USING CONODONTS TO CORRELATE ABIOTIC EVENTS: AN EXAMPLE FROM THE LOCHKOVIAN (EARLY DEVONIAN) OF NE SPAIN

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Valenzuela-Ríos, J.I. and García López, S. 1998. Using conodonts to correlate abiotic events: an example from the Lochkovian (Early Devonian) of NE Spain. *In:* H. Szaniawski (ed.), Proceedings of the Sixth European Conodont Symposium (ECOS VI). — *Palaeontologia Polonica* **58**, 191–199.

A sharp lithologic and color change of dark siliciclastic to clear carbonates coinciding with the first occurrence of the conodont genus *Ancyrodelloides* (Lochkovian) is observed in five pelagic sections belonging to two different sedimentary basins in northeastern Spain. Comparison and correlation of the conodont sequences from these sections suggest that these changes were not simultaneous. Consequently, we suggest that the use of color changes in pelagic sequences as indicators of supraregional events (e.g., T-R cycles) should be verified by other time-significant methods or data.

Key words: Conodonta, correlation, events, Devonian, Lochkovian, Spanish Central Pyrenees, Catalonian Coastal Ranges, Spain.

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Received 15 February 1997, accepted 9 August 1997

INTRODUCTION

Two important contributions of paleontological studies to geological research are the accurate description of the fossil sequences contained in carefully measured sections and the subsequent correlation of these sequences among distant areas. Dearth of such paleontological studies for the Lower Devonian of northeastern Spain (Spanish Central Pyrenees – SCP, and Catalonian Coastal Ranges – CCR) has impeded reconstruction of the geological history for this area and its comparison with neighboring areas, especially with the Iberian Chains and the Cantabrian Mountains.

BOERSMA's (1973b) initial attempt of a paleogeographic reconstruction for the Early Devonian of the Pyrenees and its correlation with other areas in northern Spain was based only on doubtful lithostratigraphic correlations. Even though BOERSMA (1973b: p. 335) stated that his reconstruction was "fairly speculative", the results have remained untested. Because of this, and because of lack of biostratigraphic control, the lower Devonian relations of the Pyrenean basins have still remained unresolved.

During the Lochkovian, pelagic environments were dominant in both SCP and CCR areas. Reliable biostratigraphic analyses of Lower Devonian pelagic rocks require detailed micropaleontological studies. In this case, the conodonts are the most abundant fossils providing the highest resolution in subdividing and correlating stratigraphic sequences.

The main purpose of this paper is to establish an initial correlation between comparable conodont sequences and lithostratigraphic units for the Lower Devonian of northeastern Spain and to describe and date by means of conodonts the sharp color and lithologic change observed in both areas. Based on our paleontological results, we question the direct use of color changes in pelagic sequences as indicators of global events.

All material from the Pyrenees is deposited at Museum of Paleontology, University of Zaragoza (MPZ numbers); the material from the Catalonian Coastal Ranges is housed at Departament of Paleontology, University of Oviedo (DPO numbers).

Acknowledgments. — The Alexander von Humboldt Foundation supported research of J.I.V.R. Spanish Grant DGE-95-PB 1047 funded research of S.G.L. We are grateful to Prof. Emeritus Michael A. MURPHY (University of California) for reading and commenting supportively on the manuscript. Prof. Dr. Jenaro GARCÍA-ALCALDE (Universidad de Oviedo) provided constructive comments on this paper. Dr. Javier SANZ-LOPEZ (Universidad de La Coruña) provided helpful information on his unpublished collections and sections. This paper had the benefit of critical review by Prof. Dr. Ruth MAWSON (Macquarie University). Herr H. STOSNACH (Geowissenschaften, T.U. Braunschweig) kindly printed the negatives of the figures documented here.

