

BIOSTRATIGRAPHY OF THE GENUS *CALIX* (ECHINODERMATA, DIPLOPORITA) IN THE MIDDLE ORDOVICIAN OF THE SOUTHERN CENTRAL IBERIAN ZONE (SPAIN)

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INTRODUCTION

Diploporite cystoids are relatively common in the Middle Ordovician formations of SW Europe, where they are represented by the genera *Calix* Rouault, *Aristocystites* Barrande, *Codiacystis* Jaekel, *Phlyctocystis* Chauvel, *Batalleria* Chauvel and Meléndez and *Oretanocalix* Gutiérrez-Marco (Chauvel, 1941, 1973, 1977, 1980; Meléndez, 1951, 1958; Chauvel and Meléndez, 1978, 1986; Gutiérrez-Marco et al., 1984, 1986; Gutiérrez-Marco and Baeza Chico, 1996; Couto and Gutiérrez-Marco, 1999; Gutiérrez-Marco and Aceñolaza, 1999; Gutiérrez-Marco, 2000; Gutiérrez-Marco and Bernárdez, 2003). However, the identification of most species included in these genera poses a significant problem, due to the fact that the available and published material commonly corresponds to internal moulds of the aboral region of the thecae, where only *Codiacystis*, and to a lesser extent *Oretanocalix* and *Aristocystites*, are recognizable. Thus, almost all the described species need a deep taxonomic review in terms of modern diploporite taxonomy, which is based on a number of structural details of the theca and its openings. These details are totally unknown in most of the taxa described from the Middle Ordovician shales and sandstones of the Ibero-Armorican and North African parts of the Gondwana margin.

In spite of the taxonomical problems regarding the generic affiliation of many of these diploporite echinoderms, the vertical distribution of some species of the genus *Calix* have a significant biostratigraphic interest. This note focuses on the proposal of some regional biozones based on this genus, that are complementary of those derived from other fossil groups (Fig. 1). These *Calix* biozones can be recognized over an area covering the southern part of the Central Iberian Zone, and with correlation potential with other areas of NW Spain, the Iberian Cordillera and, to some extent, the Armorican Massif of western France and the Moroccan Anti-Atlas.

TAXONOMIC NOTE

The diploporid "cystoid" *Calix* Rouault, 1851 (= *Dorycystites* Klouček, 1917; *Lepidocalix* Termier and Termier, 1950) ranges from the early Oretanian to the late Berounian (earliest Darriwilian 2 to latest Katian 2 in terms of global stages and substages: Bergström et al., 1999) from SW and central Europe to North Africa, in a paleogeographic setting of high Gondwanan paleolatitudes. This typical member of the family Arystocystididae Neumayr is characterized by an elongate conical to cylindrical theca, provided with an aboral terminal tubercle and composed of numerous plates, mostly of irregular shape. The plates corresponding to the aboral region bear a central tubercle or prominence, and the tubercles are irregularly arranged or forming definite cycles, in this case showing great intraspecific variability. Mouth elongate, tetradiate, with scarcely developed and unbranched ambulacra, ended in articular facets for brachiole insertion adjacent to mouth. Diplopores with simple oval or slightly curved pits covered over with epitheca, when the latter is preserved.

The genus *Calix* (re-described by Rouault, 1878, 1883) comprises the following valid species: *Calix sedgwicki* Rouault, 1851 (type species), *C. purkynei* (Klouček, 1917) [= *C. rouaulti buchoti* Chauvel, 1936; *C. rouaulti* Chauvel, 1936 p.p.], *C. pulchra* (Termier and Termier, 1950b) and *C. gutierrezzi* Chauvel and Meléndez, 1986, bearing all of them aboral tubercle and tuberculiferous plates (the tetraradiate peristome is fully known only from the type species). Other species incompletely characterized and probably related to the genus are: *Calix? inornatus* Meléndez, 1958 (with tetraradiate peristome but without evidence of tubercles: exterior aboral region unknown); *C.? rotundipora* Chauvel, 1980 (with small tubercles and circular diplopores, remaining theca unknown); *C.? cornuta* Chauvel, 1978 (horn-shaped aboral annulated interior, remaining details unknown); *C.? segaudi* (Termier and Termier, 1950a) (tuberculiferous plates replaced by primary and secondary cycles of strongly domed plates; remaining theca unknown); and *C.? hajraensis* Chauvel, 1978, a rare Upper Ordovician species densely ornamented by conical tubercles, apparently with a tetradiate peristome but resembling other diploporite genera or even a Moroccan specimen of *C.? segaudi* (see Chauvel, 1978, pl. 2, fig. 1).

