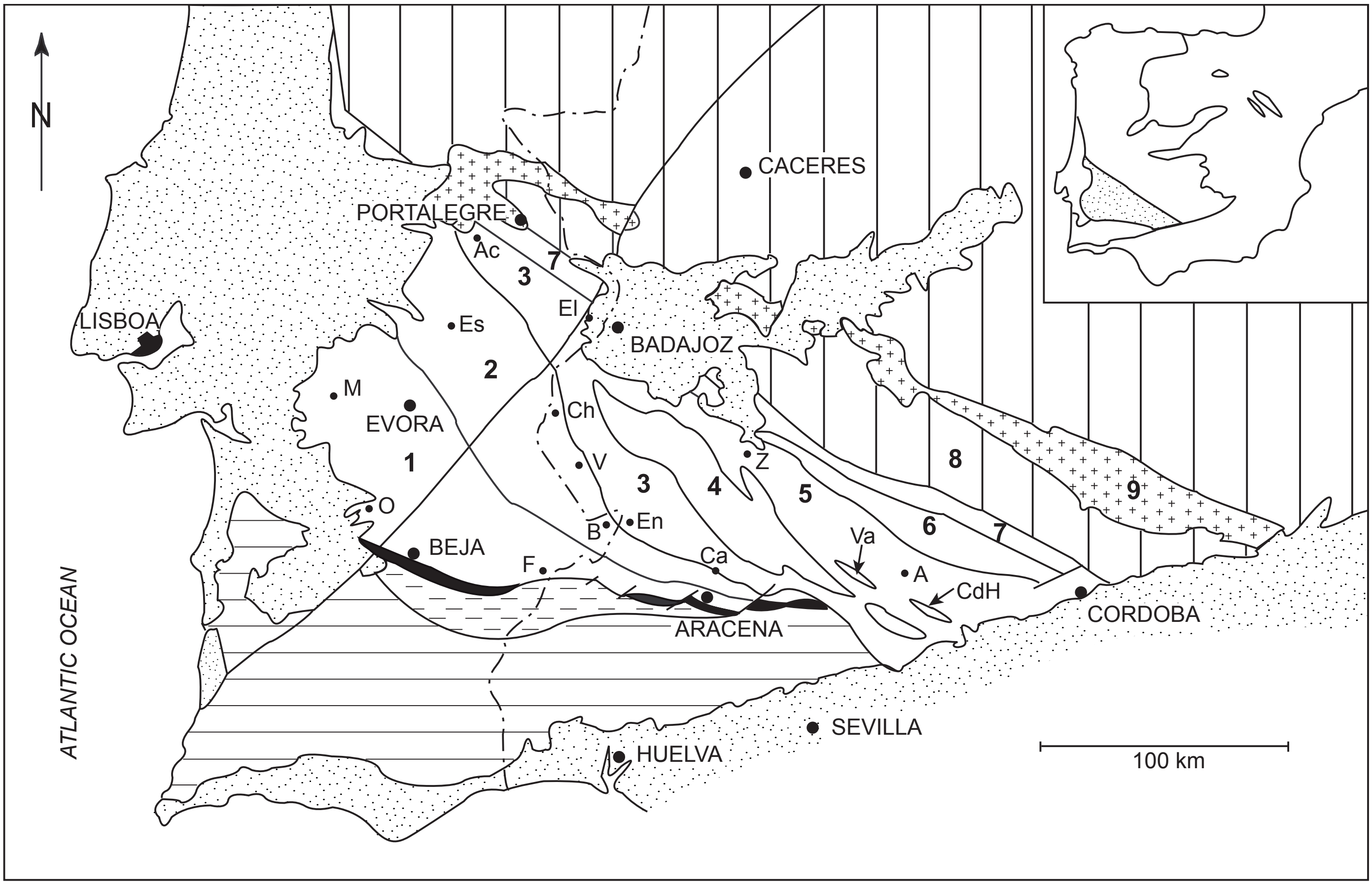

Fig. 1.- Sketch map of the southern part of the Iberian Peninsula showing the Ossa-Morena Zone, the southern Central Iberian Zone (vertical ruling with 8, Obejo-Valsequillo-Puebla de la Reina Unit; 9, Los Pedroches batholith), the South Portuguese Zone (horizontal ruling), the Beja-Acebuches ophiolites (in black), the Pulo-do-Lobo oceanic Unit (dashes) and the post-Palaeozoic deposits (dotted).- Abbreviations for the main units of the Ossa-Morena Zone (after Apalategui *et al*., 1990): 1, Beja-Aracena Massif; 2, Montemor-Ficalho Unit; 3, Alter do Chão-Elvas Unit; 4, Olivenza-Monesterio Antiform; 5, Zafra-Córdoba-Alanís Unit (Va: Valle syncline; CdH: Cerrón del Hornillo syncline); 6, Sierra Albarrana Unit; 7, Badajoz- Córdoba Shear Zone. -Localities mentioned in the text: A, Alanís; AC, Alter-do-Chão; B, Barrancos; Ca, Cañaveral-de-León; Ch, Cheles; El, Elvas; En, Encinasola; Es, Estremoz; F, Ficalho; M, Montemor-o-Novo; O, Odivelas; V, Villanueva del Fresno; Z, Zafra.

Fig. 1.- Esquema geológico del sector meridional de la Península Ibérica, donde se indican la parte meridional de la Zona Centroibérica (rayado vertical: 8, Unidad de Obejo-Valsequillo-Puebla de la Reina; 9, Batolito de Los Pedroches), la Zona de Ossa Morena (sectores 1 a 7), la Zona Surportuguesa (rayado horizontal), la ofiolita de Beja-Acebuches (en negro), la unidad oceánica "Pulo do Lobo" (rayado horizontal discontinuo) y los materiales post-paleozoicos (punteado).- Las abreviaturas de las principales unidades diferenciadas en la Zona de Ossa Morena, de acuerdo con Apalategui *et al*. (1990) son las siguientes: 1, Macizo Beja-Aracena; 2, Unidad Montemor-Ficalho; 3, Unidad Alter do Chão-Elvas; 4, Antiforme Olivenza-Monesterio; 5, Unidad Zafra-Córdoba-Alanís (Va: sinclinal del Valle; CdH: sinclinal del Cerrón del Hornillo); 6, Unidad Sierra Albarrana; 7, Zona de Cizalla Badajoz-Córdoba.- Localidades representadas: A, Alanís; AC, Alter-do-Chão; B, Barrancos; Ca, Cañaveral-de-León; Ch, Cheles; El, Elvas; En, Encinasola; Es, Estremoz; F, Ficalho; M, Montemor-o-Novo; O, Odivelas; V, Villanueva del Fresno; Z, Zafra.

1990a, 1990b; Pereira and Silva, 1997 and references therein). In the present paper, the Badajoz-Córdoba Shear Zone is considered to represent the northern boundary of the Ossa-Morena Zone and the regions extending between this shear zone and the Los Pedroches Batholith (i.e. the Portalegre-Montoro "subzone" of Hammann *et al*., 1982, equivalent to the Obejo-Valsequillo-Puebla de la Reina "domain" of Apalategui and Pérez-Lorente, 1983) are regarded as the southernmost areas of the Central Iberian Zone.

The pre-Carboniferous Palaeozoic sedimentary rocks of the Ossa-Morena Zone comprise mainly Cambrian rocks that constitute extensive outcrops. However, sedimentary rocks of Ordovician, Silurian and Devonian age have been preserved in several of the structural units (frequently referred to as "domains" or "sectors" in the regional literature) that compose the Ossa-Morena Zone (Fig.1). They have been identified and studied especially:

- in the Valle and Cerrón del Hornillo synclines of the southeastern part of the Zafra-Alanís-Córdoba Unit,
- south of the so-called Olivenza-Monesterio Antiform, near Cañaveral de León, in a complex area where the Alter do Chão-Elvas-Cumbres Mayores and the Barrancos-Hinojales units are tectonically juxtaposed along the

Juromenha thrust fault.

- in the Estremoz-Barrancos-Hinojales Unit, where the structural complexity often makes precise stratigraphic studies difficult. The most precise knowledge of the stratigraphic succession in this unit has been established in the Barrancos area in Portugal.

Summarized overviews on the Ordovician, Silurian and Lower Devonian of the Ossa-Morena Zone can be found in recent syntheses (Robardet and Gutiérrez-Marco, 1990a, 2002; Gutiérrez-Marco *et al*., 1998, 2002) and more precise informations on several localities are also available in the excursion guide-book of the 1998 Field Meeting of the International Subcommission on Silurian Stratigraphy in the Ossa-Morena Zone (Robardet *et al*., 1998).

The present paper, which includes the most recent data, should be an up to date and comprehensive review of the Ordovician, Silurian and Devonian sedimentary rocks of the whole Ossa-Morena Zone.

2. Ordovician

The new Global Ordovician Scale being still unachieved (see Webby, 1998; IUGS, 2000; Gradstein and Ogg, 2002), and based on graptolite and conodont species that do not occur in the Iberian Peninsula (and furthermore in the whole North Gondwana Province), the chronostratigraphy used here is the regional scheme for North Gondwana (Fig. 2; see discussion and references in Gutiérrez-Marco *et al*. 2002).

2.1 Valle and Cerrón del Hornillo synclines

In the northern part of the Seville Province, within the southeastern part of the Zafra-Alanís-Córdoba Unit, the Valle and the Cerrón del Hornillo synclines (Fig. 1) occur within extensive outcrops of Cambrian rocks. Up to the 1970s the post-Cambrian formations remained poorly known (Carbajal and Acuña, 1944) and the geological maps figured undifferenciated "Ordovician-Silurian" or "Silurian" rocks, without any other precision, although Simon (1951) had already described the Ordovician succession and part of the Silurian of the Valle syncline. In spite of their small size, these two synclines comprise fossiliferous rocks of Ordovician, Silurian, Devonian and Early Carboniferous age and have yielded a lot of information on the post-Cambrian Palaeozoic succession (Robardet, 1976; Robardet *et al*., 1998 and references therein).