PREVIOUS WORK IN THE SPANISH CENTRAL PYRENEES (SCP)

Studies of Devonian rocks in the Pyrenees were started in the last century by MALLADA (1878) who described and mapped numerous outcrops in the Aragonian Pyrenees. Subsequently, DALLONI (1910, 1930) and SCHMIDT (1931) published many faunal lists and ennumerated diverse outcrops. These initial works were mostly geological surveys. Later on, during the 1960's and early 1970's, members of the geological team of Leiden headed by DE SITTER published geological maps and numerous papers on Devonian stratigraphy (MEY 1967a, b, 1968; HARTEVELT 1970; HABERMEHL 1970). In the same time, DE VILLALTA and ROSELL (1969) established the stratigraphic framework for the Lower Devonian of the Noguera Pallaresa Valley, and, slightly later, BOERSMA (1973b) provided initial dating and correlation for Pyrenean sequences, especially for the Upper Devonian.

Prior to VALENZUELA-RÍOS (1990), who detailed the Lochkovian conodont sequence in Gerri de la Sal (Noguera Pallaresa Valley) and reported a change from anaerobic to aerobic conditions near the base of the former *Ancyrodelloides delta* Zone (approximately coincident with the base of the *Ancyrodelloides* part, see below), only a few works dealing with Lower Devonian conodonts from the SCP were published. BOERSMA described the species *Ozarkodina carlsi* and *Polygnathus pireneae* (1973a) and listed several species of *Icriodus, Ozarkodina*, and *Polygnathus* from Lower Devonian sections in the Spanish Pyrenees (1973b). Based on his lists of fossil, he recognized the informal Lochkovian biostratigraphic units of ZIEGLER (1971): *Icriodus postwoschmidti* Fauna and *Ancyrodelloides–Icriodus pesavis* Fauna. Later on, VALENZUELA-RÍOS

(1991a, b, 1994a) established a local conodont zonation for the Lochkovian of the SCP, and VALENZUELA-RÍOS (1994b) and VALENZUELA-RÍOS and MURPHY (1994, 1997) proposed a detailed intercontinental correlation of the Pyrenean faunas with similar faunas of Western North America, mainly from Central Nevada.

PREVIOUS WORK IN THE CATALONIAN COASTAL RANGES (CCR)

The Devonian of the CCR is composed of numerous small outcrops that were first studied by ALMERA (1891) and BARROIS (1893). These authors established the stratigraphic sequence noting the presence of "Gedinnian" and "Siegenian" rocks. During the 1960's and early 1970's, four papers of interest appeared: GREILING and PUSCHMANN (1965) who mentioned Silurian and "Gedinnian" graptolites from Santa Creu d'Olorda; ALBERTI (1970) who cited "Gedinnian" dacryoconarids; and two reports by PUSCHMANN (1968a, b) where Famennian conodonts in other CCR outcrops were identified.

More detailed knowledge was acquired in mid-80's when JULIVERT *et al.* (1985) established the stratigraphy and general graptolite-biostratigraphy of the Silurian and Lower Devonian of the area. JULIVERT *et al.* (1986) and JULIVERT *et al.* (1987) detailed the pre-Carboniferous stratigraphic sequence, formally defined Silurian and Lower Devonian lithostratigraphic units and presented new data on Lochkovian and Pragian conodonts and dacryoconarids.

In the most complete work to date, that included details on structural geology, facies and biostratigraphy of Silurian and Lower Devonian rocks, GARCÍA-LÓPEZ *et al.* 1990 used conodonts and dacryoconarids to recognize an interval spanning from approximately the Silurian/Devonian boundary to the Emsian (*Polygnathus inversus/P. laticostatus* Zone). They noticed an anoxic interval, corresponding lithologically to Member A of the Olorda Formation (Lochkovian).