The species *Calix rouaulti* Chauvel, 1936, one of the most commonly cited among all the echinoderm literature from the Ordovician of SW Europe, is very poorly known and was regarded as highly polymorphic by Chauvel (1980). As the holotype of *C. rouaulti* (the "morphotype c" of Chauvel) is clearly conspecific with *C. purkynei* (Klouček, 1917), the name "rouaulti" becomes a junior synonym of the Czech species. However, the usage of *Calix "rouaulti"* s.l. is maintained provisionally here in order to refer to the remaining morphotypes (other than *C. purkynei*) designated by Chauvel (1980), some of which deserve biostratigraphic potential but that are impossible to characterize taxonomically until complete specimens are found.

Other highly questionable species of *Calix* are "*C. barrandei* Rouault" and "*C. davidsoni* Rouault" both proposed by Lebesconte (in Rouault, 1883, note infra to pl. 8) based on poorly preserved specimens either of *C. rouaulti* or *C. sedgwicki* s.l. (Chauvel, 1941); "*Calix halli*" Rouault, 1851 (type species of the genus *Pachycalix* Chauvel, 1936), which is only known from poorly preserved specimens most probably related to the genera *Aristocystites* or *Phlyctocystis*; "*Calix lebescontei*" Chauvel, 1936, an Upper Ordovician minute form, with some tubercles, but of dubious generic assignment (Chauvel, 1941, p. 84); "*C. murchisoni*" (Verneuil and Barrande, 1855) sensu Meléndez (1958), often synonymized with *Calix "rouaulti"* s.l. (starting from Chauvel, 1980), sometimes considered as a separate species of *Calix* (Meléndez and Chauvel, 1983) and lately re-evaluated as the type species of the genus *Oretanocalix* (Gutiérrez-Marco, 2000); "*C. sampelayoi*" (Meléndez in Bouyx, 1962), never described and finally

CHRONOSTRATIGRAPHY		GRAPTOLITES	CHITINOZOANS	TRILOBITES	BRACHIOPODS	"CYSTOIDS"			
GLOBAL	MEDITERRANEAN REGIONAL (POLAR GONDWANA)								
UPPER ORDOVICIAN	HIRNANTIAN (= KOSOVIAN)	graptolites absent in Iberia	<i>S. oulesiviri</i>	triobolites almost absent	Hirnantia Fauna (rare)				
			<i>T. elongata</i>						
	KRALODVORIAN		<i>An. merga</i>	<i>H. insculpta</i>	<i>L. pranlii</i>	"Heterocritites Fauna"			
			<i>Ar. nigerica</i>	<i>S. cf. obliata</i>	<i>G. luesmae</i>				
	BEROUNIAN	upper	"Dp." <i>vulgatus</i> - <i>Oc. lingulitheca</i>	?	<i>D. malladai</i>		<i>A. meneghiniana</i>	Calix <i>sultervei</i>	
			middle	graptolites almost absent (in study) without zonation	<i>Ac. barbata</i>				<i>S. hayliceki</i>
		lower			<i>T. fistulosa</i>				<i>S. armoricana</i> - <i>G. melout</i>
					<i>B. robusta</i>		<i>Ce. djordjini</i> - <i>D. seunesi</i>		
	MIDDLE ORDOVICIAN	SANDBIAN		<i>L. dalbyensis</i>			<i>Ce. chauveli</i>	<i>T. loi</i>	
				<i>O. bekkeri</i>	<i>L. denuffi</i>				
DOBROTIVIAN		upper	<i>C. aff. vicornis</i> (Bobemii)	<i>L. ponceti</i>	<i>Ma. burgau</i>		FAD <i>Jezereta</i>	Calix " <i>rouaulti</i> " s.l.	
			<i>H. reyauscultus</i>		<i>P. (C.) borni</i>		<i>H. koforeni</i>		
		lower	<i>G. timarssani</i>	<i>L. pissotensis</i>	<i>M. luyati</i> (FAD <i>P. boerei</i>)	<i>A. mariana</i>	<i>E. musculosus</i>	Calix? <i>segauuli</i>	
					<i>P. (C.) M. primitiva</i>			Calix <i>purkynei</i>	
DARRIVILLIAN		upper	<i>P. dist.</i>	<i>L. waldya</i>	<i>Z. toledana</i> - <i>E. macrophthalmia</i>	<i>H. morgatensis</i>	Calix <i>sedgwicki</i>		
			<i>D. marchison</i> - <i>D. clavulus</i> <i>Pterogi.</i>	<i>C. renkansi</i>	<i>E. deustombesi</i>	<i>C. ribermi</i>			
		lower	<i>D. spinulosus</i> - <i>D. artus</i>	<i>S. formosa</i>					
				<i>C. calix</i>			<i>Orth.-Siv. nocillio</i>	Calix? <i>inornatus</i>	
"ARENIGIAN"	upper	FAD <i>Co. retroflexus</i>	<i>H. protocalix</i>	<i>P. (P.) cambriensis</i>					
		<i>E. horvado</i>	<i>D. ballu</i>						
		<i>T. r. abbreviatus</i>	<i>B. honey</i> - <i>D. anensis</i>						