The Ordovician succession of the Valle syncline (Fig. 3) is the best documented of the whole Ossa-Morena Zone with ?uppermost Tremadocian, Arenigian, Oretanian, Dobrotivian, Berounian, Kralodvorian and Kosovian formations dated by macro- and microfossils (Simon, 1951; Robardet, 1976; Hafenrichter, 1979, 1980; Gutiérrez-Marco *et al*., 1984; Sarmiento, 1993). The coeval succession from the Cerrón del Hornillo syncline is not so well known, but the upper units ("Pelmatozoan Limestone" and Valle Formation) are the same in both synclines (García-Ramos and Robardet, 1992; Robardet *et al*., 1998).

In the Valle syncline, the lowermost Ordovician lithological unit consists of green shales and siltstones (more than 200 metres) that have yielded rare and poorly preserved brachiopods and trilobite remains and abundant and well preserved specimens of the basal Arenigian graptolite *Tetragraptus phyllograptoides*. These levels are thus younger than the Barriga Shales of the Venta del Ciervo locality (see below). However, the fossiliferous levels are underlain by an important thickness of shales, and it cannot be excluded that, in the future, the Tremadocian-Arenigian transition could be identified also in the Valle syncline. However it will not be possible to study the Cambrian-Ordovician transition because the contact between the two systems is everywhere tectonized.

The green shales are overlain by 10-15 m of nodule-bearing dark shales with trilobites (*Ormathops*? sp., *Selenopeltis* aff. *buchi*, *Kodymaspis puer*, *Nerudaspis* cf. *aliena*), brachiopods (*Euorthisina minor*), echinoderms (*Laginocystis pyramidalis*), bivalves, hyolithids and ostracods. This Oretanian fauna closely compares with that of the Sárka Formation from the Barrandian of Bohemia and also with that of the Ancenis Unit of the southern Armorican Massif of France.

The dark shales with nodules are followed by a few metres of micaceous sandstones and ferruginous oolithic levels.

Then come 60-80 metres of light grey to whitish micaceous sandstones with brachiopods and trilobites (*Placoparia (Coplacoparia)* sp.), probably of Dobrotivian age.

The overlying decalcified sandy limestones (a few metres) have yielded various fossil fragments (trilobites, brachiopods, bryozoans, etc) and a chitinozoan assemblage (*Desmochitina juglandiformis, Calpichitina lenticularis, Conochitina homoclaviformis, Belonechitina robusta*) indicative of the *Belonechitina robusta* Biozone (Paris, 1981, 1990) of upper middle Berounian age.

The following "Pelmatozoan Limestone" and Valle formations show the same characteristics in the Valle and Cerrón del Hornillo synclines.

The "Pelmatozoan Limestone" (15-20 m) contains conodonts (*Amorphognathus ordovicicus, Hamarodus europaeus, Sagittodontina robusta, Scabbardella altipes*, etc) indicative of the *Amorphognathus ordovicicus* Biozone that corresponds to the Kralodvorian and Kosovian

GLOBAL SERIES	GLOBAL STAGES	NORTH GONDWANA REGIONAL STAGES & SUBSTAGES		BRITISH REGIONAL SERIES & STAGES	
UPPER ORDOVICIAN	"STAGE 6" (Ashgillian emend?)	KOSOVIAN		ASHGILL	Hirnantian
		KRALODVORIAN			Rawtheyan
					Cautleyan
	?	BEROUNIAN	Upper (Bohdalecian)		Pusgillian
	? "STAGE 5" (Caradocian emend.?)			CARADOC	Streffordian
			Middle (Lodenician)		Cheneyan
					Burrellian
			Lower (Chrustenician)		Aurelucian
MIDDLE ORDOVICIAN	DARRIWILIAN	DOBROTIVIAN	Upper / Lower	LLANVIRN	Llandeilian
		ORETANIAN	Upper / Lower		? Abereiddian
		"ARENIGIAN"	Upper	ARENIG	Fennian
	"STAGE 3" (Volkhovian emend.?)		Middle		Whitlandian
LOWER ORDOVICIAN	"STAGE 2" (unnamed)		Lower		Moridunian
	TREMADOCIAN	TREMADOCIAN	Upper	TREMADOC	Migneintian
			Lower		Cressagian

Fig. 2.- Ordovician chronostratigraphy, with Global Series and Stages, and North Gondwana and Avalonian regional schemes (respectively after Webby, 1998 / IUGS, 2000; Gutiérrez-Marco *et al*., 2002; Fortey *et al*., 1995).

Fig. 2.- Cronoestratigrafía del Ordovícico, con referencia a las Series y Pisos internacionales (Webby, 1998; IUGS, 2000), y su correlación con los esquemas regionales para el norte de Gondwana (Gutiérrez-Marco *et al*., 2002) y Avalonia (Fortey *et al*., 1995).

(Robardet, 1976; Hafenrichter, 1979, 1980; Sarmiento, 1993). In the Cerrón del Hornillo syncline, this unit has also yielded trilobites (*Symphysops* sp., *Cyclopyge* sp., *Cekovia perplexa perplexa*; Robardet, 1976; Hammann, 1992, p. 22), the microdomatid gastropod *Eopagodea sevillana* (Fryda *et al*., 2001) and fragments of brachiopods, crinoids, bryozoans and ostracods. Considering the Ordovician-Silurian transition (see below), the "Pelmatozoan Limestone" is most probably Kralodvorian. In the Valle syncline, its uppermost part shows a karstified morphology most probably due to weathering and erosion resulting from the sea-level fall that followed the growth of the Kosovian African ice-cap.

The Valle Formation consists of a thick sequence (up to 200 m?) of dark shales and siltstones with rare sandy intercalations; it comprises also some contorted beds and clast-bearing microconglomeratic levels reminiscent of the uppermost Ordovician glaciomarine deposits that occur in other areas of the Iberian Peninsula and of the North-Gondwanan regions (Robardet and Doré, 1988; Paris *et al*., 1995). Although the fossil record is very poor and limited to crinoid fragments (probably reworked), rare bivalves and a single specimen of the trilobite *Mucronaspis*, the Valle formation is considered Kosovian in age, this interpretation being also supported by the earliest Silurian age (basal Rhuddanian) of the overlying graptolitic blackshales (Jaeger and Robardet, 1979).

2.2 Venta del Ciervo

Ordovician rocks are also known ca. 20 km north of Aracena, in the Venta del Ciervo farm area (Fig. 3) which was studied first by Schneider (1939, 1951) and revised more recently (Racheboeuf and Robardet, 1986; Mette, 1987, 1989; Robardet *et al*., 1998).

The lowermost unit of the Ordovician, the Barriga Formation, consists of 45 metres of finely laminated green shales that overlie unconformably the Middle Cambrian sandstones of the Umbría-Pipeta Formation. The erosional unconformity is underlined by an irregular basal conglomeratic level. The Barriga Fm. has yielded ichnofossils (*Chondrites*, *Phycodes*?, *Thalassinoides*), phyllocarid remains, a rich "*Cymatiogalea messaoudensis-Stelliferidium trifidum*" acritarch assemblage (Mette, 1989; Servais and Mette, 2000), a unique specimen of a pelagic trilobite and, above all, graptolites first cited by Schneider (1939, 1951) and later investigated in more detail by Gutiérrez-Marco (1982a, 1986), Erdtmann *et al*. (1987), Gutiérrez-Marco and Aceñolaza (1987) and Aceñolaza *et al*. (1996). Two successive graptolite assemblages have been identified in the road section between Cañaveral de León and Corteconcepción: the lower one (9-16.40 m above the base of the green shales), with *Paradelograptus onubensis* and other species, ends with a mass-accumulation of giant rhabdosomes of *Araneograptus murrayi*; the upper one (25-34 m above the base) contains *Hunnegraptus* aff. *copiosus*, *Tetragraptus* cf. *krapperupensis* and *Clonograptus (Clonograptus)* cf. *multiplex*. Both assemblages correspond to the latest Tremadocian (pre-*Tetragraptus phyllograptoides* or pre-*T. approximatus* biozones), equivalent to the Early Hunneberg stage of Scandinavia and to Lancefieldian 2 of Australia.

Although the transition is not exposed along the road, the section along the Ribera de Montemayor shows clearly that the Barriga Fm. is overlain by the dark shales and siltstones of the Barrancos Formation which includes an oolitic ironstone level (1 m thick). These dark shales have yielded acritarch assemblages that comprise about 40 species. Some of these species are known from the Arenigian of Thuringia (*Schizodiacrodium ramiferum, Vogtlandia imperfecta, Striatotheca frequens*) and from