MATERIAL AND METHODS

The material stems from five sections in northeastern Spain, three (Gerri 1.1, Gerri 1.2 and Segre 1) in the SCP and two (C, Escama III and D, Escama IV at Santa Creu d'Olorda) in the CCR (Figs 1, 2). Detailed descriptions of lithostratigraphic and paleontologic data have already been presented in VALENZUELA-RÍOS (1990, 1994a) and VALENZUELA-RÍOS and MURPHY (1997) for the Pyrenean sections and in GARCÍA-LÓPEZ *et al.* (1990) for the Catalonian sections. The biostratigraphic subdivision used here was discussed by VALENZUELA-RÍOS and MURPHY (1994, 1997). The Lochkovian was subdivided into three parts on the basis of the genus *Ancyrodelloides*: lower (= pre-*Ancyrodelloides* part); middle (= *Ancyrodelloides* part) and upper (= post-*Ancyrodelloides* part). VALENZUELA-RÍOS (1994a) subdivided the middle Lochkovian into four parts ("intervals") defined by the successive occurrence of *Ancyrodelloides* species including, in ascendent order: *A. omus, A. transitans, A. trigonicus*, and *A. kutscheri*. The datums used here for biostratigraphical correlations correspond to species of the genera *Ancyrodelloides* and *Flajsella*. The studied sequence comprises the *A. omus*, *A. transitans*, and lower part of *A. trigonicus* intervals.

BIOSTRATIGRAPHIC CORRELATION

The origin of *Ancyrodelloides transitans* is unknown; however, this taxon occurs in more or less the same stratigraphic position (between the last occurence of *A. omus* and the first occurrence of *Flajsella*) in various areas including Alaska, Nevada, Carnic Alps and the Pyrenees. The first occurrence of this taxon in the section Gerri 1.1 is in Bed 16d, and in Segre 1 in Bed 11 (Fig. 2). In section Gerri 1.2, the joint occurrence with its descendent, *A. trigonicus*, in Bed 6g suggests that *A. transitans* should occur also earlier in this section, but such occurence has not been found yet. In section C, Escama III, Bed 44 (CCR) the co-occurrence of *A. transitans* (Pl. 1: 6) and *F. schulzei* (Pl. 1: 1a, b, 4) is anomalous. But because yields in CCR are low, it is uncertain if the CCR data indeed represent the true range of the species.

The first occurrence of *A. trigonicus* is considered by VALENZUELA-RÍOS and MURPHY (1997) as an evolutionary event that can be documented in sections in western North America, Spain, and the Carnic Alps. In the SCP, the first occurrence of this species is in Bed 17e in section Gerri 1.1, Bed 6g at Gerri

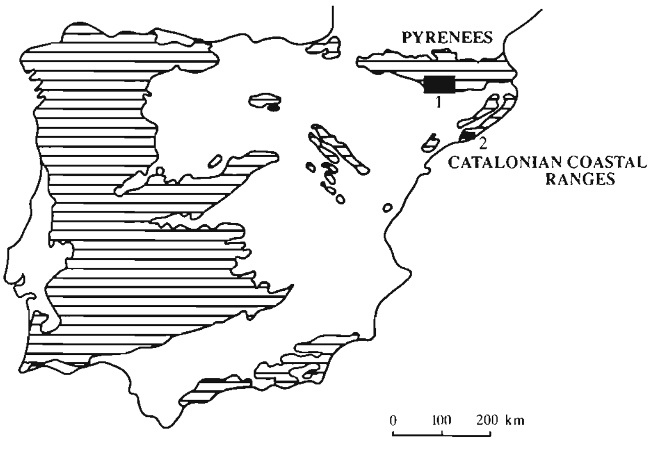

Fig. 1
Map of the Iberian Peninsula showing distribution of Paleozoic rocks (horizontal lines); black squares represent the two areas studied here. 1 – Spanish Central Pyrenees (sections Gerri 1.1, Gerri 1.2 and Segre 1); 2 – Catalonian Coastal Ranges (section C, Escama III and section D, Escama IV). Precise location of these sections can be found in VALENZUELA-RÍOS 1994a for SCP sections and in GARCÍA-LÓPEZ *et al.* 1990 for the CCR sections.

1.2, and Bed 14a in Segre 1. Since the phylogenetic history of this taxon is known, its first occurrence provides an excellent time-marker for correlation purposes, and it serves to trace the base of the *A. trigonicus* interval (VALENZUELA-RÍOS 1994a) at Gerri 1.1 and Segre 1. The record of *Ancyrodelloides* spp. in Gerri 1.2 section is incomplete. In CCR, a specimen transitional between *A. transitans* and *A. trigonicus* was recovered from Bed 51 of section C, Escama III (GARCÍA-LÓPEZ *et al.* 1990: pl. 1: 17, 18, reillustrated here, Pl. 1: 7a, b) suggesting that the entry of *A. trigonicus* is close to this bed.