Figure 1. Correlation chart of the main Middle and Upper Ordovician biostratigraphical units defined in SW Europe, redrawn and updated from Gutiérrez-Marco et al. (2002), to which a right column ("Cystoids") has been added to show the diploporite biozones considered in this work.

synonymized with morphotype "f" of *C. "rouaulti"* s.l. (Chauvel and Meléndez, 1978; Chauvel, 1980); "*C. termieri*" Chauvel, 1966, a problematic taxon described from a very incomplete specimen, reported as an "ambiguous species" by Chauvel (1980, p. 8); and "*C. toledensis*" Chauvel and Meléndez, 1978, a taxon restricted to its inconclusive holotype by Gutiérrez-Marco and Aceñolaza (1999).

BIOSTRATIGRAPHY

The studied material comes from fourteen Ordovician sections extending across the southern Central Iberian Zone of the Iberian Massif, located in the synclines of Los Yébenes, Navas de Estena, La Chorrera, Guadarranque, Piedrabuena, Corral de Calatrava, Valdepeñas, Herrera del Duque, Almadén, Puertollano-Almuradiel and Guadalmez, plus the areas of El Centenillo and Eastern Sierra Morena (see San José et al.,

1992 and Gutiérrez-Marco et al., 2002, for location and summary of the main lithostratigraphic units). The vertical distribution of 12 diploporite species belonging to 6 genera has been studied, and their relative ranges plotted with reference to other trilobite and brachiopod biozones (Fig. 1), and dated by graptolites occurring in the assemblages. Our results show that there are some diploporite species related with *Calix* that are widespread in the studied area and show a restricted vertical distribution, being therefore of biostratigraphic interest. Five regional biozones are here proposed and named according to the respective diploporite species, and the contribution of *Calix gutierrezzi* is analyzed in the frame of the rhombiferan-dominated assemblages of the Upper Ordovician “Heliocrinites Fauna”. The new units are described below in ascending biostratigraphical order.

