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JURASSIC PALEONTOLOGICAL HERITAGE OF MURCIA (BETIC CORDILLERA, SOUTH-EASTERN SPAIN)

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Abstract. Jurassic rocks of the External and Internal Zones of the Betic Cordillera are widespread in the province of Murcia. Four areas are considered of special interest for stratigraphical and paleontological analysis: a) Sierra Quípar and b) Sierras Lúgar-Corque (External Subbetic), c) Sierra Ricote (Median Subbetic) and d) Sierra Espuña (Malaguide Complex). The first two contain Jurassic sections including Sinemurian-Tithonian deposits, and major stratigraphic discontinuities, containing significant cephalopod concentrations of taphonomic and taxonomic interest, occuring in the Lower-Upper Pliensbachian, Lower/Middle Jurassic and Middle/Upper Jurassic boundaries. These areas are also relevant for biostratigraphical analysis of the Middle-Upper Jurassic interval. In the Sierra de Ricote, the Mahoma section is of especial interest for the study of Lías/Dogger transition. Casa Chimeneas section constitutes the best Subbetic site for the analysis of the Lower/Upper Bajocian boundary. In the La Bermeja-Casas de Vite area, the Bajocian-Tithonian interval is well-represented, including a parastratotype of the Radiolarite Jarropa Formation. Finally, the Malvariche section in Sierra Espuña represents the best Jurassic succession of Internal Zones of the Betic Cordillera and could be considered as a reference section for this Betic Domain. In this paper a heritage evaluation has been carried out for these classical jurassic sections with the object of protecting these sites according to the legal framework prevailing in the province of Murcia.

Riassunto. Le rocce giurassiche della Zona Interna ed Esterna della Cordigliera Betica sono assai diffuse nella provincia di Murcia. Quattro aree sono considerate di speciale interesse per l'analisi stratigrafica e paleontologica: a) Sierra Quípar e b) Sierras Lúgar-Corque (Subbetico Esterno), c) Sierra Ricote (Subbetico Medio) e d) Sierra Espuña (Complesso di Malaguide). Le prime due contengono sezioni giurassiche comprendenti depositi del Sinemuriano-Titoniano, e discontinuità stratigrafiche maggiori, che contengono significative concentrazioni di cefalopodi di interesse tafonomico e tassonomico, e si ritrovano ai limiti Pliensbachiano inferiore-superiore, Giurassico inferiore/medio e Giurassico medio/superiore. Queste aree sono rilevanti anche per l'analisi biostratigrafica dell'intervallo Giurassico medio-superiore. Nella Sierra de Ricote, la sezione di Mahoma è di particolare interesse per lo studio del passaggio Giurassico inferiore/medio. La sezione di Casa Chimeneas costituisce il miglior sito del Subbetico per l'analisi del limite Bajociano inferiore/superiore. Nell'area di La Bermeja-Casas de Vite, l'intervallo Bajociano-Tithoniano è ben rappresentato, e comprende un parastratotipo della Formazione Radiolarite Jarropa. Infine, la sezione di Malvariche nella Sierra Espuña rappresenta la miglior successione giurassica delle Zone Interne della Cordigliera Betica e può essere considerata una sezione di riferimento per questo Dominio Betico. In questo lavoro è stata effettuata una valutazione di patrimonio per queste classiche sezioni giurassiche, con l'obbiettivo di proteggere tali siti secondo il contesto legale prevalente nella provincia di Murcia.

Introduction

Jurassic outcrops are widely represented in different areas of the province of Murcia, especially in its central and northern sectors. Since the first half of the 20th Century, Jurassic outcrops of Murcia have been considered by many European geologists (mainly French, German and Dutch), as being of special interest for the study of the Alpine Cordilleras. Geologically, the Jurassic of Murcia belongs to the eastern sector of the Betic Cordillera (Fig. 1). These outcrops include the Internal Zones (Malaguide Complex) and especially the External Zones (Subbetic and Prebetic). Many outcrops are clearly exposed displaying abundant and well-preserved fossil assemblages, especially

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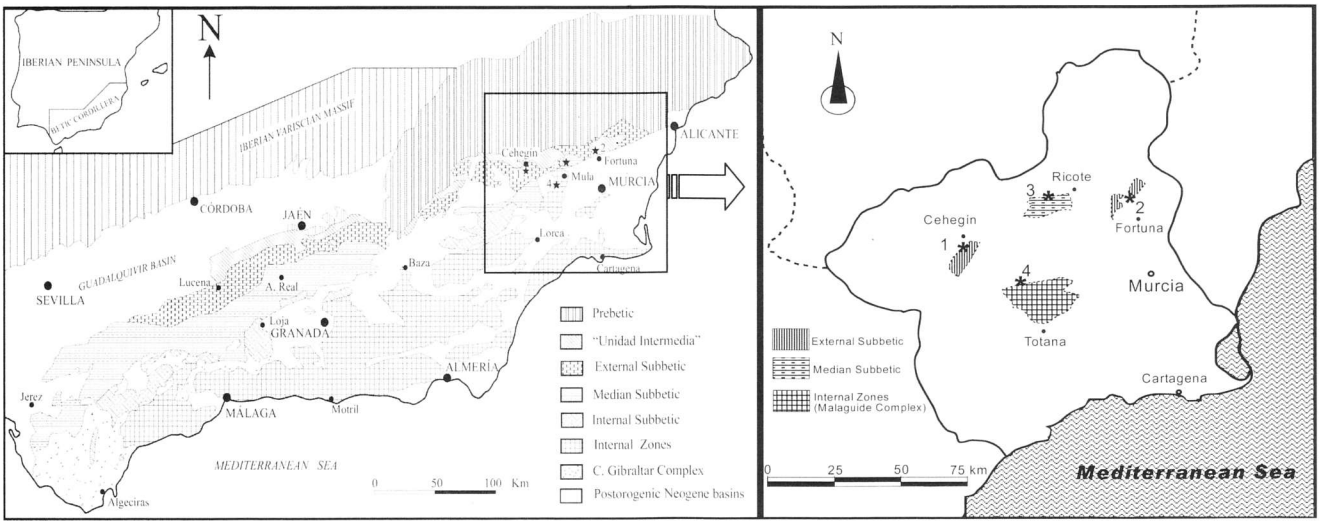


Fig. 1 - Geographical and geological sketch map showing the paleogeographic domains of the Betic Cordillera and the position of the studied sections: 1, Sierra de Quípar; 2, Sierra de Lúgar and Corque; 3, Sierra de Ricote; 4, Sierra Espuña.

ammonites and belemnites. Among the many Jurassic outcrops of great geological interest in the province of Murcia, we have selected only four areas, which we consider the most interesting sites from a stratigraphical and paleontological standpoint. These areas belong to the Sierra Quípar and Sierras Lúgar-Corque (External Subbetic), Sierra Ricote (Median Subbetic), and the Malvariche area in Sierra Espuña (Malaguide Complex, Internal Zones).

The only law applicable to the paleontological outcrops in the province of Murcia is that referring to sites of Good Cultural Interest (GCI), as included in the Historical Heritage Law of 1985. But this figure of GCI does not adjust to the patrimonial characteristics of the different paleontological sites. In order to improve the present situation, the Heritage Service of the Cultural Department of the Autonomous Community of Murcia is carrying out a research project in collaboration with the University of Murcia to benefit its palaeontological heritage (Mancheño & Romero 2000; Iniesta & Romero 2001).