F. schulzei and *F. stygia* VALENZUELA-RÍOS *et* MURPHY, 1997 are present in both regions. The co-occurrence of *Flajsella* and *A. transitans* in Bed 44, section Escama III in CCR, corresponds to the overlapping range of these two taxa in the upper part of the *A. transitans* interval, below the first appearance of *A. trigonicus*.

Because *F. schulzei* appears earlier than *F. stygia* in the Nevadian and Pyrenean sections (VALENZUELA-RÍOS and MURPHY 1997) as well as in the Alpine sections (SCHÖNLAUB 1980), their association in Bed 44, section C, Escama III (CCR) indicates that *F. schulzei* should occur below this bed. The co-occurrence of these two species is tentatively aligned with Bed 17c in section Gerri 1.1 (SCP) where they are found together with *A. transitans* below the first occurrence of *A. trigonicus*. The latter probably does not occur in the CCR, section C, Escama III below Bed 51.

Another taxon that refines this correlation corresponds to the late forms of *A. eleanorae* (= *A. omus* GARCÍA-LÓPEZ *et al.* 1990: pl. 1: 11–14, partially re-illustrated here, Pl. 1: 11a, b; VALENZUELA-RÍOS 1994a: pl. 4: 10–12, 14–16; and Pl. 1: 3 here) that occurs slightly higher than the first *Flajsella* and below *A. trigonicus* in the northeastern Spanish sections.

In terms of lithologic equivalence, the base of lithosome "B" in SCP (VALENZUELA-RÍOS 1994a) is correlated with the base of Member B of the Olorda Fm. in CCR. This correlation is based on the comparable color (black to clear colors) and lithologic changes (from siliciclastic to carbonate rocks) that are observed in both regions and that, as will be shown below, are only slightly diachronous.

FACIES CHANGE: A DIACHRONOUS EVENT NEAR THE BEGINNING OF THE MIDDLE LOCHKOVIAN

In the SCP and in the CCR, a sharp lithologic change occurs in the lower part of the Lockhovian. The lithologic change is accompanied by a remarkable color change, from black to light colored sediments, noted already by VALENZUELA-RÍOS (1990, 1994a) in the SCP and by GARCÍA-LÓPEZ *et al.* (1990) in the CCR. In the SCP, the fossil record allows the recognition of a faunal change as well.

The lower Lochkovian sediments in the SCP are composed of black shales with a few interbeds of black limestones. This facies is better represented in section Gerri 1.1 (Fig. 2), where the lower boundary of the Devonian System is correlated with Bed 1 (VALENZUELA-RÍOS 1990, 1994a). In Gerri 1.1, the lower Lochkovian is composed of, at least, 12 m of black shales with two limestone beds (10, 11) and three nodular levels (6a, b, c) that have yielded important conodonts (VALENZUELA-RÍOS 1990, 1991b, 1994a) and small bivalves, orthoceratids, ostracods, and fish. The middle Lochkovian is first recognized in a 15 cm thick orange limestone bed containing the first occurrence of *Ancyrodelloides*. Upward from this level, the lithologic sequence is composed of well bedded orange and yellow limestones with centimetre intercalations of red-orange marls.