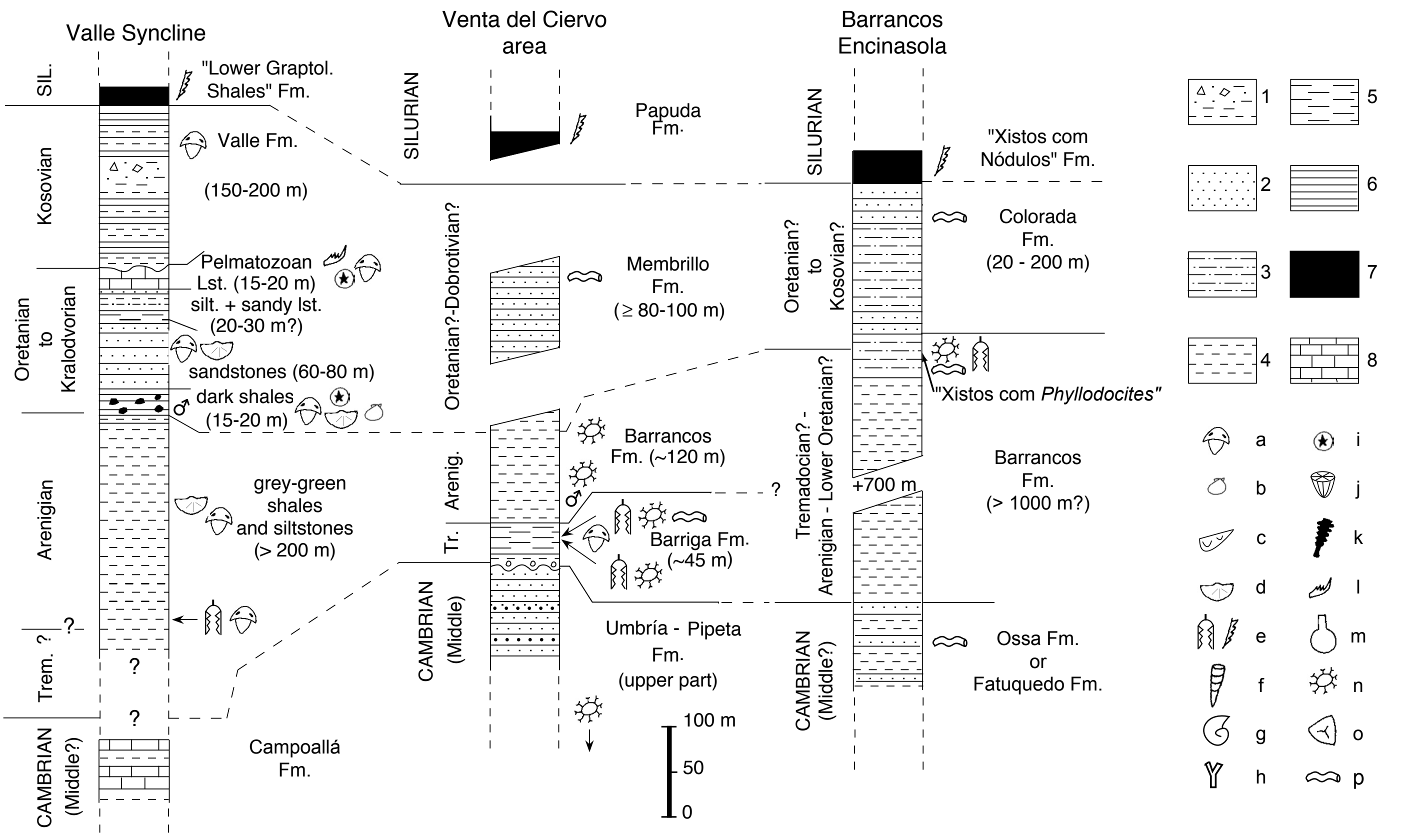

Fig. 3.- Ordovician successions from the Valle syncline, the Venta del Ciervo and Barrancos-Encinasola areas (after Gutiérrez-Marco *et al*., 1984, 1998, 2002; Piçarra, 2000). Key symbols (for figures 3, 5, 6 and 7).- Lithofacies: 1, glaciomarine diamictites; 2, sandstones and quartzites; 3, sandy siltstones; 4, siltstones; 5, shales; 6, black shales; 7, black cherts ("lydites"); 8, limestones.- Fossils: a, trilobites; b, bivalves; c, ostracods; d, brachiopods; e, graptolites; f, orthocone nautiloids; g, goniatites; h, bryozoans; i, echinoderms; j, corals; k, tentaculitids; l, conodonts; m, chitinozoans; n, acritarchs; o, spores; p, ichnofossils.

Fig. 3.- Sucesiones ordovícicas del Sinclinal del Valle y áreas de Venta del Ciervo y Barrancos-Encinasola (según Gutiérrez-Marco *et al*., 1984, 1998, 2002; Piçarra, 2000).- Símbolos utilizados (figuras 3, 5, 6 y 7) - Litofacies: 1, diamictitas glaciomarinas; 2, areniscas y cuarcitas; 3, limolitas arenosas; 4, limolitas; 5, pizarras; 6, pizarras negras ("ampelitas"); 7, silexitas negras ("liditas"); 8, calizas.- Fósiles: a, trilobites; b, bivalvos; c, ostrácodos; d, braquiópodos; e, graptolitos; f, nautiloideos ortoconos; g, goniatites; h, briozoos; i, equinodermos; j, corales; k, tentaculítidos; l, conodontos; m, quitinozoos; n, acritarcos; o, esporas; p, icnofósiles.

the lower Oretanian of Morocco (*Striatotheca triangulata, Micrhystridium* aff. *acuminosum*). It is thus assumed that the fossiliferous levels are late Arenigian-early Oretanian in age (Mette, 1987, 1989, with full list of species).

The brownish sandstones of the Membrillo Formation, that have yielded only ichnofossils, are considered to be younger than the Barrancos Fm. and of Oretanian-early Dobrotivian age (Mette, 1989).

Younger Ordovician rocks have not been identified in the Venta del Ciervo area and the Ordovician-Silurian transition remains unknown.

2.3 Barrancos-Encinasola

Within the Barrancos-Hinojales Unit, the Encinasola area (in Spain) and the Barrancos area (in Portugal) contain Ordovician rocks corresponding to the Barrancos and Colorada formations. These formations are better known in Portugal where Delgado (1908, 1910) first studied the succession (Fig. 3) and mentioned Early Ordovician graptolites and ichnofossils.

North and NNE of Barrancos (in the Alter do Chão-Elvas Unit), the lowermost part of the Barrancos Fm. is conglomeratic and discordantly overlies the Fatuquedo Formation; SW of Barrancos (in the Estremoz-Barrancos Unit), the transition between the Barrancos Fm. and the underlying Ossa Formation is gradual. Although they have yielded no fossils, the Fatuquedo and Ossa formations are considered equivalent to the Umbría-Pipeta Fm. the Middle Cambrian age of which is based on acritarchs (see above).

The Barrancos Formation mainly consists of dark, green and reddish micaceous shales and siltstones (up to ?1000 m thick). The upper part, sometimes considered to be a distinct formation (e.g. Piçarra, 2000), also comprises psammites ("Xistos com *Phyllodocites*" of Delgado 1908) with abundant ichnofossils (*Nereites jacksoni, Phyl-*

	SERIES	STAGES	GRAPTOLITE BIOZONES
SILURIAN	PRIDOLI		*M. bouceki - I. transgrediens*
			N. branikensis - N. lochkovensis
			N. parultimus - N. ultimus
	LUDLOW	LUDFORDIAN	*F. formosus*
			B. bohemicus tenuis - Nc. kozlowskii
			S. leintwardinensis
		GORSTIAN	*Lo. scanicus*
			Nd. nilssoni
	WENLOCK	HOMERIAN	*Co. ludensis*
			Co. praedeubeli - Co. deubeli
			P. parvus - G. nassa
			C. lundgreni
		SHEINWOODIAN	*C. rigidus - C. perneri*
			M. riccartonensis - M. belophorus
			C. centrifugus - C. murchisoni
	LLANDOVERY	TELYCHIAN	*C. lapworthi - C. insectus*
			O. spiralis interval zone
			Mo. griestoniensis - Mo. crenulata
			Sp. turriculatus - Str. crispus
			Sp. guerichi
		AERONIAN	*St. sedgwicki*
			L. convolutus
			M. argenteus
			D. triangulatus - D. pectinatus
		RHUDDANIAN	*Cr. cyphus*
			Cy. vesiculosus
			Pa. acuminatus

Fig. 4.- Silurian Series, Stages, and standard graptolite biozones (after Koren *et al*., 1996). Abbreviated graptolite genera: *B, Bohemograptus; C, Cyrtograptus; Co, Colonograptus; Cr, Coronograptus; Cy, Cystograptus; D, Demirastrites; F, Formosograptus; G, Gothograptus; I, Istrograptus; L, Lituigraptus; Lo, Lobograptus; M, Monograptus; Mo, Monoclimacis; N, Neocolonograptus; Nc, Neocucullograptus; Nd, Neodiversograptus; O, Oktavites; P, Pristiograptus; Pa, Parakidograptus; S, Saetograptus; Sp, Spirograptus; St, Stimulograptus; Str, Streptograptus.*

Fig. 4.- Series, Pisos y biozocronozonas del Sistema Silúrico (según Koren *et al*., 1996).- Abreviaturas empleadas para los géneros de graptolitos*: B, Bohemograptus; C, Cyrtograptus; Co, Colonograptus; Cr, Coronograptus; Cy, Cystograptus; D, Demirastrites; F, Formosograptus; G, Gothograptus; I, Istrograptus; L, Lituigraptus; Lo, Lobograptus; M, Monograptus; Mo, Monoclimacis; N, Neocolonograptus; Nc, Neocucullograptus; Nd, Neodiversograptus; O, Oktavites; P, Pristiograptus; Pa, Parakidograptus; S, Saetograptus; Sp, Spirograptus; St, Stimulograptus; Str, Streptograptus.*

lodocites saportai, Dictyodora tenuis, Palaeophycus cf. *striatus, Gordia marina*, etc.). These levels have yielded graptolites (Delgado, 1908, 1910; Perdigão, 1967) and acritarchs. The occurrence of *Expansograptus sparsus* and *E. hirundo,* in the famous quarry "pedreira do Mestre André" of the Barrancos anticline, indicates the upper Arenigian *Expansograptus hirundo* Biozone, equivalent to the Fennian stage of the British Isles (Gutiérrez-Marco, 1982b; Piçarra, 2000 with previous references therein). The acritarchs found in the upper part of the "Xistos com *Phyllodocites*" of the western limb of the Terena syncline (*Aureotesta clathrata, Frankea sartbernardensis, Coryphidium bohemicum, C. minutum, Goniosphaeridium dentatum*, etc.), confirm this stratigraphical attribution (Cunha and Vanguestaine, 1988).

The overlying Colorada Formation ("Grauvaques da Serra Colorada" of Delgado 1908) mainly comprises psammites and quartzites (20-200 m). The only fossils found up to now in this formation are ichnofossils (*Skolithos, Palaeophycus, Planolites*) without precise biostratigraphical value. The Colorada Fm. has been considered frequently to correspond both to the Middle and Upper Ordovician (Oliveira *et al*., 1991). Graptolites of the basal Silurian *Parakidograptus acuminatus* Biozone have been found, in two distinct localities, within quartzite-black chert alternations corresponding apparently to the gradual transition into the overlying "Xistos com Nódulos" Formation, and the uppermost levels of the Colorada Fm. could be earliest Silurian in age (Piçarra *et al*., 1995, 1997; Piçarra, 2000).