Calix? inornatus Biozone

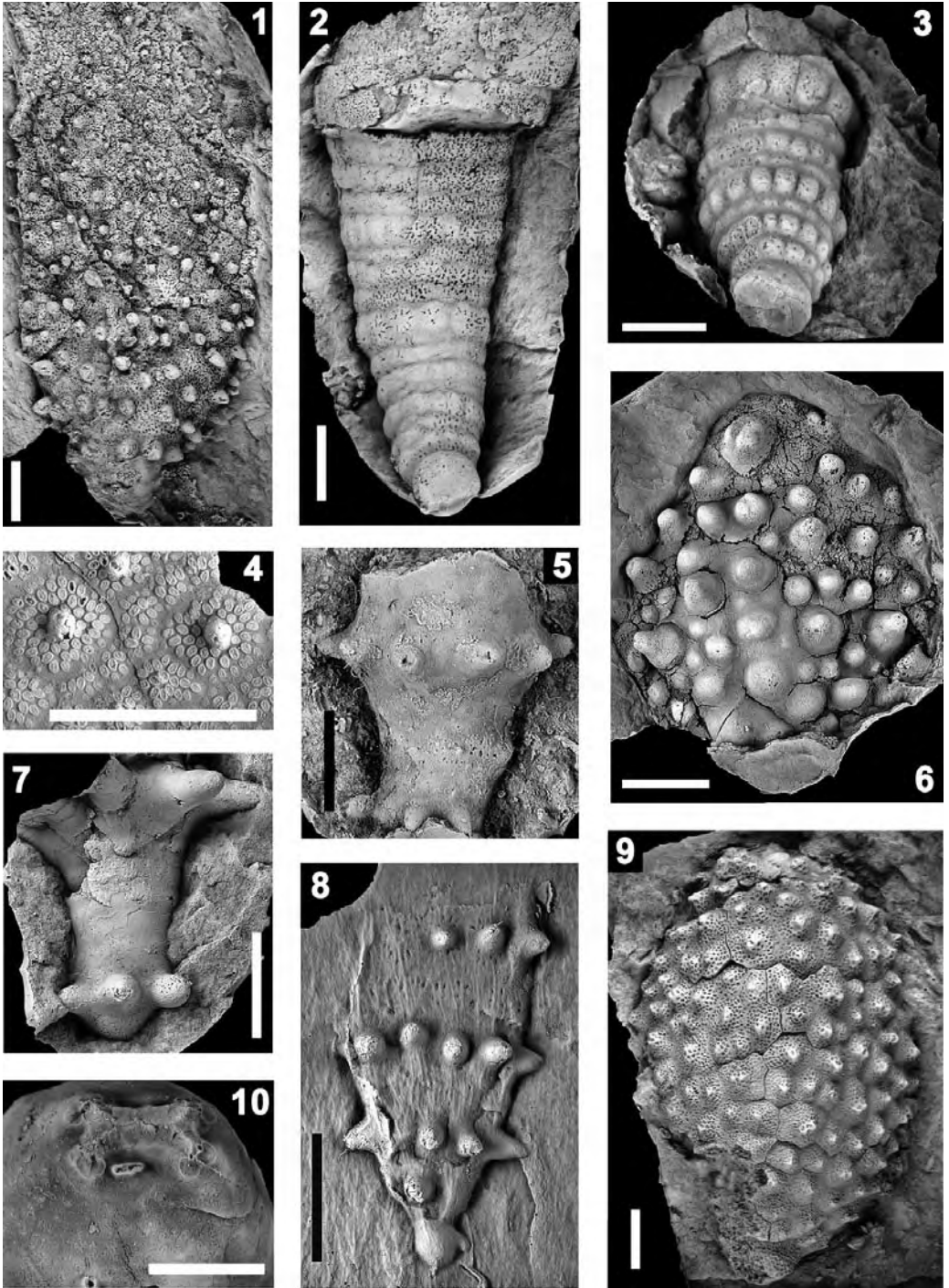
Defined by the entire vertical range of *Calix? inornatus* Meléndez, 1958 (Pl. 1, fig. 10), a species very easily recognizable by its carrot-shaped thecae, with a smooth and inflated oral region, that spans through the range of the *Orthambonites-Sivorthis noctilio* brachiopod Zone (see Reyes Abril et al., 2010, 2011) and is also recorded abundantly with trilobites of the upper part of the *Placoparia cambriensis* Zone, especially in the Montes de Toledo area. The *C.? inornatus* biozone can be dated as early Oretanian (earliest mid Darriwilian), as indicated by concurrent graptolite fauna (Fig. 1). Other valid species of diploporids recorded from this biozone are *Calix? rotundipora* Chauvel and *C.? cf. cornuta* Chauvel, present in some localities with a single specimen (e.g. *C.? rotundipora* from Ventas con Peña Aguilera: Chauvel, 1980).

Calix sedgwicki Biozone

This biozone is defined by the appearance and vertical extent of *C. sedgwicki* Rouault, 1851, a species of elongate morphology with numerous small tubercles irregularly distributed over the whole theca, and where most of the diplopores have a characteristic rim (Pl. 1, figs. 1 and 4). The FAD of the nominal species is clearly below the base of the *Cacemia ribeiroi* and *Placoparia tournemini* brachiopod and trilobite zones, respectively, and their total range is paralleled by that of the *Didymograptus murchisoni* graptolite Zone, which indicates a late Oretanian age (late mid–early late Darriwilian 2 substage).