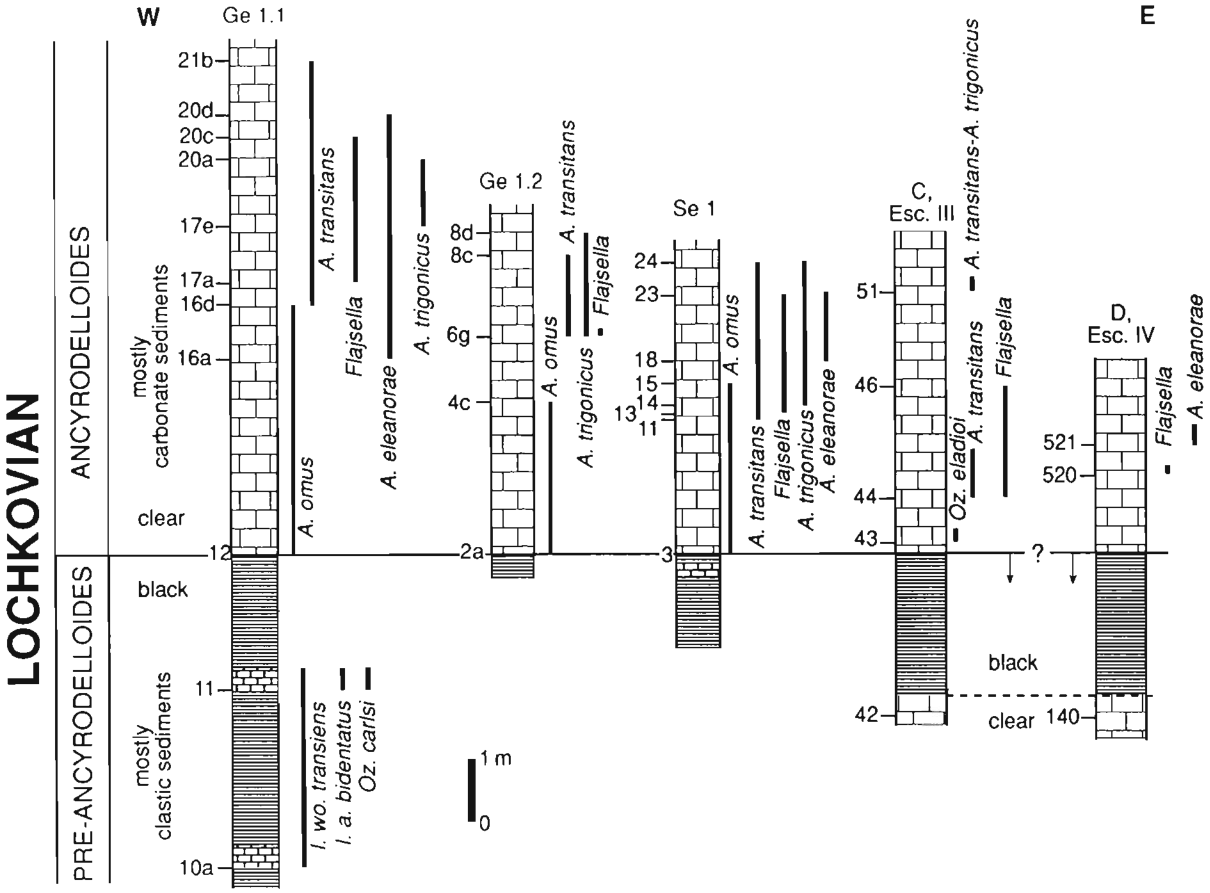

Fig. 2
Correlation of relevant taxa from SCP (Gerri 1.1 = Ge 1.1; Gerri 1.2 = Ge 1.2; Segre 1 = Se 1) and CCR (C, Escama III; D, Escama IV) sections. The upper boundary of black to light-colored sediments in the CCR sections does not coincide with the Pre-*Ancyrodelloides–Ancyrodelloides* limit. This fact is indicated in the figure with two arrows pointing downwards and by the question mark sign(?). Late forms of *A. eleanorae* in section Gerri 1.1 appear in the upper part of Bed 17a, a few centimetres above the occurrence of the first *Flajsella*. Only partial stratigraphic columns and ranges of relevant taxa have been illustred herein; full stratigraphic columns and complete conodont distributions can be found in VALENZUELA-RIOS 1994a for SCP sections and in GARCÍA-LÓPEZ *et al.* 1990 for CCR sections. Numbers left of the stratigraphic columns indicate first and last occurrences of the taxa.

In the other two Pyrenean sections, the lithologic change from black to light colored deposits coincides with the first appearance of *Ancyrodelloides*. These sections represent only the uppermost lower Lochkovian (2 m in section Gerri 1.2 and 2.4 m in Segre 1), which is composed of black shales with some thin interbedded limestone beds and nodular levels. Below the boundary event, diagnostic fauna is lacking and does not allow precise correlation.