However, the glaciomarine lithofacies that are so typical of the uppermost Ordovician in the whole north gondwanan Province have never been observed in the Barrancos area and the age of the Colorada Fm. remains a problem. Several authors have expressed serious doubts as to the idea that the Colorada Fm. could represent the whole Middle and Upper Ordovician. Quesada and Cueto (1994) are rather inclined to consider that in the Encinasola area, it is Middle Ordovician in age and that the Upper Ordovician is missing. Conversely, Giese *et al*. (1994a, fig. 9) consider that the Colorada Fm. corresponds only to the "Ashgill" and that the underlying Barrancos Fm. extends from the Arenigian up to the upper part of the "Caradoc". Piçarra (2000, vol. 1 p. 34-35 and vol. 2 p. 14-15) considers unlikely that the Colorada Fm. might correspond to the whole Oretanian-earliest Llandovery time interval and suggests , as a third alternative, that it would include an important stratigraphical hiatus separating a lower part of Arenigian-early Oretanian (?) age from an upper part of Kosovian-early Rhuddanian age. The age of the Colorada Fm. thus remains an open question.

NNW of Encinasola, in the Villanueva del Fresno, Rabito and Cheles areas (geological maps 1/50000 no. 852, 851 and 826, respectively), micaceous sandstones, laminated grey-green shales and siltstones that underlie the quartzitic levels of the Ordovician-Silurian transition and the graptolitic black shales of the Silurian are thus most probably Ordovician and equivalent to the Barrancos

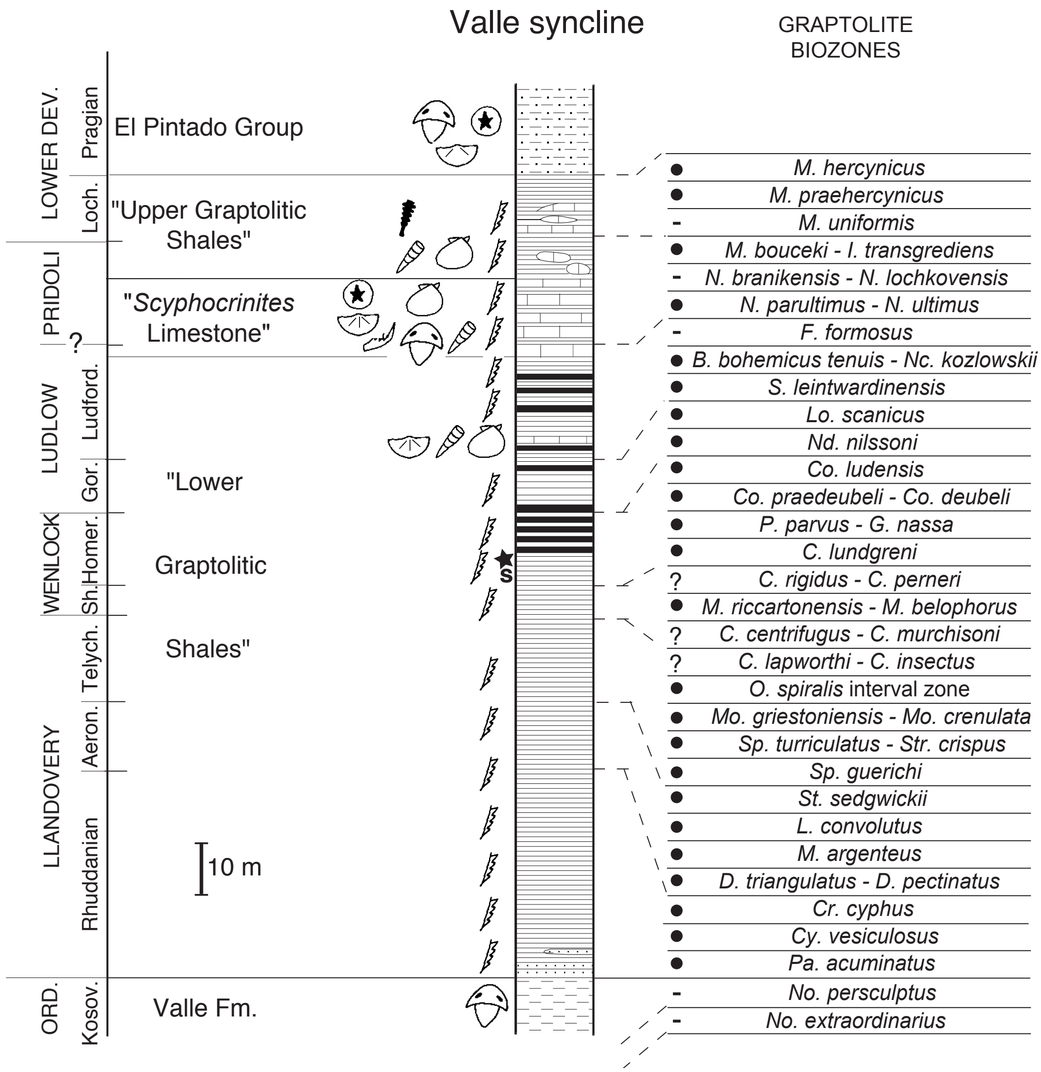

Fig. 5.- The Silurian succession in the Valle syncline (after Jaeger and Robardet, 1979; Robardet *et al*., 1998, 2000).- For key symbols see figure 3; star, "yellow band" coincident with the Lundgreni Extinction Event; s, sponges.- Graptolite Biozones: identified, black dot; probable, ?; still not evidenced, -.

Fig. 5.- Sucesión silúrica del Sinclinal del Valle (según Jaeger y Robardet, 1979; Robardet *et al*., 1998, 2000).- Para abreviaturas generales ver figura 3; la estrella corresponde a la "capa amarilla" que marca el Evento Lundgreni de Extinción; s, fósiles de esponjas.- Con puntos negros se indican las biozonas de graptolitos plenamente identificadas; con interrogación las de presencia probable; y con guión aquellas biozonas que restan aún por caracterizar.

and/or Colorada formations, but they have up to now not yielded any fossil (see Piçarra *et al*., 1997 and references therein).

3. Silurian

The graptolite biozones used in the following text are those of the generalized standard Silurian graptolite zonal sequence (Fig. 4) ratified by the International Subcommission on Silurian Stratigraphy (see Koren *et al*., 1996).

3.1 Valle and Cerrón del Hornillo synclines

The best documented Silurian successions in the Ossa-Morena Zone are without any doubt those of the Valle and Cerrón del Hornillo synclines in the northern part of the Seville province.

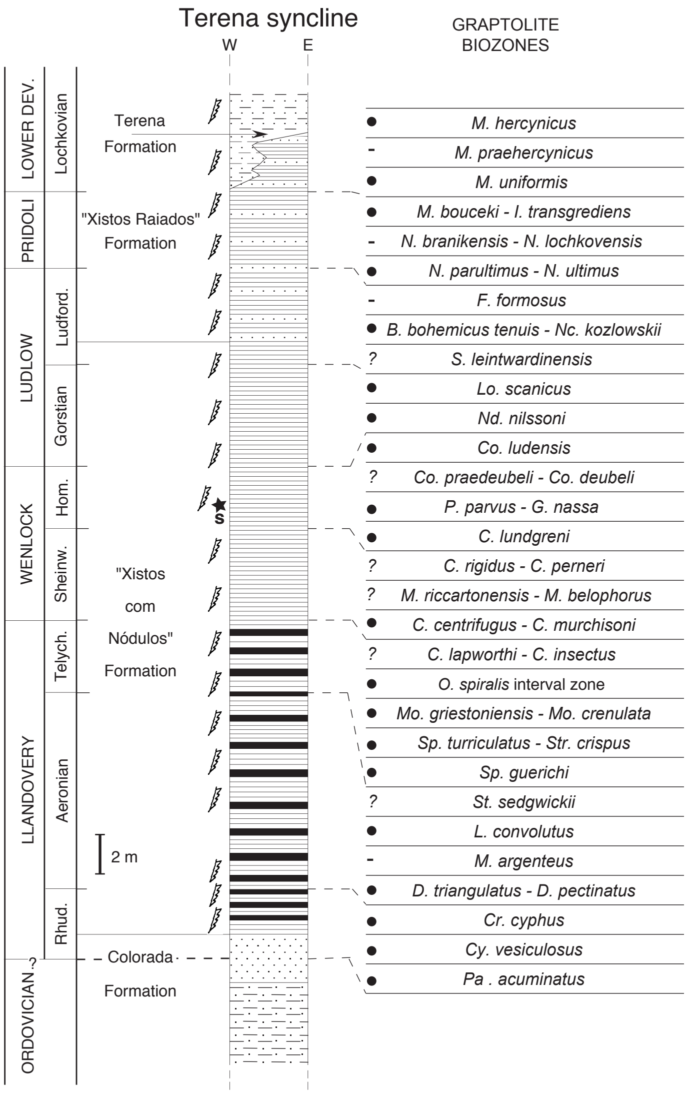

Fig. 6.- The Silurian succession in the Barrancos area (after Piçarra, 2000). For key symbols see figures 3 and 5.

Fig. 6.- Sucesión silúrica del área portuguesa de Barrancos (según Piçarra, 2000). Para símbolos y abreviaturas ver figuras 3 y 5.

The Silurian succession is almost the same in both synclines, but the best exposed and most complete sections are in the Valle syncline, especially on the northern bank of the El Pintado reservoir lake (see Jaeger and Robardet, 1979). The earliest Silurian to earliest Devonian sequence, about 150 m thick, mainly consists of argillaceous black shales with some levels of hard siliceous slates and black cherts (Fig. 5). It comprises also a few sandy levels in the lowermost part (Rhuddanian) and a thin level (0.5 to 0.8 m) of dark-grey limestone in the upper part (Ludlow). However, the most important lithological change occurs in the Pridoli with the so-called "*Scyphocrinites* Limestone" that consists of 10-15 m of alternating dark limestones and calcareous shales, and divides the black shale sequence into the "Lower Graptolitic Shales" (ca 120 m) and the "Upper Graptolitic Shales" (20 m).