The species *C. sedgwicki* was defined in the French Armorican Massif, where its detailed biostratigraphic position within the Oretanian-Dobrotivian range is still unknown. In Morocco, *C. sedgwicki* has been recorded in the Bou-Zeroual Formation of the First Bani Group, that according to Gutiérrez-Marco et al. (2003) is of late Oretanian age.

Plate 1. Some diploporite echinoderms/Arystocystitid “cystoids” with biostratigraphic interest from the Ordovician of the Central Iberian Zone, Spain. 1 and 4, *Calix sedgwicki* Rouault, 1851, lower Oretanian of Navas de Estena: 1, latex cast from the external mould of an almost complete theca in lateral view, JLC-102; 4, detail of tubercles and diplopores with preserved epitheca, latex cast from specimen JLC-103. Lateral view.-- 2-3, *Calix? segaudi* (Termier and Termier, 1950a), lower Dobrotivian of Navas de Estena: latex cast of two thecae with partly preserved epitheca showing details of aboral tubercle, specimens JLC-128 and JLC-127, respectively.-- 5, 7 and 8, *Calix purkynei* (Klouček, 1917). Dobrotivian from Czech Republic, Retuerta del Bullaque and Alía, respectively: 5, lateral view (latex cast) of holotype specimen; 7, aboral portion of a theca with widely spaced cycles of tubercles, MT-82; 8, latex cast of a flattened specimen in shale, lateral view of JLC-121, showing isolated tubercle among the aboral tubercle and first cycle.-- 6, *Calix “rouaulti”* Chauvel, 1936 s.l., terminal lower Dobrotivian from El Viso del Marqués, latex cast of a fragmentary specimen showing irregularly arranged conical tubercles.-- 9, *Calix gutierrezzi* Chauvel and Meléndez, 1986, uppermost Berounian of Almadén, latex cast of holotype specimen MF-227 showing tubercles and “polygonal” diplopores.-- *Calix? inornatus* Meléndez, 1958, lower Oretanian, Ventas con Peña Aguilera. Latex cast of the oral region showing thecal apertures in oblique-lateral view, MGM-2000-0). Scale bars, 10 mm.



Calix purkynei Biozone

This biozone is defined by the total range of *C. purkynei* (Klouček, 1917) [= "*C. rouaulti* Chauvel forme c"], a species easily recognizable by its elongated conical theca ornamented by tubercles of variable length, which are arranged in regular cycles separated by smooth areas, corresponding to constrictions in the internal mold (Pl. 1, figs. 5, 7 and 8). On the same beds, the species is locally associated with rare specimens of *C.? cornuta* Chauvel and also to *Calix? segaudi* (Termier and Termier), which makes its first appearance in this biozone. In the studied area, the first record of *C. purkynei* preceded the tempestitic sedimentation generalized in the southern part of the Central Iberian Zone during the early Dobrotivian, and is dated by the record of graptolites of the *Hustedograptus teretiusculus* Zone and their association to *Placoparia tournemini* (trilobite) and *Heterorthis morgatensis* (brachiopod) as early Dobrotivian (early Darrwilian 2 age of the global scale).

The species has also been recorded from Bohemia (Klouček, 1917; Prokop, 1964), represented by a single fragmentary specimen (Pl. 1, fig. 5) found in the Skalka quartzite (Dobrotivá Formation), and also from Dobrotivian shales in the French Armorican Massif (= "*C. rouaulti*", morphotypes "a" and "c" of Chauvel, 1980) and possibly also in Morocco. In Spain, *Calix purkynei* was also found in lower Dobrotivian shales from NW Spain (Gutiérrez-Marco and Bernárdez, 2003) and from the Iberian Cordillera (Gutiérrez-Marco et al., 1996), in both cases misidentified as "*C. rouaulti*".

Calix? segaudi Biozone

This biozone is based on the local abundance, in the Montes de Toledo, of *C.? segaudi* (Termier and Termier, 1950), unknown in coeval beds of the remaining Central Iberian Zone because the development of thick sandy tempestites that do not show recognizable diploporid remains. In its laterally-equivalent strata in the north of the region, these sandy tempestites change into a distal tempestite facies developed as lutitic alternations very rich in cystoids. Besides the highly characteristic *C.? segaudi* (Pl. 1, figs. 2-3), *C.? cornuta* Chauvel, *C. "rouaulti"* s.l. and several forms of the genera *Oretanocalix*, *Codiacystis* and *Phlyctocystis* have been recognized (Gutiérrez-Marco et al., 1984).