This local event is marked by significant biological changes as well. The more endemic faunas including species of *Icriodus*, which survived and flourished in neighboring regions (Guadarrama, Iberian Chain, see CARLS 1969, 1975, 1987; CARLS and GANDL 1969), disappeared and were replaced by a cosmopolitan fauna including *Ancyrodelloides*. This faunal change is better documented in section Gerri 1.1, where the black colored sediments below Bed 12 (Fig. 2) contain the following sequence: (1) lobolites of *Scyphocrinites* and the conodont *Icriodus woschmidti woschmidti* in Bed 1; (2) *I. wo. transiens*, which is phylogenetically connected to *I. wo. woschmidti* (CARLS and GANDL 1969), in Bed 10a; (3) numerous specimens of *Ozarkodina carlsi* and of *I. angustoides bidentatus* in Bed 11; and (4) the first appearance of *Ancyrodelloides* and disappearance of the endemic conodonts, that hand longer ranges in the Ibero-American region, in Bed 12. The endemic conodont faunal association below Bed 12, with taxa that are common in Ibero-Armorica, enabled an initial correlation of Beds 10a to 11 in the Pyrenean section Gerri 1.1 with the unit d1c γ of CARLS (1969, 1987) in the Iberian Chains and Guadarrama (VALENZUELA-RÍOS 1990, 1991b, 1994a).

In the CCR, a similar facies change is observed in two sections (C, Escama III and D, Escama IV) at Santa Creu d'Olorda (Figs 1, 2) where dominant fine-grained siliciclastic black deposits are overlain by mixed siliciclastic-carbonate deposits with abundant pelagic organisms. The black deposits indicate a short anoxic episode represented by about 3 m in section C of Escama III and section D of Escama IV. This thickness strongly contrasts with the minimum thickness (12 m) of the anoxic interval at Gerri 1.1. The conodont record suggests a shorter duration for this anoxic episode in the CCR than in the SCP: the Silurian/Devonian boundary at Santa Creu d'Olorda has been located in the upper beds of the thick massive calcareous Santa Creu Fm, Bed 54 of section D, Escama IV (GARCÍA-LÓPEZ *et al.* 1990: p. 149) whereas in this section the dark siliciclastic interval begins 5.1 m above Bed 54. By lithologic criteria, this level is correlated with a level located 7.9 m below the clear limestone-dark siliciclastic horizon in section C, Escama III. These data indicate that the anoxic interval in CCR begins within the lower Lochkovian (pre-*Ancyrodelloides*), later than in the Pyrenees.

Based on dating, the present data suggest that the upper boundary of this event is slightly diachronous. In the three Pyrenean sections, the lowest occurrence of the genus *Ancyrodelloides* is recorded in the first clear-colored limestone bed, just above the color change corresponding to the species *A. omus*, the oldest *Ancyrodelloides* (MURPHY *et* MATTI, 1983). Because the sequence of entries of *Ancyrodelloides* species in these three Pyrenean sections is consistent with stratigraphic occurrences in western North America and Alpine sections, we consider that the upper boundary of the anoxic event in the Pyrenean sections coincides with the base of the middle Lochkovian (*Ancyrodelloides* part). Given the lack of conodont-bearing beds in the parts of the sections Gerri 1.2 and Segre 1 that correspond to the anoxic episode, it might appear that the stratigraphic range of *A. omus* extends downwards and that the genus *Ancyrodelloides* could already have appeared during the episode. Exhaustive sampling of limestone beds in the black facies of section Gerri 1.1 has provided numerous specimens of *O. carlsi, I. angustoides bidentatus, I. woschmidti transiens, O. eladioi,* and *O. excavata* but none of *Ancyrodelloides*. Thus, we consider that, in these three sections, the first appearance of *Ancyrodelloides* took place inmediately after the end of the anoxic episode.