The most common fossils are the graptolites that occur abundantly all along the black shale sequence and have allowed identification of most of the Silurian and Lochkovian graptolite biozones (Jaeger and Robardet, 1979; Oczlon, 1989; Gutiérrez-Marco *et al*., 1996; Lenz *et al*., 1997; Piçarra *et al*., 1998a). Orthoconic nautiloids (*Michelinoceras michelini*, *Arionoceras* cf. *arion*) and bivalves (*Cardiola docens*) occur in the Ludlow limestone bed (Bogolepova *et al*., 1998). The "*Scyphocrinites* Limestone" has yielded (Robardet *et al*., 2000 and references therein) scyphocrinoid remains (columnal plates, crowns and loboliths), bivalves (*Praecardium* cf. *adolescens*, *Joachimia* cf. *impatiens*, *Snoopya insolita, Patrocardia evolvens*, etc.), trilobites (*Cromus* cf. *kromulsi, C.* aff. *leirion, Crotalocephalus* cf. *transiens*, *Bohemoharpes (Unguloharpes)* sp., *Leonaspis* sp.), ostracods (*Bolbozoe* sp.), cephalopods (*Cycloceras bohemicum*), rare and poorly preserved solitary corals, brachiopods and conodonts. The most important fossils are the graptolites (*Neocolonograptus parultimus, N. ultimus, Pristiograptus dubius, Linograptus* sp., *Istrograptus transgrediens*) and the conodonts (*Oulodus elegans, Pseudooneotodus beckmanni, Ozarkodina remscheidensis, O. confluens, O. eosteinhornensis, O. excavata*) which indicate that most of the limestones corresponds to the Pridoli. However, the fossil record is very poor in the lowermost 4 metres and it cannot be excluded that these lowermost levels could be Late Ludlow in age and that the Ludlow-Pridoli boundary could be placed within this part of the formation.

The "Lower Graptolitic Shales" extend from the basal Rhuddanian *Parakidograptus acuminatus* Biozone up into the basal Ludfordian *Saetograptus leintwardinensis* Biozone and probably slightly above with *Pristiograptus dubius thuringicus* and *Linograptus posthumus posthumus* (Jaeger and Robardet, 1979).

The Wenlock sequence of the Valle syncline shows evidence of the Lundgreni Extinction Event of the evolutionary history of graptolites. The black shales of the lower Homerian *Cyrtograptus lundgreni* Biozone and those of the upper Homerian *Pristiograptus parvus*-*Gothograptus nassa* concurrent range Biozone are separated by a few centimetre thick orange-colored soft band (possibly a weathered volcanic ash bed) whose basal part sometimes contains monaxonid desmosponge remains associated with *Pristiograptus dubius* and *Monograptus flemingii* of the uppermost *C. lundgreni* Biozone (Gutiérrez-Marco *et al*., 1996; Rigby *et al*., 1997).

Most of the "*Scyphocrinites* Limestone" is Pridoli in age, its base being either in the uppermost Ludlow or basal Pridoli and its upper limit lying within the *I. transgrediens*

Biozone (Piçarra *et al.*, 1998a).

The "Upper Graptolitic Shales" comprise a lower part of late Pridoli age (*Istrograptus transgrediens* Biozone) and an upper part of Lochkovian age where the tentaculitid *Homoctenowakia bohemica bohemica* and graptolites of the *Monograptus praehercynicus* and *M. hercynicus* Biozones have been identified (Jaeger and Robardet, 1979; Oczlon, 1989; Gessa *et al.*, 1994; Lenz *et al.*, 1997).

The Silurian-earliest Devonian succession of the Valle and Cerrón del Hornillo synclines is a continuous euxinic sequence, where the Lochkovian is represented by graptolitic black shales that prolongate the euxinic deposits of the Silurian. The change of lithofacies only occured close to the Lochkovian-Pragian boundary, with the lower part of the El Pintado Group in the Valle and the Tamajoso Formation in the Cerrón del Hornillo syncline. This succession thus appears precisely equivalent to the "thuringian triad" ("Lower Graptolitic Shales", "Ockerkalk", "Upper Graptolitic Shales") that occurs in Thuringia (Germany), SE Sardinia (Italy) and in some localities of North Africa (see Jaeger, 1976, 1977). Due to their outstanding quality, the Silurian sections from the Valle syncline can be considered equivalent of the classical reference standard sections of Thuringia in Germany and Bohemia in the Czech Republic (Rábano *et al.*, 1999).

3.2 Venta del Ciervo

In the Venta del Ciervo area, neither the Ordovician transition nor the basal Llandovery have been identified. The graptolites collected in the black shales and black cherts of the Papuda Formation are indicative of various biozones of the Llandovery (from the Aeronian *Lituigraptus convolutus* Biozone up to the Telychian *Oktavites spiralis* Biozone) and possibly the lowermost Wenlock. There is no evidence of younger Silurian graptolites, but acritarch assemblages found in alternating black shales, siltstones and sandstones include several species (*Baltisphaeridium* cf. *granuliferum*, *Filisphaeridium* cf. *williereae*) which indicate a Wenlock or Ludlow age (Mette, 1987, 1989). Neither Pridoli nor Lochkovian rocks have been identified in this area and the Silurian-Devonian transition remains unknown.

3.3 Barrancos-Encinasola

In the Barrancos-Encinasola area, there is no continuous exposure of the entire Silurian succession. The best sections occur in Portugal, especially in the eastern limb of the Terena syncline (Piçarra, 2000); the Encinasola area, in the direct prolongation of the Barrancos units, shows the same formations, with abundant graptolite faunas in the Llandovery-lower Ludlow black shales (von Hoegen, 1989 and in Giese *et al.*, 1994a) but the fossil record from post-lower Ludlow rocks is extremely poor.

The Silurian of Barrancos (Fig. 6) corresponds to a condensed sequence (maximum thickness 80 m) that comprises, from base to top, the uppermost quartzitic levels of the Colorada Formation (?), the black cherts (lydites) and black shales of the "Xistos com Nódulos" Formation (= "Ampelitas y Liditas Negras" Fm. of Quesada and Cueto, 1994; "Alumn shale and chert" Fm. of Giese *et al.*, 1994a) and part of the alternating dark shales and siltstones of the "Xistos Raiados" Formation. At Barrancos there is no evidence of the "*Scyphocrinites* Limestone", but limestones have been mentioned in the equivalent Múrtiga Formation of the Encinasola area by Giese *et al*. (1994a). Although orthoconic nautiloids, bivalves, brachiopods, crinoids (Delgado, 1908) and sponges (Rigby *et al.*, 1997) also occur, graptolites are the most common fossils in the Silurian. They allow precise bio- and chronostratigraphical assignments: up to now, 19 graptolite biozones have been identified in the Silurian succession of Barrancos (Piçarra, 2000 and references therein) and several biozones can also be identified in the Encinasola area (Assmann, 1959; von Hoegen, 1989; Giese *et al*., 1994a; Piçarra *et al*., 1997).

As already noted above, a graptolite assemblage of the basal Silurian *Parakidograptus acuminatus* Biozone has been found within black cherts, a few decimetres above the conventional upper limit of the Colorada Fm. (Piçarra *et al.*, 1995). However, the Ordovician-Silurian boundary cannot easily be defined in the Barrancos area where there are no biostratigraphical data definitely indicative of Upper Ordovician rocks (the youngest Ordovician fossiliferous levels being upper Arenigian or lower Oretanian) and where the typical lithologies of the uppermost Ordovician glaciomarine diamictites have never been observed.

The "Xistos com Nódulos" Formation comprises 5 to 8-10 metres of alternating black shales and lydites where black cherts predominate, overlain by 20 to 30 metres of black shales, whitish when strongly weathered, with rare lydite levels. The lower part of the "Xistos com Nódulos" Fm. (where lydites dominate) corresponds to the interval between the Rhuddanian *Parakidograptus acuminatus* and the Telychian *Oktavites spiralis* biozones. The middle and upper parts correspond to the interval between the Telychian *Cyrtograptus centrifugus-Cyrtograptus murchisoni* Biozone and the Ludfordian *Saetograptus leintwardinensis* and *Neocucullograptus kozlowskii* biozones. As in the Valle syncline, this part of the succession includes a 12 cm thick yellow band characterized by a graptolite assemblage of very low diversity (*Pristiograptus parvus* and *Gothograptus nassa*) that marks the Lundgreni Event of graptolite extinction (Gutiérrez-Marco *et al.*, 1996); some

12-14 cm below the yellow band, the uppermost level of the *Cyrtograptus lundgreni* Biozone has yielded the sponges *Protospongia iberica*, *Diagoniella* sp. and *Gabelia* ? sp. (Rigby *et al*., 1997).

The uppermost levels of the «Xistos com Nódulos» Fm. pass up gradually into laminated dark siltstones, alternating with thin (1-2 mm) sandy lenses, that correspond to the "Xistos Raiados" Formation (30-40 m). The lower part of the "Xistos Raiados" Fm. has yielded graptolites diagnostic of the lower and middle Pridoli *Neocolonograptus parultimus-N. ultimus* and *Monograptus bouceki* biozones (Piçarra *et al*., 1998a, 1998b). Near the Mercês farm, in the northern flank of the Terena syncline, the uppermost 12 m are already of early Lochkovian age, as attested by the presence of *Monograptus uniformis* (Piçarra, 1998), which indicates that, in this locality, the Silurian-Devonian boundary lies within the "Xistos Raiados" Fm. It can be noted that the absence of the "*Scyphocrinites* Limestone" in the Barrancos area is not the result of tectonic complications, the levels with Pridoli graptolites of the "Xistos Raiados" Formation being time equivalents of the limestone unit of the Valle and Cerrón del Hornillo synclines.

Silurian rocks are also known in Spain, N and NNW of Barrancos, in the Villanueva del Fresno area (Meseguer Pardo and Prieto Carrasco, 1944; Hernández Sampelayo, 1960; Kalthoff, 1963) where black shales and lydites (40-60 m) have yielded graptolite assemblages of Aeronian and Telychian age (Piçarra *et al*., 1997 and references therein).

SW of Barrancos, in the Montemor-Ficalho area of the Beja-Aracena Unit, Silurian black shales and lydites (Negrita Formation) are probably of Telychian age (Piçarra and Gutiérrez-Marco, 1992).