Calix "rouaulti" s.l. Biozone

This is an informal zone based on an incorrectly named taxon, due to the fact that *C. rouaulti* Chauvel, 1936 sensu stricto (its holotype specimen) is a junior synonym of *C. purkynei* (Klouček, 1917). With the exception of morphotypes "a" and "c" (= *C. purkynei*), morphotypes "f" and "g" of *Calix "rouaulti"* sensu Chauvel are usually restricted to beds of latest-early to late Dobrotivian age, as indicated by the remaining fossil groups of stratigraphical value (Fig. 1). In the terminal lower Dobrotivian shales, *C. rouaulti* s. l. may be locally accompanied by *Aristocystites metroi* Parsley and Prokop, and in higher upper Dobrotivian beds by rare *C.? cornuta* Chauvel and representatives of the genera *Batalleria* and *Phlyctocystis*, the latter involving specimens of giant size with thecas formed by more than 2,000 plates. As indicated in the taxonomic note above, the name for this biozone is provisional, and should be changed when the involved *Calix* taxa are accurately reviewed after complete specimens are found.

Biostratigraphic potential of *Calix gutierrezzi*

Diploporite echinoderms became rare in Upper Ordovician strata from Ibero-Armorica, where they were replaced in number and diversity by the rombiferans that characterize the "*Heliocrinites* Fauna" (genera *Heliocrinites*, *Caryocrinites*, *Hemicosmites*, *Rhombifera* and *Echinosphaerites*?; for references see Chauvel and Le Menn, 1979). The few diploporids recorded from the Kralodvorian (Katian 3-4 substages) belong to the sphaeronitid genus *Eucystis* Angelin (= *Proteocystites* Barrande), but in Berounian beds some indeterminate aristocystidids still persisted together with the last representatives of the genus *Calix*. Two of them ("*C. lebescontei*" Chauvel and "*C. hajraensis*" Chauvel) are questionable forms (see taxonomic note above), but *C. gutierrezzi* Chauvel and Meléndez, 1986 is a distinct form, characterized by its closely-set diplopores arranged in a polygonal pattern (Pl. 1, fig. 9). The type material of this species comes from the late Berounian sandstones in the Central Iberian zone, but probably the species is already present in the mid Berounian shales from the Iberian Cordillera (Gutiérrez-Marco et al., 1996). If so, in absence of other fossils, *C. gutierrezzi* can be used provisionally to estimate a biostratigraphic range comprised between the basal Middle Berounian until the topmost Berounian (from uppermost Sandbian to topmost Katian 2 substage of the global scale), which cannot be regarded as a biozone owing to its scattered occurrences, limited some Spanish areas.

CONCLUSIONS

Despite their abundance in Ordovician rocks from Ibero-Armorica and North Africa, *Calix* is a poorly known genus represented by four valid species and six other taxa probably related to it, but left in open nomenclature at present.

The study of the vertical distribution of all these taxa in fourteen Ordovician sections representative of the southern Central-Iberian Zone of the Iberian Massif, allow the definition of five regional biozones based on the distribution of diploporite echinoderms, that are paralleled with those of brachiopods and trilobites previously recognized from the same area. These biozones display potential value for correlating fossiliferous strata in absence of better biostratigraphical markers, as in this case, where the applicability of some of them could be extended to other areas of NW and NE Spain, as well as Morocco and western France. In terms of Mediterranean regional chronostratigraphy (see Gutiérrez-Marco et al., 2008 and Bergström et al., 2009 for their equivalence with the global scale), the *C. ? inornatus* Biozone is restricted to the lower Oretanian, the *C. sedgwicki* Biozone to the upper Oretanian, the *C. purkynei* biozone to the lowermost Dobrotivian, the acme of *C. ? segaudi* with the lower Dobrotivian s.l., and the *C. "rouaulti"* s.l. Biozone to the uppermost lower Dobrotivian and to the upper Dobrotivian. Finally, the range of *Calix gutierrezzi* extends from middle to upper Berounian strata in the frame of the Upper Ordovician "*Heliocrinites* Fauna".

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