In the CCR, *F. schulzei, F. stygia*, and *A. transitans* are found in Bed DC44, section C, Escama III, 1 m above the end of the siliciclastic interval. This association characterizes the upper part of the *A. transitans* interval. Bed DC43, located 0.2 m above the color change, yielded *O. eladioi* with morphologic characteristics comparable to those exhibited by specimens of *O. eladioi* that occur in levels spanning the interval from the upper part of the *A. omus* to the lower part of the *A. transitans* interval in the Pyrenean sections. The 1 m between Bed DC44 and the top of the anaerobic episode doesn't seem to be sufficient to span the lower part of the *A. transitans* interval and the whole *A. omus* interval. Conodont data from this segment of the section are scarce and the first appearance of *Ancyrodelloides* cannot be determined in this section. In DC43, *A. omus* may have occured earlier than the beginning of the aerobic interval. In brief, these conodont data are not sufficient to confirm wether or not *Ancyrodelloides* appeared first above or below of the abrupt lithologic change in the CCR.

SANZ-LOPEZ (personal communication, 1996) found *Ancyrodelloides* sp. within black levels in other areas of the CCR. Because correlation between his sections and the sections studied here has not been established yet, the facies time-equivalence cannot be determined here. Nevertheless, his records agree with our opinion that the color changes in the pelagic facies of northeastern Spain do not result from a supraregional synchronic event.

DISCUSSION OF RESULTS AND CONCLUSIONS

The presence of common taxa in the same stratigraphic position in five sections of the SCP and CCR permits us, for the first time, to establish a detailed correlation between the two areas for most of the middle Lochkovian. The cosmopolitan character of these taxa allows comparison of the five sequences with the sequences in western North America (Alaska and, especially, Nevada) and Carnic Alps, and therefore, reinforces and validates the middle Lochkovian correlation.

The coincidence in facies and stratigraphic position of faunas in the two regions provides the base for future paleogeographic studies and palynspastic reconstructions of the Lower Devonian in northeast Spain. The marked change in facies and faunas around the times of the first appearance of the genus *Ancyrodelloides* in northeastern Spain is diachronous and it is interpreted as a local event. This fact challenges the general opinion that sharp color and lithologic changes in pelagic sequences are expressions of global events, and cautions against the direct correlation of such changes to global sea-level fluctuations. The results prove that fossils are useful tools in unravelling the physical history of the earth, and show the importance of the contribution of paleontological studies to modern concepts in geological sciences. Without the information that can be provided by the fossil record, erroneous assumptions on global events could be promulgated.

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PLATE 1

Flajsella schulzei VALENZUELA-RÍOS *et* MURPHY, 1997

1. Specimen DPO114153. 1a upper view, 1b lateral view. Section C, Escama III, Bed DC-44; × 110.
2. Specimen MPZ8372/1 in lateral view. Gerri 1.1, Bed 17c; × 80.

Ancyrodelloides eleanorae (LANE *et* ORMISTON, 1979)