The studied areas

The External and Internal Zones of the Betic Cordillera, with their corresponding paleogeographical domains, are extensively exposed in the province of Murcia. From a stratigraphic and paleontological point of view, the areas of greatest potential interest are the External and Median Subbetic and the Maláguide Complex in the Internal Zones. Below, we describe some of the sections of greatest interest in these areas:

The Sierra de Quípar Section (External Subbetic)

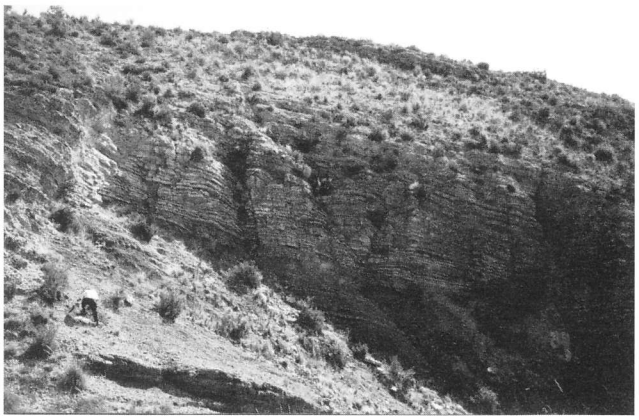
The Sierra de Quípar outcrop (Fig. 1) is located southwest of Cehegín in the Loma Solana Unit (Paquet 1969), which belongs to the External Subbetic (Rey 1993; Caracuel 1996). The most important works on the area are those of Barthel et al. (1966) in the Mai-Valera sector (biostratigraphy of ammonites and calpionellids), Van Veen (1966, 1969), who defined the Tollo Formation (210 m of thickness in the stratotype, Upper Jurassic-Lower Berriasian) and Rey (1993). Geel (1973) defined the Maimon Formation of the Aalenian-Upper Tithonian age. Subsequently, Seyfried (1978, 1981) studied the condensed Ammonitico Rosso facies and others of Jurassic age in the province of Murcia. The most relevant paleontological studies are those of Alleman et al. (1975) and Enay & Geysant (1975), who studied the calpionellids and the ammonites across the Jurassic-Cretaceous boundary. Mangold (1979) partially described the Middle Jurassic series of the Sierra de Quípar, recognising the Middle/Upper Bathonian. Sandoval (1983) studied ammonites of the Bajocian/Bathonian and established the biostratigraphy level by level in sampled sections of the Sierra de Quípar and Cerro Mai Valera. Tavera (1985) studied three sections of the Upper Tithonian (Transitorius and Simplisphinctes? zones) and Berriasian (Jacobi, Andrussowi and Boissieri zones).

Although Jurassic materials range from the Sinemurian age (limestones of the Gavilán Fm.) to the Tithonian surface in the Sierra de Quípar, only the Middle and Upper Jurassic display special interest from a stratigraphic and paleontological point of view (Fig. 2). The outcrops of this age show a varied lithology, excellently defined stratigraphy and an abundant and well preserved fossil content among other features, which makes this area one of the most interesting in the Jurassic of the Betic Cordillera (Pl. IA).

In the Sierra de Quípar, the Middle Jurassic is limited both at the base and top by stratigraphic discontinuities, related to condensed levels with substantial concentrations of macrofossils, especially ammonites and belemnites. Associated to the lower discontinuity, the boundary between the Zegrí and Veleta Fms., there is a discontinuous layer (0-50 cm) with laminar concentrations and abundant concretions of Fe-Mn oxides. This layer also contains abundant macrofossils, especially orientated belemnites and ammonites ranging in age from the Upper Toarcian to the Lower Bajocian. Over this ferruginous crust appear materials from the Upper Bajocian: a) two levels (50-60 cm) of violet or yellowish nodular limestones showing condensation and abundant fossil content (ammonoids, belemnoids, brachiopods, bivalves, gastropods, etc.) belonging to the Niortense Zone; b) 2.5 m of violet marls with thin intercalations of partially nodular marly-limestones. c) 4.5 m of grey marly-limestones and limestones with chert nodules and d) approximately 5 m of red marls and nodular limestones. These three intervals contain Late Bajocian ammonoids (Garantiana and Parkinsoni zones).

The thickness of the Bathonian sediments is approximately 8 m, and the individual thickness of the beds ranges between 5 and 90

A



B

C

D

PLATE 1

A - Partial view of the Sierra de Quípar section. B - Partial view of the Sierra de Lúgar section (Oxfordian limestones). C - Partial view of the Casas de Vite section. Middle and Upper Jurassic (Callovian-Oxfordian) red siliceous nodular limestones (Jarropa Fm.). D - Partial view of the Malvariche section at the Sierra Espuña.

cm. Lower Bathonian is represented by 5 m of violet or red marls and nodular marly-limestones. Red nodular limestones dominate the Middle Bathonian materials (3 m). Macrofossils are basically represented by ammonites, providing valuable data for biostratigraphy. The Zigzag, Aurigerus (Lower Bathonian), Sofanus, Costatus (Middle Bathonian) zones are recognized. No Upper Bathonian materials were registered. Bathonian rocks end in an intra-Bathonian rupture characterised by synsedimentary fractures with neptunian dykes, mainly N-S, associated to a multiple layered (four levels) crust with Fe and Mn minerals and fauna (uncompleted ammonites and orientated belemnites) and nodular concretions of Fe-Mg ("snuff-box" type structures).

Callovian sediments are scarcely represented in Sierra de Quípar, where they constitute a discontinuous bed of a few centimetres (associated to the previous levels) with abundant Fe-Mn and ammonites often neomorphised. Ammonite zones of Bullatus?, Gracilis and Anceps can be recognised.

Oxfordian levels begin with nodular-marly limestones with occasional slumps (northward direction) and intraformational breccias (pebbly-mudstones) above. Similar features have been recognised towards the upper part of the Paturattensis Zone and at the base of the Bimammatum Zone. During the rest of the Upper Oxfordian and Lower Kimmeridgian the carbonated character increases towards the Strombecki Zone. Above this, red Ammonítico Rosso sedimentation begins again to reach thick banks (13-14 m) in the Albertinum/Darwini zones. The rest of the Verruciferum Zone is made up of marly Ammonítico Rosso facies, which rapidly turn to massive calcareous with a pseudonodular appearance in the Burckhardticeras and Lower Transitorius zones (23-25 m). Some levels have nodular tops and reduced nodular marly-limestone interbeds, which become more important towards the upper part of the succession. Above, the succession expands with 20-25 m of limestone layers with top slumps and 10 m of marly limestone rhythmite in contact with the 20-30 m of massive limestones or red and grey breccias (Caravaca Red Member). In the top of this last member 1-2 m thick sequences appear, thicking upward and very rich in crinoids, forming a boundary with the Carretero Fm. (Valanginian-Hauterivian).