The Barrancos, "Xistos com Nódulos", and "Xistos Raiados" formations occur also in the Estremoz area, 80-100 km WNW of Barrancos. The fossil record is more limited, but Rhuddanian to Homerian graptolites have been found in the "Xistos com Nódulos" Fm. (Piçarra, 2000). In addition, microconglomeratic levels, with quartz and quartzite clasts dispersed within an argillaceous matrix, that occur locally within psammites attributed to the Upper Ordovician (Piçarra *et al*., 1997), are reminiscent of the Kosovian glaciomarine diamictites, when they have never been observed in the Barrancos area.

In this region, a particular problem is the age of the "Estremoz Marbles" that belong to the so-called "Volcano-Sedimentary Complex" and were traditionally considered either Lower Cambrian or Ordovician (see references in Oliveira *et al*., 1991). Some samples from the upper part of these marbles have yielded crinoid columnals which indicate that these rocks cannot be older than the Middle Ordovician (Piçarra and Le Menn, 1994). More recently, one of these localities has also yielded conodonts: although poorly preserved, these fossils contain specimens of *Oulodus* sp. and *Ozarkodina* sp. that suggest a Silurian or Devonian age (Sarmiento *et al*., 2000; Piçarra, 2000).

4. Lower Devonian

As mentioned above, the lowermost Devonian (Lochkovian) rocks are graptolitic black shales. Younger levels of Early Devonian age, with shelly faunas of trilobites, ostracods, bivalves, crinoids, corals and brachiopods, have been identified in the Cerrón del Hornillo and Valle synclines, and in the Venta del Ciervo and Barrancos areas (Delgado, 1908; Schneider, 1939, 1951; Perdigão, 1973; Perdigão *et al*., 1982; Robardet, 1976; Racheboeuf and Robardet, 1986; Robardet *et al*., 1991; Oliveira *et al*., 1991; Pereira *et al*., 1999; Le Menn *et al*., 2000, 2002).

In the Cerrón del Hornillo syncline, the fossiliferous level, known from a unique locality, belongs to the Tamajoso Formation that overlies Lochkovian graptolitic shales, but in the fossiliferous locality the contact is tectonized. The fossiliferous green to brown siltstones, only a few tens of metres thick, and unconformably overlain by conglomerates of the Early Carboniferous, have yielded trilobites, ostracods, bivalves, corals, and abundant brachiopods (Robardet, 1976; Racheboeuf and Robardet, 1986; Robardet *et al*., 1991).

In the Valle syncline, the Lochkovian graptolitic black shales are conformably overlain by green to brown shales and siltstones of the lower part of the El Pintado Group (Fig. 7) that has yielded brachiopods, trilobites and ostracods (Racheboeuf and Robardet, 1986; Oczlon, 1989; Robardet *et al*., 1991).

In the Venta del Ciervo area, fossiliferous Lower Devonian rocks (Verdugo Formation) were identified first by Schneider (1939, 1951) who mentioned trilobites, brachiopods, ostracods and rugose corals. These rocks were later studied by Racheboeuf and Robardet (1986), Mette (1987) and Robardet *et al*. (1991).

In the Barrancos-Encinasola area (Fig. 8), Lower Devonian shelly fossils were mentioned first by Delgado (1908) in Portugal. More recent studies by Perdigão (1973), Racheboeuf and Robardet (1986), Piçarra *et al.* (1999), Pereira *et al*. (1999) and Le Menn *et al*. (2000, 2003), have focussed also on the Portuguese territory and, up to now, no identifiable fossils have been found in the Encinasola area where the Barrancos units prolongate in Spain (Quesada and Cueto, 1994).

The Early Devonian fossil assemblages found in the Ossa-Morena Zone have more pronounced "Hercynian" ("Bohemian") affinities than those of the Central Iberian Zone which are globally of "Renish" type.

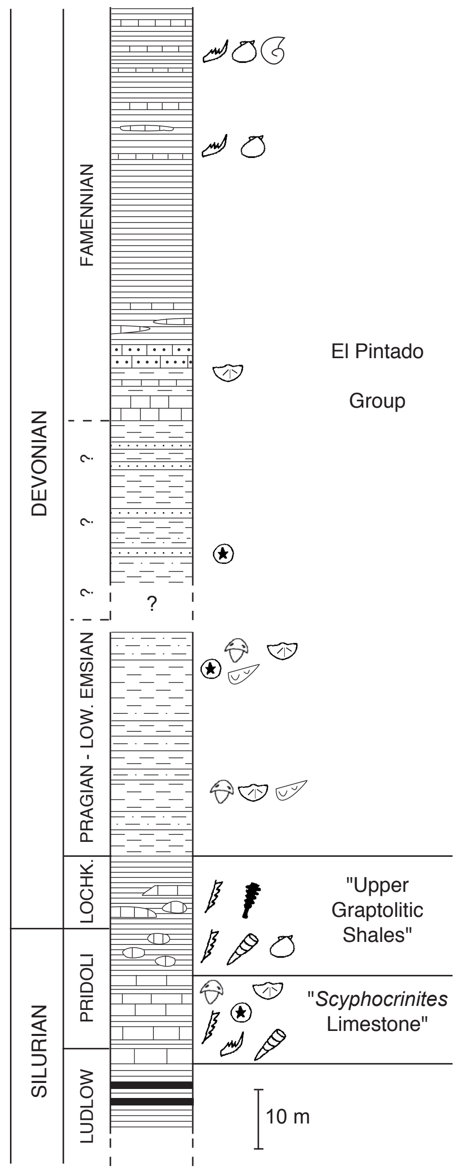

Fig. 7.- The Devonian succession in the Valle syncline (after Racheboeuf and Robardet, 1986; Robardet *et al*., 1988, 1991; Weyant *et al*., 1988). For key symbols, see figure 3.

Fig. 7.- Sucesión Devónica del Sinclinal del Valle (según Racheboeuf y Robardet, 1986; Robardet *et al*., 1988, 1991; Weyant *et al*., 1988).- Para símbolos, ver figura 3.

In the Valle and Cerrón del Hornillo synclines and at the Venta del Ciervo locality, these assemblages include (Racheboeuf and Robardet, 1986; Robardet *et al*., 1991):

- brachiopods, with *Plectodonta (Dalejodiscus) minor minor, Ctenochonetes robardeti* (both especially abundant in the Cerrón del Hornillo syncline), *Plicanoplia (Plicanoplia) carlsi, Hollardiella drotae, Hysterolites hystericus, Lissatrypa villosa*, etc., and *Andalucinetes hastatus* (only known in the Venta del Ciervo locality),

- trilobites, dominated by Phacopidae in the Valle and by Asteropyginae in the Cerrón del Hornillo, with *Phacops (Prokops) benziregensis benziregensis, P. (P.) chlupaci, Metacanthina lips lips, Treveropyge wallacei, Plagiolaria* ? aff. *senex,* etc.

- ostracods, with *Gibba schmidti, Cornikloedenina*? *meridiana*, and the "fingerprint" taxon *Morenozoe racheboeufi* in the Venta del Ciervo locality.

These assemblages were first considered late Pragian-Emsian (Racheboeuf and Robardet, 1986), a conclusion slightly modified after the study of the trilobites and ostracods (Robardet *et al*., 1991) that suggest the whole Pragian and the early Emsian. It can be added that the Verdugo Formation has yielded, at the Venta del Ciervo locality, a single specimen of a monograptid graptolite with hooked thecae that represents the youngest graptoloid known in southwestern Europe, but the poor preservation does not allow a more precise taxonomical identification (Lenz *et al*., 1997).

Moreover, it must be noted that Famennian rocks occur within the uppermost part of the El Pintado Group (Fig. 7), in the core of the Valle syncline. The Middle Devonian seems absent, and the Famennian overlies concordantly the Lower Devonian part of the El Pintado Group. The Famennian rocks reach a minimum thickness of ca. 60 m, with 10-15 m of limestones and calcareous sandstones with brachiopods and conodonts, and ca. 50 m of black shales and black argillaceous limestones with bivalves and conodonts. The whole sequence is Famennian in age and corresponds to the interval between the upper *Palmatolepis crepida* Zone and the uppermost *Palmatolepis marginifera* Zone of the conodont biozonation (Robardet *et al*., 1986, 1988; Weyant *et al*., 1988).

In the Barrancos area (Fig. 8), the grey-green shales with crinoidal limestone lenses of the Russianas Formation have yielded trilobites, brachiopods (*Plectodonta (Dalejodiscus) minor, Euryspirifer pellicoi, Hysterolithes* cf. *hystericus* a.o.), tabulate corals (*Pleurodictyum* sp., *Petridictyum* e.g. *petrii*, *Procteria (Granulidictyum)* sp.), bryozoans and crinoid columnals. The precise age of these levels within the Early Devonian has long been somewhat uncertain (Perdigão, 1973; Perdigão *et al*., 1982; Oliveira *et al*., 1991 and references therein). Precise stratigraphical assignements came recently from palynological investigations, especially on spores, that indicate the Pragian *Verrucosisporites polygonalis-Dictyotriletes emsiensis* zone (Pereira *et al*., 1999) and from crinoid assemblages that contain several species already known in the Lower Devonian of the French Armorican Massif (Piçarra *et al*., 1999; Le Menn *et al*., 2000, 2003). A first assemblage, with *Botryocrinus punctuatus, Asperocrinus radiatus, Trybliocrinus plougastelensis*, etc., can be ascribed to the lower Pragian; the second, with *Botryocrinus montguyonensis, Asperocrinus annulatus, Pteriocrinus* cf. *salviensis*, etc.,