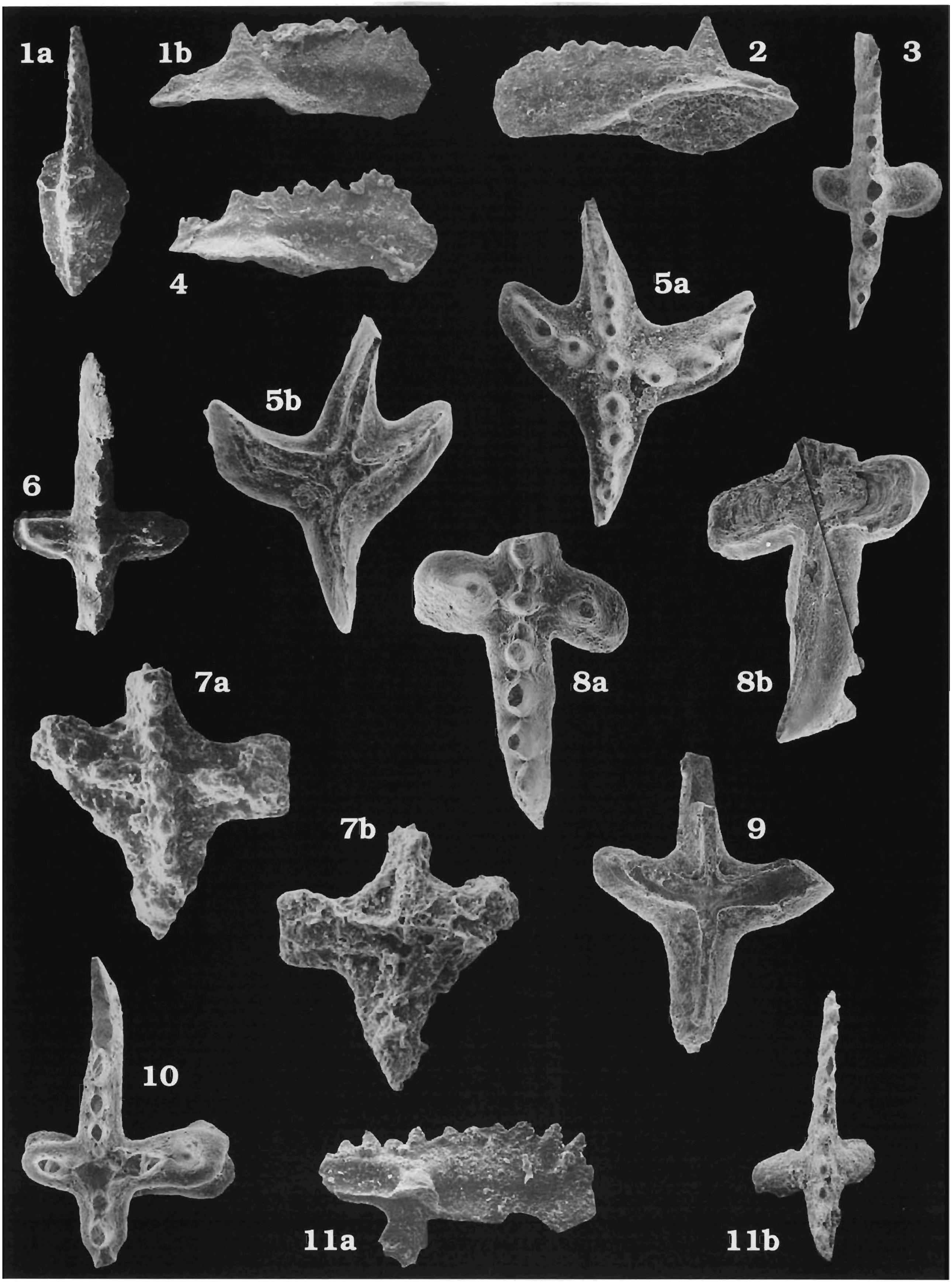
3. Specimen MPZ8247; upper view. Gerri 1.1, Bed 16c; × 45.
11. *A. eleanorae* (LANE *et* ORMISTON, 1979) late form, DPO114158; section D, Escama IV, Bed DC-521. 11a lateral view; 11b upper view, × 90.

F. stygia VALENZUELA-RÍOS *et* MURPHY, 1997

4. Specimen DPO114154. Section C, Escama III, Bed DC-44, × 112.

A. transitans (BISCHOFF *et* SANNEMANN, 1958)

5. Specimen transitional to *A. trigonicus* (BISCHOFF *et* SANNEMANN, 1958), MPZ8290; Gerri 1.1, Bed 19a. 5a upper view; 5b lower view, × 54.
6. Specimen DPO114159; upper view. Section C, Escama III, Bed DC-44, × 90.
7. Specimen transitional to *A. trigonicus* (BISCHOFF *et* SANNEMANN, 1958), DPO114160; Escama III, Bed DC-51. *7a* upper view; *7b* lower view, × 90.
8. Specimen MPZ8268/1, Gerri 1.1, Bed 17a. *8a* upper view × 50; *8b* lower view × 55.
9. Specimen MPZ8278/1; Gerri 1.1, Bed 20e; lower view, × 60.
10. Specimen MPZ8268/2; Gerri 1.1, Bed 17a; upper view, × 60.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