The Sierras de Lúgar and Corque Sections (External Subbetic)

The Sierras de Lúgar and Corque (Fig. 1) are located in the NW and W of Fortuna at the westside of the province of Murcia. Geologically, they lie in the eastern part of the External Subbetic, and present a Middle/Upper Jurassic series with a degree of exposure and stratification that facilitates detailed studies (Fig. 3). Fallot (1931-34, 1945) made the first stratigraphic and tectonic considerations. Subsequently, Azéma (1966) assigned the Corque and Lúgar Sierras to the western Prebetic. The stratigraphic succession, which is only visible in the

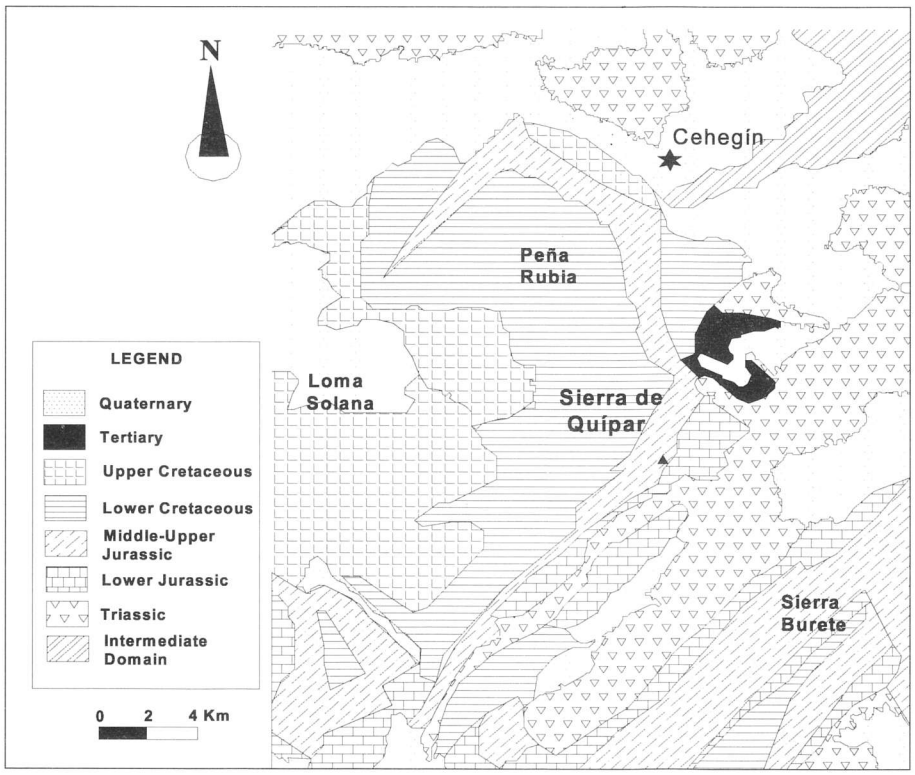


Fig. 2 - Geological scheme of the Sierra de Quípar.

southern flank of the Sierra del Corque, is of Lías-Lower Cretaceous age. The Corque succession is detailed in Azéma (1971) and Azéma et al. (1971). There are abundant ammonites (*Aspidoceras* gr. *altenense*, *A.* gr. *circumspinosum*, *Dichotomoceras* gr. *bifurcatus*, *Epipeltoceras* aff. *treptense*, *Gregoryceras* sp. and indeterminate perisphinctids) from the Middle and Upper Oxfordian.

Seyfried (1978) described 78 m of the Middle/Upper Jurassic succession in the Sierra de Lúgar, recognising a resedimented breccia (level 5) with ammonites of the Toarcian/Lower Bajocian age. The same author attributed the following sections (levels 6a, 6b and 6c) of limestones with chert, laminated limestones and marls, partially nodular marly limestones and nodular limestones, to the Upper Bajocian/Middle Bathonian, while the following level (a limonitic crust, level 7) would correspond to the Callovian. The Upper Jurassic begins with a section (level 8) of red, marly nodular limestones from the Upper Callovian to the Upper Oxfordian (Planula Zone). Levels 9a, 9b and 9c are 18 m of nodular limestones which precede the facies removed from the top of the succession exposed in sector 9d, which are considered characteristic of the "type C series" of the Subbetic (northern External Subbetic sensu Ayala et al. 1988).

Mangold (1979) analysed the biostratigraphy of the Bathonian in two sections of the Sierra de Lúgar, while Sandoval (1990) considered the section of the Sierra de Lúgar among the most characteristic for the Bajocian of the External Subbetic. Checa & Sequeiros (1990) presented a detailed study of the basal 115 cm of the Upper Jurassic section of Corque, referring ammonite associations with *Peltomorphites*, *Peltoceratoides*, *Parawedekindia*, *Euaspidoceras babeanum*, *Creniceras*, *Neocampylites*, *Prososphinctes*, and *Pseudogregoryceras*, which characterise the Renggeri and Atletoides zones of the Lower Oxfordian. Nieto (1997) defined the Lúgar-Corque Unit and included the Middle/Upper Jurassic of this unit in the Veleta and Upper Ammonitico Rosso Fms. defined in the central part of the Betic Cordillera. Sandoval (1998) and Osete et al. (2000) studied the Bajocian/Bathonian boundary in the Betic Cordillera and considered the Sierra de Lúgar as a reference for this boundary in the Mediterranean domain. Caracuel et al. (1999, 2000) carried out paleontological detailed studies with ammonites in the Oxfordian of the Sierra de Lúgar (Pl. IB). The rest of the succession, in facies of more compact nodular limestones and grey-green massive limestones, are poorer in macrofauna (*Mesosimoceras* sp. of the Middle Kimmeridgian).

In this area, as in the Sierra de Quípar, Bajocian sediments are well represented, although important stratigraphical gaps occur in the Lias/Dogger and Lower/Upper Bajocian boundaries. In the base, overlying a decimetre condensed and brecciated level with reworked Upper Toarcian to Lower Bajocian ammonites, the following succession occurs: a) 10-12 m of well bedded grey micritic limestones, locally with chert nodules, which end in a nuclearly marked discontinuity; b) 8 m of grey marls and marly-limestones with chert nodules, in which trace fossils (*Zoophycos*, *Thalassinoides*, and *Chondrites*) are locally abundant; the bed thickness ranges between 20 and 100 cm; c) 3 m of grey to pinkish nodular limestones with bed thickness ranging between 15 cm and 1.20 m, and d) 3 m of yellowish-red marls, nodular marly-limestones and red nodular limestones where bed thickness varies from 10 to 50 cm. Abundant and diversified ammonites, especially in the Ammonitico Rosso facies, allow the recognition of the standard Mediterranean zones of Discites, Propinquans, Humphriesianum, Niortense, Garantiana and Parkinsoni.

The thickness of the Bathonian sediments is approximately 10 m, although the individual thickness of the beds varies between 5 and 90 cm. Violet-yellowish or red marls and nodular marly-limestones predominate in the Lower Bathonian (8 m), whereas red nodular limestones (Ammonitico Rosso) dominate the Middle and the Upper Bathonian sediments (2 m). Ammonites, among which typically Mediterranean phylloceratids fundamentally represent the macrofossils and lytoceratids, predominate. However, the ammonitids are also common, providing significant data for biostratigraphical analysis. Zigzag, Aurigerus (Lower Bathonian), Sofanus, Costatus (Middle Bathonian) and Aspidoides? (Upper Bathonian) zones are clearly distinguished.