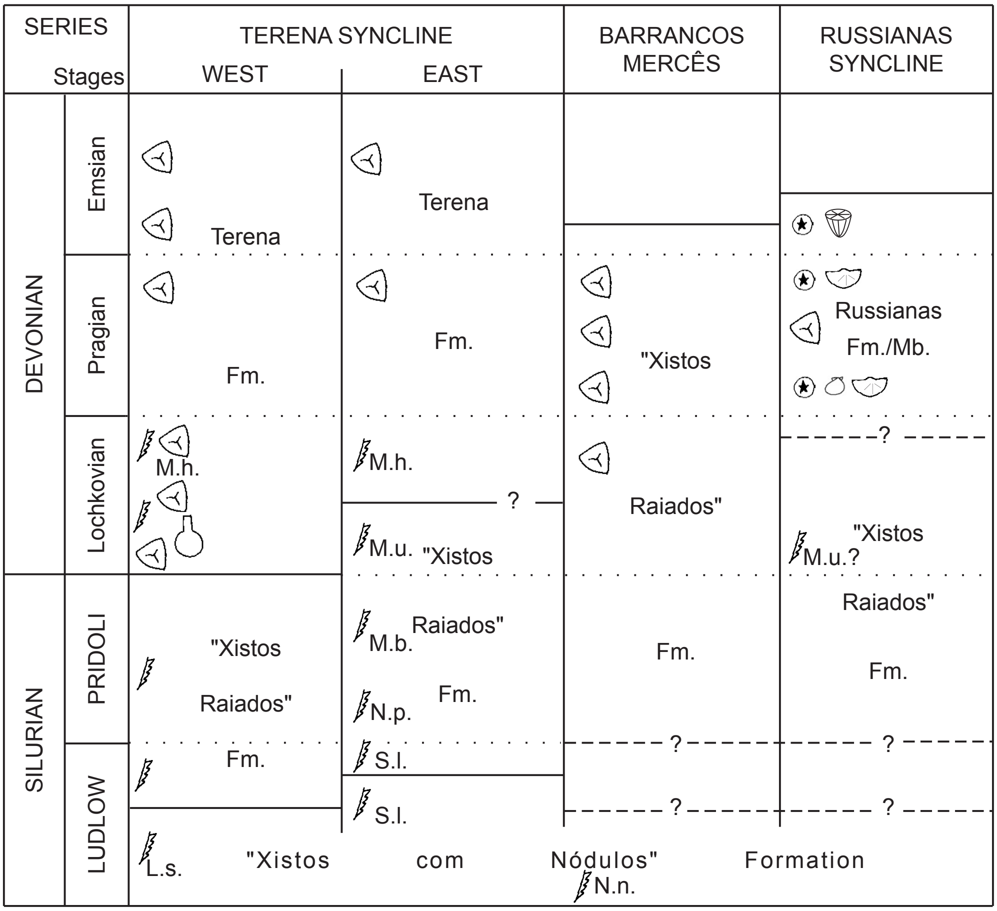

Fig. 8.- The Lower Devonian succession in the Barrancos area (after Piçarra *et al*., 1999; Piçarra, 2000; Le Menn *et al*., 2002).- For fossil symbols see figure 3. Abbreviations for graptolites: L.s., *Lobograptus scanicus*; M.b., *Monograptus bouceki*; M.h., *Monograptus hercynicus*; M.u., *Monograptus uniformis*; N.n., *Neodiversograptus nilssoni*; N.p., *Neocolonograptus parultimus*; S.l., *Saetograptus leintwardinensis.*

Fig. 8.- Sucesión del Devónico Inferior del área portuguesa de Barrancos (según Piçarra *et al*., 1999; Piçarra, 2000; Le Menn *et al*., 2002).- Para símbolos de fósiles ver figura 3. Abreviaturas taxonómicas de graptolitos: L.s., *Lobograptus scanicus*; M.b., *Monograptus bouceki*; M.h., *Monograptus hercynicus*; M.u., *Monograptus uniformis*; N.n., *Neodiversograptus nilssoni*; N.p., *Neocolonograptus parultimus*; S.l., *Saetograptus leintwardinensis.*

is late Pragian in age.

The Russianas Fm. has been considered classically as a distinct formation, overlying the "Xistos Raiados" Fm., and cropping out within narrow synclinal bands in the Russianas syncline (e.g. Perdigão, 1973; Perdigão *et al*., 1982). However, most authors have noted the great similarity of the lithofacies observed in the two formations and their gradual transition (e.g. Perdigão *et al*., 1982; Oliveira *et al*., 1991). It has been suggested that the Russianas lithofacies constitute a member within the "Xistos Raiados" Fm. rather than a different lithostratigraphical unit (Oliveira *et al*., 1991; Quesada and Cueto, 1994; Piçarra *et al*., 1999).

Finally, it must be noted that Lower Devonian macro- and microfossils are also known in the "Xistos Raiados" and Terena formations. The "Xistos Raiados" Fm., considered previously as Wenlock-Ludlow in age, recently yielded Pridoli and Lochkovian graptolites (Piçarra, 1998, 2000; Piçarra *et al*., 1998a, 1998b; see above) as well as Pragian spores (Pereira *et al*., 1998, 1999). The greywackes and shales with conglomeratic levels of the Terena Formation, the age of which (Early Devonian vs. Late Devonian-Early Carboniferous) was a matter of debate (see Oliveira *et al*., 1991 and references therein), have yielded Lochkovian graptolites and spores from their lowermost part, and Pragian and Emsian spore assemblages from higher levels (Piçarra, 1997, 1998; Pereira *et al*., 1998,1999). These recent data raise palaeogeographical or structural problems because three different formations of the same age seem to occur within the Barrancos region (Fig. 8), and it has been suggested that this area possibly comprises various tectonic slices (Piçarra, 2000, vol. 2, p. 143).

5. Early Variscan tectonic events

It is not within the scope of the present paper to discuss fully the Palaeozoic tectonic and geodynamic evolution of the Ossa-Morena Zone. However, the stratigraphical hiatuses, unconformities and synorogenic deposits characterized within the lower and middle Palaeozoic succession (Fig. 9) can provide some important informations on the early episodes of the Variscan tectonic evolution.

First, it must be noted that several authors had asserted that "Caledonian" tectonic events occurred during the Cambrian, and at the Cambrian-Ordovician and Silurian-Devonian boundaries and were the cause of unconformities supposedly observed within the succession of the southwestern Ossa-Morena Zone (e.g. Hernández Enrile and Gutiérrez Elorza, 1968; Gutiérrez Elorza, 1970). It has also been considered that Hercynian tectonometamorphic episodes began as early as the Late Ordovician (Apalategui, 1980). These interpretations, that resulted from erroneous stratigraphical attributions, must be abandonned because it is now clearly established that the Lower Ordovician-lowermost Devonian succession does not show any other hiatus than those related to the latest Ordovician glaciation.

The Lower Ordovician is transgressive directly on Middle Cambrian formations in the Ossa-Morena Zone as in several other regions of the Iberian Peninsula. In many publications, this pre-Ordovician hiatus has been related to a "Sardic phase" ("Sardic unconformity"), which is an improper denomination as the true "Sardic phase" in Sardinia is intra-Ordovician (see discussion in Hammann *et al.*, 1982; Gutiérrez-Marco *et al.*, 2002). The pre-Ordovician stratigraphical hiatus corresponds to the transition between the Cambrian rift phase and the Early Ordovician-Early Devonian passive-margin phase of the sedimentary evolution of the region. This transition was marked by the absence of Upper Cambrian deposits that resulted most probably from an emersion due to regional "doming" and block tilting and not from a penetrative deformational phase (Quesada, 1990, 1991; Ribeiro *et al.*, 1990).

Stratigraphical hiatuses of varying importance occur in the uppermost Ordovician and at the Ordovician-Silurian boundary in most North Gondwanan regions, in relation to the Late Ordovician African glaciation; in the Ossa-Morena Zone their importance is extremely limited (Gutiérrez-Marco *et al.*, 1998, 2002 and references therein).

At the Silurian-Devonian transition the euxinic sedimentation was continuous, without any hiatus, as attested by the fossil record in the Pridoli and the Lochkovian.

Middle Devonian rocks are unknown in almost all regions of the Ossa-Morena Zone (Puschmann, 1967, 1970; Julivert *et al.*, 1983; Robardet *et al.*, 1988; Weyant *et al.*, 1988), even in the Valle syncline where Famennian rocks have been identified. The only exceptions are two localities in SW Portugal where Eifelian conodonts have been identified: 1) in the "Pedreira da Engenharia" limestones, near Montemor-o-Novo (Boogaard, 1972), and 2) in the "calcarios da barragem de Odivelas" in the Beja Massif (Oliveira *et al.*, 1991). The mid-Devonian stratigraphical gap has been interpreted frequently as the echo of the first Variscan tectonic episode related to the initial subduction of oceanic lithosphere (Pulo do Lobo Ocean) in the south of the Iberian Peninsula (Oliveira *et al.*, 1991).

It has been admitted generally that, in the Ossa-Morena Zone, the first Palaeozoic synorogenic rocks corresponded to flyschoid and molassic deposits of Late Devonian and Early Carboniferous age that overlie unconformably folded older rocks. It was also accepted that these synorogenic formations were progressively younger from SW to NE (see Apalategui *et al.*, 1990; Quesada *et al.*, 1990; Oliveira *et al.*, 1991 and references therein). This was based on the Frasnian age of the Cabrela Fm. in the Montemor-Ficalho area (Boogaard, 1983; Ribeiro, 1983); the post-Eifelian, probably Late Devonian age of the upper part of the Odivelas Basic Complex in the Beja Massif (Conde and Andrade, 1974; Oliveira *et al.* 1991); the Late Devonian-Early Carboniferous age and the synorogenic character accepted at that time for the Terena Fm. in the Barrancos-Hinojales Unit; and the Early Carboniferous age of the small basins (Cerrón del Hornillo, Los Santos de Maimona, Valdeinfierno, Benajarafe, etc.) known in the Zafra-Alanís-Córdoba Unit (Quesada *et al.*, 1990 and references therein).

However, the recent biostratigraphical data obtained from the Terena Formation (Piçarra, 1997, 1998, 2000; Pereira *et al.*, 1999) have made the problem more complicated because the lower part of the Terena Fm. is now dated Early Devonian and its base apparently follows concordantly and gradually the underlying "Xistos Raiados" Formation.

Although they have not fully discussed the problem, Giese *et al.* (1994a, figs. 8 and 9, 1994b) have considered that the Terena Fm. comprises a lower part of Early Devonian age ("Lower Terena Fm.") and an upper part of Famennian-Visean age ("Upper Terena Fm."), this assumption being based on the Early Carboniferous age of the "Álamo Breccia" and of the "La Java Greywacke". However, up to now, palynological studies in the Terena Fm. of the Terena syncline have only revealed Early Devonian spore assemblages (Pereira *et al.*, 1998, 1999).