Callovian sediments are scarcely represented in the Sierras de Corque and Lúgar, which thickness ranges from a few centimetres to 1 m (Fe-Mn crust). The lithology consists of red, sometimes nodular limestones with abundant Fe-Mn concretions, sometimes containing ammonites. The ammonite zones of Bullatus, Gracilis, Anceps, Coronatum? and Athleta can be recognised. Major or minor stratigraphic discontinuities and gaps occur in the Upper Bathonian/Lower Callovian and Callovian/Oxfordian boundaries.

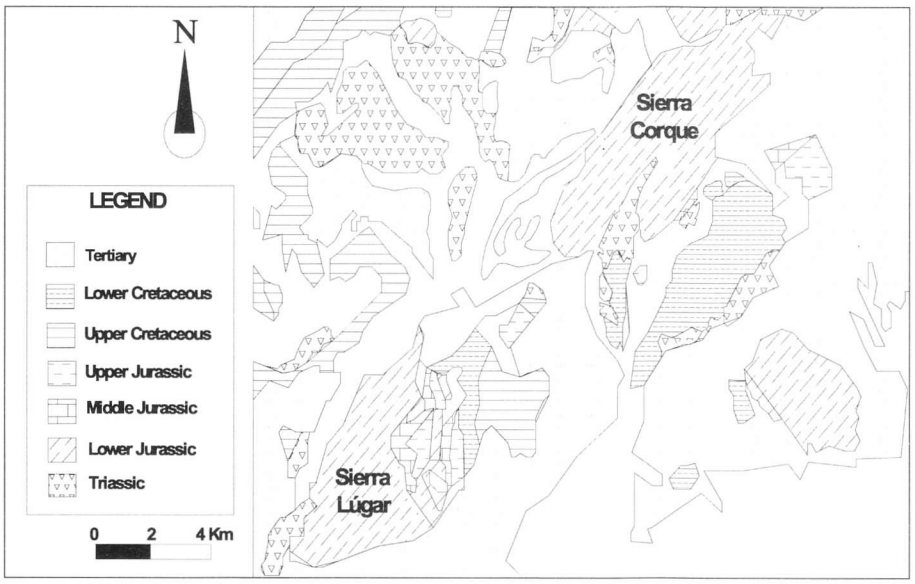


Fig. 3 - Geological scheme of the Sierra de Lúgar and Corque.

As regards the Upper Jurassic, as for the Middle Jurassic, both stratigraphic sections, which are geographically very close, possess a very similar succession to that of the Sierra de Quípar. At the base there is a first section of marly limestones of an intense red colour (10 m) with abundant fauna, which characterises the zones from the Lower Oxfordian to the basal Kimmeridgian (Paturattensis-Platynota). Above this, there is a transition to some strong levels (50 cm), in which the nodularity is lost. Besides *Chondrites* and *Thalassinoides*, which occur in the rest of the section, traces of *Arenicolites* can be seen in these levels. The following 12 m consists of nodular facies with carbonated banks. No significant fauna have been identified in the following 7 m. There are solid banks, sometimes more than 1 m thick, amalgamated, nodular-looking and without interlevels. The well-exposed section clearly shows gentle lap-out towards the north and occasionally strong interruptions of the strata towards the south.

The rest of the succession (16-17 m) is again nodular; although varied lithofacies follow each other with breccias, marly, nodular levels and even marls. The succession is abruptly interrupted at the top by an erosive megabreccia which enters at least 3 m and which includes rocks of variable size and individual levels or fragments of the succession itself, folded and included in the remobilization. The biostratigraphic study with the calpionellids being more conclusive than the ammonites in this case reveals the little importance of the associated hiatus ("Doliphormis" Subzone and part of the Alpine Zone).

The Sierra de Ricote Section (Median Subbetic)

The Sierra de Ricote is situated in the central part of the province of Murcia (Fig. 1). Geologically, it constitutes the most eastern outcrop of the Median Subbetic, in which domain Fallot (1931-1934, 1945) included it. Subsequently, the Sierra has been the object of several studies, some of them monographic such as those of Rios & Almela (1953) and Almela & Rios (1954), in which the authors analysed its stratigraphy and tectonics, referring several ammonites from the Jurassic. Paquet (1969) differentiated three superimposed tecto-sedimentary units, from internal to external and from lower to the upper being, La Mezquita, La Garita and La Bermeja. In his study of the Jurassic of Murcia, Seyfried (1978) considered the type section of the Sierra de Ricote (series of the La Bermeja Unit) as the most representative of the type E sections that can be included in the Median Subbetic. In the Jurassic of the Sierra de Ricote, Nieto (1997) differentiated the Gavilán (Lower Lías), Zegrí (Toarcian-Aalenian), Veleta (Bajocian-Bathonian), and Milanos (Upper Jurassic) Fms., along with a radiolaritic sequence that he attributed to the Callovian-Oxfordian. Furthermore, the same author defined the Ricote Fm. by the oolitic limestones of the Lower Bajo-

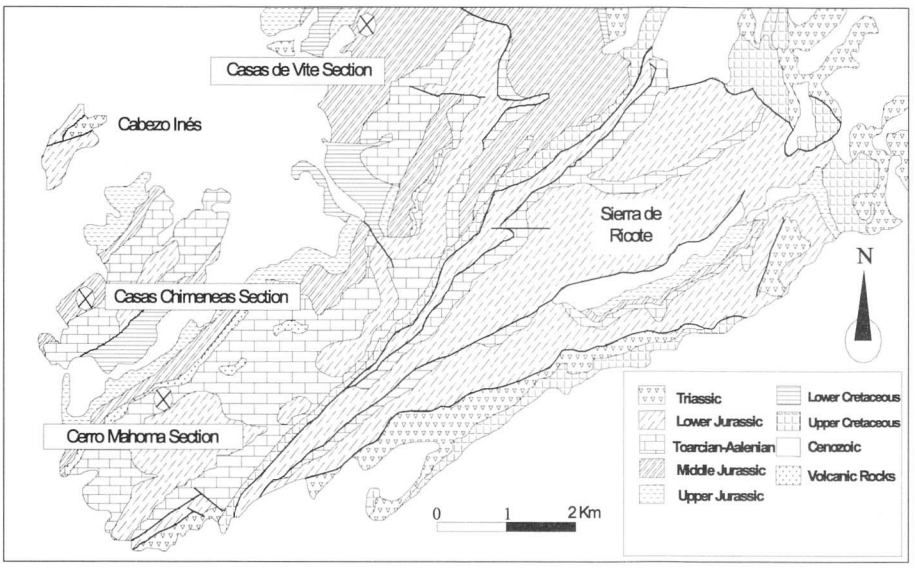


Fig. 4 - Geological scheme of the Sierra de Ricote.