On another hand, in the Zafra-Alanís-Córdoba Unit: 1) the Famennian rocks identified in the Valle syncline apparently conformably overlie Lower Devonian rocks, without any evidence of a pre-Famennian deformational phase, and 2) there is only a disconformity (and not a true unconformity) at the base of the Mid-Tournaisian synorogenic rocks (with plant remains and conodonts) in the Cerrón del Hornillo syncline, where the true folding phase is younger (Robardet *et al.*, 1986, 1988; Weyant *et al.*, 1988).

It is thus rather difficult to give a clear global picture and timing for the first Variscan tectonic events that could be applied to the whole Ossa-Morena Zone.

6. Conclusions: Palaeogeographical and Geodynamical implications

A general overview on the Palaeozoic succession of the Ossa-Morena Zone (Fig. 9) allows distinction of three successive stages in the Palaeozoic evolution. It is assumed generally that the Early Ordovician-Early Devonian interval corresponded to a passive margin phase that followed a Cambrian rift phase and was succeded by a Late Devonian-Permian synorogenic phase (Quesada, 1990).

Although there is absolutely no doubt that both zones are of North Gondwanan type for sediments and faunas, the Lower Ordovician-Lower Devonian succession of the Ossa-Morena Zone differs appreciably from that of the Central Iberian Zone presently juxtaposed along the Badajoz-Córdoba Shear Zone (Robardet, 1976).

In the Ossa-Morena Zone, the Ordovician succession does not show the shallow marine inner shelf deposits that are so typical of the Central Iberian regions as are the Armorican Quartzite Formation and the overlying "Shales with *Neseuretus*" (= "*Tristani* Beds"). The shaly and silty deposits are much more developed and the faunas have more affinities with those of Bohemia. It must be noted that several authors have considered some quartzitic units of the Ossa-Morena Zone, especially in the Venta del Ciervo area, to be equivalent to the Armorican Quartzite Formation of the Central Iberian Zone (Schneider, 1939; Bard, 1966; Bege, 1970). This interpretation must be abandonned: these rocks have yielded acritarchs of Middle Cambrian age and are part of the Umbría-Pipeta Formation (Mette, 1987, 1989), and the Early Ordovician is represented by the green shales of the Barriga Formation, the dark shales and siltstones of the Barrancos Formation and similar lithologies in the Valle syncline.

In the Ossa-Morena Zone, the Silurian corresponds to a condensed, entirely euxinic, sequence of graptolitic black shales and black cherts, without any important influx of coarser siliciclastic material, that pass up into the Lochkovian. Conversely, in the Central Iberian Zone, the graptolitic black shales are restricted to the Llandovery and Wenlock, and the upper part of the Silurian (Ludlow and Pridoli) consists of thick sequences of alternating siltstones and sandstones that herald the arenaceous formations of the lowermost Devonian (Robardet and Gutiérrez-Marco, 1990b, 2002 and references therein).

Differences are still perceptible in the Pragian-Emsian sediments and benthic faunas, of "Rhenish" type in the Central Iberian Zone, and with more pronounced "Bohemian" affinities in the Ossa-Morena Zone.

The Ossa-Morena Zone is thus characterized by more distal and deeper environments than the Central Iberian Zone (Robardet and Gutiérrez-Marco, 1990a, 1990b).

It has been shown that, during Ordovician and Silurian times there was a bathymetric gradient within the Central Iberian Zone with deepening from South to North (Hammann and Henry, 1978; Gutiérrez-Marco *et al.*, 1998). This clearly indicates that the respective positions of the two zones during the early Palaeozoic were not what they are at present, and that their juxtaposition along the Badajoz-Córdoba Shear Zone was achieved during the Variscan Orogeny. When the particular characteristics of the Ossa Morena succession were first highlighted (Robardet, 1976), two distinct interpretations were suggested, depending on wether the Badajoz-Córdoba Shear Zone was considered a Variscan oceanic suture or only a major strike-slip fault. In the publications that followed, and made reference to this paper, many authors favoured the first interpretation and considered that the Badajoz-Córdoba Shear Zone was the cryptic suture of a Palaeozoic ocean obliterated by a late Variscan shear zone (e.g. Bard *et al.*, 1980; Burg *et al.*, 1981; Matte, 1986, 1991). This interpretation, although still maintained by several authors (e.g. Matte, 2002; Simancas *et al.*, 2002) should be abandonned because the existence of such an oceanic area is at variance with the distribution of benthic faunas and the pre-Variscan palaeogeography: during the whole Palaeozoic, the Ossa-Morena Zone was, as well as the other areas of the Iberian Peninsula (except the South Portuguese Zone), part of the North Gondwanan shelf that included all the regions of the future Variscan Belt and no wide ocean might have existed within these areas during the Palaeozoic (Quesada, 1991; Robardet *et al.*, 2001; Robardet, 2002). The present relations with the Central Iberian Zone are the result of Variscan transcurrent movements that have juxtaposed two distinct parts, respectively proximal and distal, of the North Gondwanan shelf along the Badajoz-Córdoba Shear Zone.

This point has a special importance for the understanding of the Variscan Belt in its Iberian part and also, more generally, in SW Europe. A large number of the geodynamical models proposed for the SW European Variscan Belt (see references in Robardet, 2002) suppose the existence of two distinct Palaeozoic oceans, the remnants of which would be found in the Iberian Peninsula along the Acebuches-Pulo do Lobo and Badajoz-Córdoba sutures. As stated above, such models can no longer be sustained because they are inconsistent with the palaeobiogeograph-

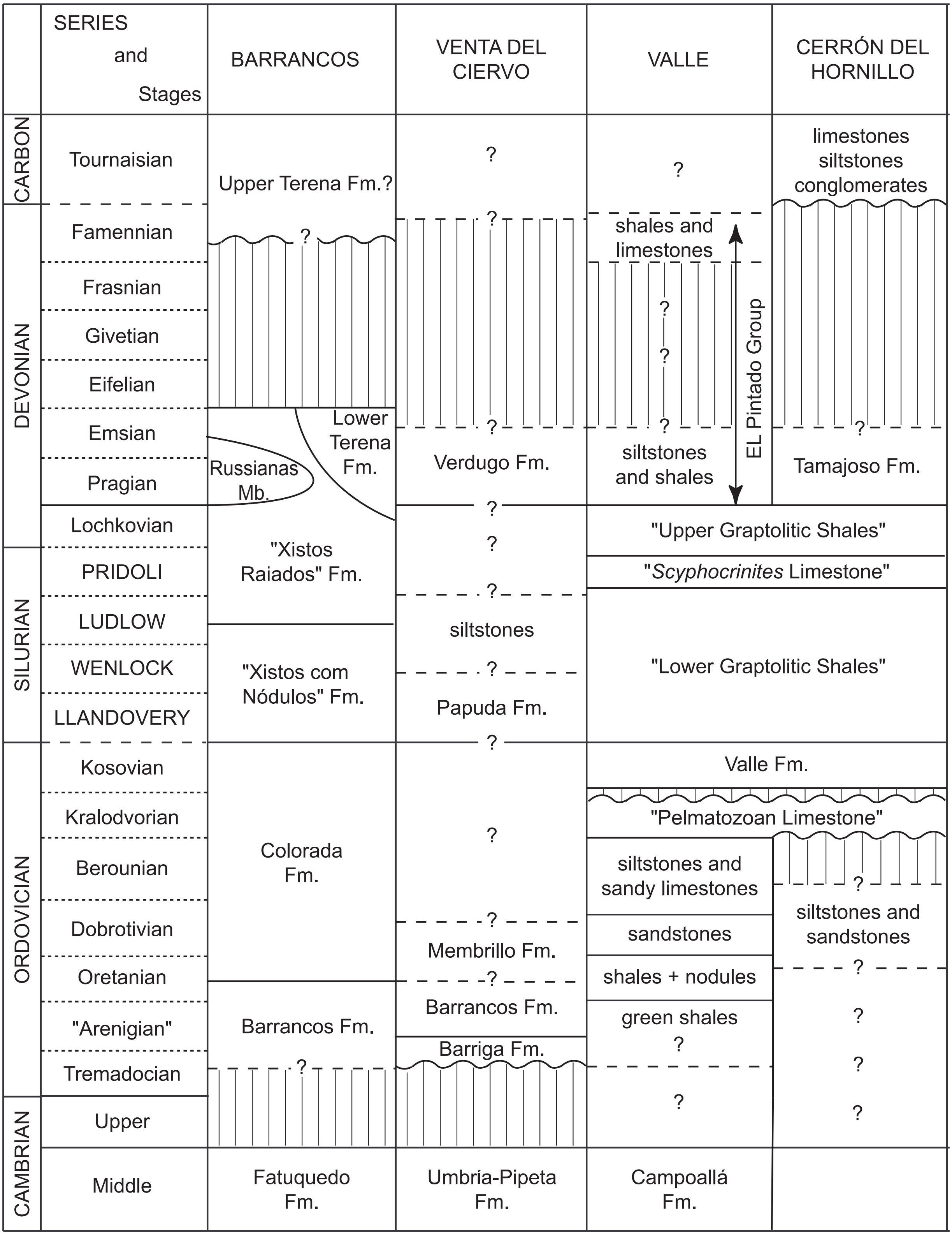

Fig. 9.- Correlation of the main stratigraphical units defined in the lower and middle Palaeozoic of the Ossa-Morena Zone, with reference to the Global Chronostratigraphy (Series and Stages) and to the Ordovician North Gondwanan regional stages. Wavy line, unconformity ; vertical ruling, stratigraphical gaps.

Fig. 9.- Correlación entre las principales unidades litoestratigráficas del Paleozoico inferior y medio de la Zona de Ossa Morena, en relación con la escala cronoestratigráfica global (Series y Pisos) y con la escala regional del norte de Gondwana. - Línea ondulada, discontinuidad erosiva; rayado vertical, laguna estratigráfica.

ical constraints, and a model with a single Variscan ocean connecting the Pulo do Lobo and Galicia sutures (Quesada *et al.*, 1994) would satisfactorily match the palaeobiogeographical data.

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