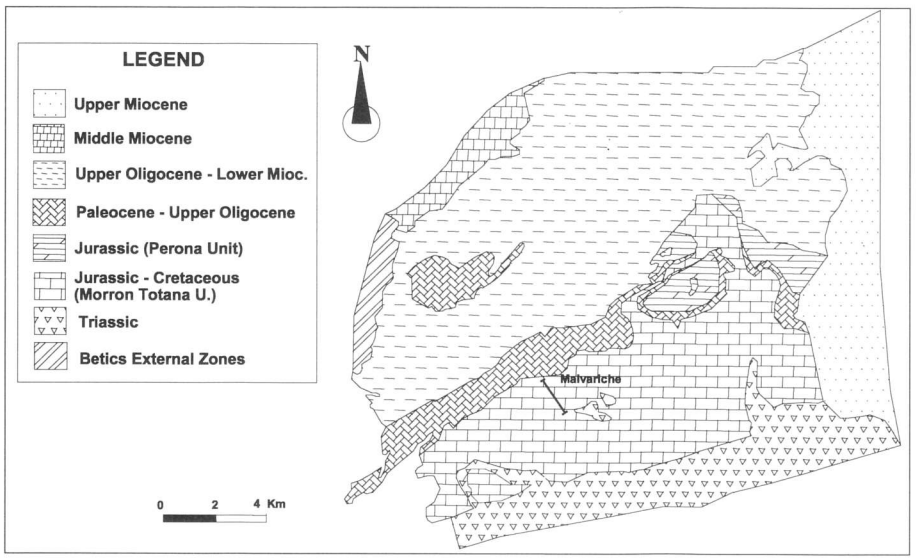


Fig. 5 - Geological scheme of the Sierra Espuña (modified from Caracuel et al. 2001).

cian of the southern part of the La Bermeja Unit. O'Dogherty et al. (1989a, 1989b) studied some siliceous sequences of the Jurassic of the northern part of the sierra and O'Dogherty et al. (1997) considered the radiolaritic series of Casas de Vite, previously analysed by Baumgartner (1987), as one of the parastratotypes of the Radiolaritic Jarropa Fm. O'Dogherty et al. (2001) also analysed some tecto-sedimentary events of the Middle Jurassic of the Bermeja Unit.

Colom (1996) studied the calpionellids of the northern part of the sierra and identified several new species. Subsequently, Linares & Sandoval (1978) studied the ammonites of the Bajocian in three sections of the Bermeja Unit and discovered one new species, *Spiroceras ricotensis*. Sandoval (1983, 1990) included some sections of La Bermeja Unit in their studies of the Middle Jurassic of the Subbetic. Linares & Sandoval (1993), García-Gómez et al. (1994) and Sandoval et al. (2001) considered the Mahoma series in the southern part of the unit as a reference series for the Lias/Dogger boundary in the Mediterranean Domain.

Jurassic sections of Sierra Ricote (Fig. 4) include Sinemurian-Tithonian sediments, which occupy the greatest part of its extent (Seyfried 1978), although only two small areas are here considered for their special interest: Cerro de Mahoma-Casa de Chimeneas, and La Bermeja-Casas de Vite. Cerro Mahoma is located in the southern part of the La Bermeja Unit. Here the Toarcian-Bajocian interval is well represented and the ammonites are abundant, representative and well preserved. This area is suitable for studying the Toarcian/Aalenian interval (Sandoval 1983; Linares & Sandoval 1993, García-Gómez et al. 1994, Sandoval et al. 2001). Likewise, the type series of the Ricote Formation is here exposed (Nieto 1997).

In the Mahoma section, the Middle Toarcian (Bifrons Zone)/Bajocian interval includes a section of great interest from a stratigraphical and paleontological standpoint. The following levels can be separated: 12-13 m of marly Ammonitico Rosso, in the upper part of which thin intercalations of limestones or marly-limestones occur; the abundant and diverse ammonites correspond to the Bifrons (Middle Toarcian) and Gradata (early Upper Toarcian) zones. Overlying a small stratigraphic discontinuity and hiatus, 20 m of grey-white marls with decimetre marly-limestones intercalations, in which Upper Toarcian ammonites (Reynesi Zone) are common. Approximately 55 m of predominantly well bedded regular alternations of pelagic grey marls, marly-limestones and limestones with sporadic chert nodules, in beds of 20 to 70 cm thickness. Trace fossils, *Chondrites* and *Zoophycos*, can be locally common. Ammonites, very abundant in some levels, allow a fine biostratigraphic study; uppermost, Toarcian and Aalenian standard ammonite zones and subzones are recognised. 2-3 m of intraformational breccias and fine-grained turbidites occur in the Lowermost Bajocian. 4-5 m of subvolcanic rocks are also present overlying the breccias. 65-70 m of oolitic limestones, marls and marly-limestones of the Ricote Fm. (Nieto 1997).

The Casa Chimeneas section is located in the NW part of the La Bermeja Unit. In this area the Lower/Upper Bajocian transition consists of approximately 100 m of grey to white marls, marly-limestones and limestones, which sometimes contain more or less irregular chert nodules. Generally calcareous beds vary from 5 to 60 cm thickness, whereas some marl beds can surpass 250 cm. In the lower part of the section, marly beds clearly dominate over marly-limestones and limestones, and chert nodules are very scarce. In the intermediate interval, just below the uppermost Lower Bajocian, calcareous beds may predominate and chert nodules are common. Finally, in the Upper Bajocian (Niortense Zone) terrigenous sediments, are clearly dominant. Ammonite-fauna, very diversified and relatively well preserved, allow a fine biostratigraphic study, and consequently this section can be selected as a possible reference for the Lower/Bajocian boundary in the Betic Domain and in the western Mediterranean.

The Middle-Upper Jurassic of the northern sector of the La Bermeja Unit presents excellent outcrops, including a parastratotype of the Jarropa Radiolarite Fm. in the Casas de Vite section (Pl. IC). In this sector, the Jarropa Fm. is limited in its lower part by Bathonian-Callovian red siliceous nodular limestones, and is overlying by the limestones and siliceous marly rhythmite of the Milanos Fm. In this section, the lower member of the Jarropa Fm., green radiolarites and siliceous marls, is approximately 2 m thick. The upper member, siliceous clays and marls with thin radiolarite intercalations, do not surpass 20 m in thickness (O´Dogherty et al. 1997).

The Sierra Espuña Section (Malaguide Complex)

The section analysed in Sierra Espuña belongs to the Malaguide Domain, a complex of non-metamorphic layers of the Internal Betic Zones (Fig. 1). Two tectonic units have been defined in Sierra Espuña, (Martín-Martín & Martín-Algarra 1997): the Morrón de Totana Unit (upper) and the Perona Unit (lower). The first one presents a strong and complete succession from the Paleozoic to the Tertiary. The Malvariche section is located next to a woodland path, which favours the exposure of the Jurassic materials of the Morrón de Totana Unit (Fig. 5). The good quality of the outcrop, with very little tectonic distortion, and the presence of several fossil-bearing levels in the section make this a reference section for the Jurassic of the Malaguide Domain (Pl. ID).

Fallot (1945), Peyre & Peyre (1960), Navarro & Trigueros (1963) and Geyer & Hinkelbein (1971, 1974) made the first studies on the Jurassic of Sierra Espuña. These authors provided details on the fossil-bearing level of Domerian age associated to Fe mineralisations in the Prado Mayor and Morrón de Alhama sections. Paquet (1969) made a

synthetic study of the Jurassic of Sierra Espuña after studying the Prado Mayor section. The same author analysed the level from the Domerian age and assigned an upper section of marly limestones to the Dogger based on the presence of *Cancellophycus*, attributing an upper section of nodular limestones to the Malm. Kampchuur et al. (1974) recognised the presence of filaments in the section that Paquet had assigned to the Dogger. Subsequently, Seyfried (1978) studied the Prado Mayor section and assigned it to the Middle Domerian, Bajocian and Oxfordian based on the ammonite associations. Finally, Caracuel et al. (2001) made a detailed stratigraphic study of the Malvariche section.

The succession of the Jurassic in the Malvariche area comprises more than 300 m of oolitic limestones with pellets, marlstones and calcareous nodular limestones. These are exposed subhorizontally in the lower area and strongly dipping to the NW in the upper section.

The first section (80 m) is composed of oolitic limestones with levels rich in oncolites, echinoids and facies with *Lithiotis*, which means that the base alternates with massive limestones traditionally considered Infra-Lias. Between 80 and 100 m there are oolitic limestones with crinoids and sandy levels with gastropods, bivalves, *Lithiotis* and some indeterminate ammonoids. At 110-124 m there is a second section with sands, which in its lower parts contains large oolites and pisolites (10 cm) with ammonites from the lower part of the Middle Domerian (Argovianum Zone, Ragazzonii Subzone). Between 124 and 150 m, the limestones with crinoids in thick banks alternate with limestones with chert. At 150-249 m facies rich in filaments occur, probably from the Middle Jurassic, in sequences containing crinoids in the lower part and progressively more chert towards the final part. A level of resedimentation and condensation of fauna appears towards 249 m, permitting the terminal part to be dated as Lower Callovian (Pátina Zone, Sequeiros 1974). Both at the top of this level and at the base of the overlying marly limestones *Globuligerina* are abundant, permitting to attribute it to the Callovian-Oxfordian.

The Upper Jurassic begins with thickening upward metric sequences of limestones and marly limestones with no apparent macrofauna, which after 257 m become thickening upward. At about 263 m appear levels that include at the top fragmented and resedimented ammonites from the terminal Kimmeridgian (Beckeri Zone). Finally, the Upper Tithonian is constituted of strong carbonated banks of nodular appearance with calpionellids.

Geological and paleontological evaluation

The Jurassic heritage of the areas considered in this work is of great interest from many points of view. Firstly, the exceptional conditions in which the outcrops are exposed, free of tectonic disturbance to complicate their study, to which must be added the outstanding value of the landscape. For this reason the areas have been the sites of many geological studies since the earliest part of the twentieth century. Furthermore, several formations have been formally defined from the Jurassic materials found in the Quípar and Corque-Lúgar areas: the Tollo Fm. (Van Veen 1966) and the Maimon Fm. (Geel 1973), for example.

Of special interest is the rich paleontological heritage represented by these condensed materials in Ammonitico Rosso facies, especially of some fossil groups such as ammonites, as well as of other marine invertebrates including belemnites, bivalves, brachiopods or crinoids. In some levels, like those, which appear in the concentrations linked to the Lower/Middle Jurassic and Middle/Upper Jurassic, they show exceptional states of preservation with shell epigenized or neomorphised to ferric minerals.

The fossil concentrations and Fe-Mn concretions associated with the stratigraphic discontinuities, which have been deteriorated in many cases through the action of collectors, favour taphonomic studies (Sandoval & Checa 2001; Checa & Sandoval 2002).

The heritage value of the Sierra de Ricote lies in its good outcrop and stratification conditions, which have provided excellent biochronological results. In this area the Ricote Fm. has been defined and the reference parastratotype of the Radiolaritic Jarropa Fm. has been proposed. The Cerro Mahoma and Casa Chimeneas sections are references for the biostratigraphy of the Toarcian/Aalenian and Lower/Upper Bajocian boundaries in the Betic Cordillera and in the domain of the Western Mediterranean. The fossil content of ammonites, radiolarians, calpionellids, etc. is of great stratigraphic, paleontological and paleobiogeographical interest. The holotypes and different paratypes of two ammonoids species, *Spiroceras ricotensis* (Linares & Sandoval 1978) and *Polyplectites psilacanthoides* (Sandoval 1983), and some paratypes of *Spinammatoceras schindewolfi* (Linares & Sandoval 1986) are found in the Middle Jurassic of the Casa Chimeneas section.

Sierra Espuña and, especially, the Malvariche section present privileged conditions for the study of the Jurassic in the Internal Zones of the Betic Cordillera. In this domain the records of Jurassic ammonite associations has been scarce, discontinuous and always restricted to the upper, non-metamorphic layers of the Malaguide Dominion. In the Malvariche section three levels (Middle Domerian: Argovianum Zone and Ragazzonii Subzone; Lower Callovian: Pátina Zone and Upper Kimmeridgian: Beckeri Zone) provide important biostratigraphic data in this Betic domain.

In addition, the fossils from the Middle Domerian age are well preserved with neomorphised shells, sometimes ferrouginised, and a high percentage of preserved body chambers. Ammonoids of smaller size usually form part of the nuclei of large ferruginous oncoids. The levels identified from the Lower Callovian and Upper Kimmeridgian show signs of taphonomic remobilization with numerous truncated ammonites and internal moulds alongside epigenized shells, which favours taphonomic studies.

Paleontological heritage management: the case of Community of Murcia

The Service of Historical Heritage of the Government of Murcia has prompted a general project for the definition and protection of the paleontological heritage of the province towards an adequate management and preservation of main paleontological values of the

region. Primary aims of this plan were: 1 - Defining the legal regulations needed for a proper study and protection of the paleontological heritage of the region. 2 - Producing a detailed inventory of fossil sites and collections. 3 - Such inventory should allow the establishment of a set of main priorities of action, and a list of major risks affecting the fossil sites. This would help defining realistic strategies for protection and research, in order to re-orient the activities of uncontrolled amateur collectors in a correct direction, and to support the professional work of paleontologists. 4 - Finally, to evaluate the available means as regards the proper storage and exhibition of paleontological collections.

In Spain, two laws are regulating the protection of paleontological sites. The first one is the Historical Heritage Law (1985) and the second one is that of the Conservation of Natural Spaces and Wild Flora and Fauna (1989). Even though the execution of these laws was transferred to the different Autonomous Communities, their development and application have not been suitably carried out. The legal framework for the preservation of paleontological heritage in the Autonomous Community of Murcia is still poorly developed. The only available legal feature so far is the so-called "Good of Cultural Interest". The fossil association of the Sierra de Quibas, a paleontological site from the Lower Pleistocene, was protected as Good of Cultural Interest by the Cultural Department in 1999 (Iniesta & Romero 2001). But this legal feature, created by the Historical Heritage Law is, however, of little use at a regional scale, so new guidelines are being produced by the Service of Historical Heritage towards an adequate management and preservation of main paleontological values of the region.

The realisation of the paleontological cartography is the first step in evaluating the wealth and the distribution of the sites to be protected. At present the "Paleontological Map of the province of Murcia" is being updated. A detailed file card has been produced to record precise site information, namely: geographical and geological description of site, fossil content, research data and evaluation criteria for each fossil site. The paleontological interest has been established and defined on the basis of groups of criteria scientific, socio-cultural and socio-economic. Which to filter and evaluate paleontological sites uses this heritage evaluation to quantify the potential importance of an individual site or at least provide rigorous objective standards. At the same time, a computerised database has been established for the fossils from Murcia, which are in the collections of the different museums.

Contrary to what occurs in others Autonomous Communities, in Murcia there is a paleontologist employed in the administrative department in charge with the preservation of paleontological heritage. Since 1995, the Community of Murcia has financed several research projects of localities and their fossils. It has executed the protection of paleontological sites (control of private and public works, reserves, etc.) and it has financed specific research projects for the study of conservation of the paleontological heritage. For example, in Jumilla (N Murcia) were founded well-preserved tracks of mammals in the Upper Miocene sediments. First was the excavation, second the restoration and protection, after the study and the end the environmental reconstruction. At present a protective hall covers the mammals tracks and this palaeontological site is specially prepared to receive visitors and to have guided tours. In this case, the Cultural Department and City council of Jumilla have supported the project. The purpose of this model of promotion of paleontological heritage is to protect the patrimony and to get economic resources from tourism attracted by it.

On the other hand, this year there will be three exhibitions about paleontology. In Torre Pacheco with fossil remains from Neanderthals, in Murcia capital where there will be a large exposition with paleontologic material from Murcia and other parts of the world, in Los Garres with fossil remains from invertebrates of the Jurassic and Cretaceous.

Finally, private cultural organisations and amateur associations in order to spread the paleontology among the population are developing an important didactical and social work.

Conclusions

The paleontological interest of the areas described is unquestionable for understanding the Jurassic in the Betic Cordillera and even the Western Mediterranean Domain. The destruction of these outcrops due to the opening up of quarries and roads, forestation works, not to mention the uncontrolled search for fossils, means that they must be protected and brought under legal control. We strongly propose their inclusion in the "Paleontological Map" which is at present being drawn up and the application of paleontological protection measures according to the legal framework prevailing in the province of Murcia.

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REFERENCES

Alleman F., Grün W. & Wiedmann J. (1975) - The Berriasian of Caravaca (Prov. Murcia) in the Subbetic Zone of Spain and its importance for the defining this stage and the Jurassic-Cretaceous boundary. *Mém. B.R.G.M.*, 86: 14-22, Paris.

Almela A. & Ríos J.M. (1954) - Estudio geológico de la Sierra de Ricote en la región de Mula (Prov. de Murcia). *Bol. Inst. Geol. Min. Esp.*, 68: 45-83, Madrid.

Ayala V., Hernández-Bravo J.A. & Sandoval J. 1988. Bioestratigrafía del Bajociense superior de las Sierras de Corque y Lúgar. Fortuna (Murcia). In: II Congr. Geol. España, Granada, Comunicaciones, 1: 257-260, Granada.

Azéma J. (1966) - Géologie des confins des provinces d'Alicante et de Murcia (Espagne). *Bull. Soc. géol. France*, 7 (8) : 80-86, Paris.

Azéma J. (1971) - Le Jurassique dans la partie orientale de Zones Externes des Cordilleres Bétiques: Le Prebetique de Cieza a Alicante. *Cuad. Geol. Ibérica*, 2: 111-124, Madrid.

Azéma J., Champetier Y., Foucault A., Fourcade E. & Paquet J. (1971) - Le Jurassique dans la partie orientale des Zones Externes des Cordilleres Bétiques: Essai de Coordination. *Cuad. Geol. Ibérica*, 2: 91-110, Madrid.

Barthel K.W., Cediel F., Geyer O.F. & Remane J. (1966) - Der subbetische Jura von Cehegín (Provinz Murcia, Spanien). *Mitt. Bayer. Staatsslg. Paläont. Hist. Geol.*, 6: 167-211, München.

Baumgartner P.O. (1987) - Age and genesis of the of Tethyan Jurassic Radiolarites. *Eclogae Geol. Helv.*, 80: 831-879, Basel.

Caracuel J.E. (1996) - Asociaciones de megainvertebrados, evolución ecosedimentarias e interpretaciones ecoestratigráficas en umbrales epioceánicos del Tethys Occidental (Jurásico Superior). Tesis Univ. Granada: 500 pp, Granada.

Caracuel J. E., Olóriz F. & Rodríguez-Tovar F. J. (1999) - Ammonite biostratigraphy from the Planula and Platinota Zones in the Lúgar Section (External Subbetic, Southern Spain). *Profil*, 16: 107-120, Stuttgart.

Caracuel J.E., Olóriz F. & Rodríguez-Tovar F.J. (2000) - Oxfordian biostratigraphy of the Lúgar Section (External Subbetic, Southern Spain). *Geo-Research Forum*, 6: 55-64, Zurich.

Caracuel J. E., Sandoval J., Martín-Martín Estévez, A. & M., Martín-Rojas I. (2001) - Datos preliminares del Jurásico del perfil de Malvariche (Complejo Malaguide: Zonas Internas Bética). *Publicaciones del Seminario de Paleontología de Zaragoza*, 5: 271-277, Zaragoza.

Checa A. & Sequeiros L. (1990) - New data on the lower Oxfordian from the Subbetic Zone (Betic Range, SE Spain). In: 1st Oxf. Meet., SEPAZ, 2: 153-160, Zaragoza.

Colom G. (1966) - Sur l'interprétation des sédiments profonds de la zone géosynclinale basléare et subbétiqiue. *Palaeogeog., Palaeoclimatol., Palaeoecol.*, 3: 299-310, Amsterdam.

Enay R. & Geysant J.R. (1975) - Faunes Tithoniques dés chaînes Bétiques (Espagne méridionale). *Mém. BRGM.*, 86: 39-55, Orléans.

Fallot P. (1931-34) - Essais sur la répartition des terrains secondaires et tertiaires dans la domaine des Alpides espagnoles (Lías, Dogger, Jurassique supérieur). Géol. Médit. Occid., Imprenta Béranger, Liège, 4, ½: 118pp., Liège.

Fallot P. (1945) - Estudio Geológico de la Zona Subbética entre Alicante y el Rio Guadiana. *Mem. Inst. Invest. Geol. Lucas Mallada*, 5: 719 pp., Madrid

García-Gómez R., Jiménez A.P., Linares A., Rivas P. & Sandoval J. (1994) - The Toarcian Aalenian boundary in the Betic Cordillera (southern Spain). *Geobios*, Mém. sp. 17: 211-222, Lyon.

Geel T. (1973) - The geology of the Betic of Malaga, the Subbetic and the Zone between these two units. The Velez-Rubio area (Southern Spain). *GUA Papers Geol.*, 5: 131 pp.

Geyer O. F. & Hinkelbein K. (1971) - Eisenoolithische Kondensations-Horizonte im Lías der Sierra de Espuña (Provinz Murcia, Spanien). *N. Jb. Geol. Paläont. Mh.*: 398-414, Stuttgart.

Geyer O. F. & Hinkelbein K. (1974) - Las Oolitas ferruginosas del Jurásico de la sierra de Espuña (prov. de Murcia). *Acta Geológica Hispánica*, t. IX-3: 102-106, Barcelona.

Iniesta A. & Romero G. (2001) - Problemática actual de la legislación sobre Patrimonio Paleontológico en la Región de Murcia: el yacimiento de Quibas como Bien de Interés Cultural. *Libro de Resúmenes de las XVII Jornadas de la SEP*, Albarracín.

Kampchuur W., Langerberg C.W., Baena J., Velando F., García-Monzón F., Paquet J. & Rondeel H.E. (1974) - Mapa y Memoria Explicativa del Mapa Geológico de España 1/50000, Hoja de Coy (932). I.G.M.E: 1-32, Madrid.

Linares A. & Sandoval J., (1978) - Contribución al estudio del Bajocense de la Sierra de Ricote (Murcia). *Cuadernos de Geología*, Universidad de Granada, 8: 277-312, Granada.

Linares A. & Sandoval J. (1986) - *Malladaites* nov. gen. et *Spinammatoceras* (Hammatoceratidae, Ammonitina) de l'Aalénien de la Zone Subbétique, Sud de l'Espagne. *Geobios*, 19: 207-224, Lyon.

Linares A. & Sandoval J. (1993) - El Aaleniense de la Cordillera Bética (Sur de España): Análisis bioestratigráfico y caracterización paleobiogeográfica. *Rev. Sociedad Geol. España*, 6: 177-206, Madrid.

Mancheño M. A. & Romero G. (2000) - Patrimonio Paleontológico de Murcia. Marco legal y líneas de actuación. *Geotemas*, 1 (2): 313-316, Alicante.

Mangold C. (1979) - Le Bathonien de l'est du Subbétique (Espagne du Sud). *Cuadernos de Geología*, Universidad de Granada, 10: 271-281, Granada.

Martín-Martín M. & Martín-Algarra A. (1997) - La estructura del área de Sierra Espuña (Contacto Zonas Internas-Externas, sector oriental de la Cordillera Bética). *Est. Geol.*, 53: 237-248, Madrid.

Navarro A. & Trigueros E. (1963) - Estudio Geológico del Borde Oriental de la Sierra Espuña. *Not y Com. I.G.M.E.*, 70: 205-210, Madrid.

Nieto L. M. (1997) - La cuenca Subbética mesozoica en el sector oriental de las Cordilleras Béticas. Tesis doctoral. Servicio de Publicaciones, Universidad de Murcia: 562 pp., Murcia.

O'Dogherty L., Sandoval J., Martín-Algarra A. & Baumgartner P.O, (1989 a) - Las facies con radiolarios del Jurásico Subbético (Cordillera Bética, Sur de España). *Mém. De Géologie* (Lausanne), 23: 717-724, Lausanne.

O'Dogherty L., Baumgartner P.O, Sandoval J., Martín-Algarra A. & Pilelvuit A. (1989 b) - Middle and Upper Jurassic radiolarian assemblages co-occurring with ammonites from the Subbetic Realm (Southern Spain). *Rev. Soc. Mex. Paleont.*, 2: 70-77, Mexico D.F.

O'Dogherty L., Molina J.M., Ruíz-Ortíz P.A., Sandoval J., & Vera J.A., (1997) - La Formación Radiolarítica Jarropa: definición y significado en el Jurásico subbético. *Estudios Geol.*, 53: 145-157, Madrid.

O'Dogherty L., Nieto L. & Sandoval J. (2001) - Depósitos de brechas intraformacionales y slumps en el Jurásico Medio del Subbético Medio (Sierra de Ricote, provincia de Murcia). In: Molina, J. M. et al. (eds.) XVI Congreso Nacional de Sedimentología, IV Coloquio del Cretácico de España. *Geotemas* 3 (1): 249-253, Jaén.

Osete C., Osete M. L., & Sandoval J. (2000) - Estudio magnetoestratigráfico del Jurásico Inferior-Medio en las Cordilleras Béticas. In: 2ª Asamblea Hispano Portuguesa de Geodesia y Geofísica, Lagos 2000: 1-2, Lagos.

Paquet J. (1969) - Etude géologique de l'Ouest de la Province de Murcie (Espagne). *Mém. Soc. géol. France*, 3: 1-270, Paris.

Peyre N. & Peyre Y. (1960) - Observaciones Geológicas Sobre Sierra Espuña. *Notas y comunicados del IGME, 59: 3-22, Madrid.*

Rey J. (1993) - Análisis de la Cuenca Subbética durante el Jurásico y el Cretácico en la transversal Caravaca Velez-Rubio. Tesis Univ. Granada: 460 pp., Granada.

Rey J. (1995) - Sedimentation answers to local tectonic events in pelagic swell (Subbetic Zone, province of Murcia, Spain). *Bull. Soc. géol. France*, 166: 479-492, Paris.

Ríos J.M. & Almela A. (1953) - Analogies entre las séries stratigraphiques de la Sierra de Ricote(Espagne) et de l'Apennin septentrional. *Bull. Soc. géol. France*, 6: 767-774, Paris.

Sandoval J. (1983) - Biostratigrafía y Paleontología (Stephanocerataceae y Perisphinctaceae) del Bajocense y Bathonense en las Cordilleras Béticas. Tesis Univ. Granada, 2 vols.: 613 pp., Granada.

Sandoval J. (1986) - Middle Jurassic Haploceratidae (Ammonitina) from the Subbetic Zone (South Spain). *Geobios*, 19: 435-463, Lyon.

Sandoval J. (1990) - A revision of the Bajocian divisions in the Subbetic Domain (Southern Spain). In: Cresta, S., and Pavia, G., (eds) Proceeding Meeting on Bajocian Stratigraphy. *Memorie descrittive Carta geologica d'Italia*, 40: 141-162, Roma.

Sandoval J. (1998) - The Bajocian-Bathonian boundary in the Subbetic Domain, Betic Cordillera (southern Spain): a typical Mediterranean domain. In: 5th International Syposium on the Jurassic System (Abstract and Program). Intern. Union. Geol. Sc.: p. 80, Vancouver.

Sandoval J &. Checa A. (2001) - Concentraciones de cefalópodos ligadas a interrupciones sedimentarias en el Jurásico subbético (Sur de España). In: XVII Jornadas de la Sociedad Española de Paleontología: Los Fósiles y la Paleogeografía. *Publ. Sem. Paleont. Zaragoza*, 5, 2: 464-472, Zaragoza.

Sandoval J., Henriques M. H., Ureta M. S., Goy A. & Rivas P. (2001) - The Lías/Dogger boundary in Iberia: Betic and Iberian cordilleras and Lusitanian basin. *Bull. Soc. géol. France*, 172: 387-395, Paris.

Seyfried H. (1978) - Der Subbetische Jura von Murcia (Südost-Spanien). *Geol. Jahrb.*, 29: 201 pp., Hannover.

Seyfried H. (1981) - Genesis of "regressive" and "transgressive" pelagic sequences in the Tethyan Jurassic. In: Farinacci, A. & Elmi, S. (eds.). Proc. Rosso Ammonitico Symp.: 547-579, Tecnoscienza, Rome.

Tavera J.M. (1985) - Los ammonites del Tithonico superior-Berriasense de la Zona Subbética (Cordilleras Béticas). Tesis Univ. Granada: 381 pp., Granada.

Van Veen G.W. (1966) - Note on a Jurassic-Cretaceous section in the Subbetic SW of Caravaca (prov. of Murcia, Spain). *Geol. Mijnb.*, 45: 391-397, Amsterdam.

Van Veen G.W. (1969) - Geological investigation in the region west of Caravaca, South-Eastern Spain. Thesis Univ. Amsterdam: 143 pp., Amsterdam.