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SHORT COMMUNICATION

The Frasnian Upper Kellwasser event and a lower Famennian stratigraphic gap in Calabria (southern Italy)

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Abstract The identification of three late Frasnian conodont biozones (MN 11–12 and 13, as defined in the Montagne Noire, France) and of several Famennian conodont biozones (Early, Late, and Latest *marginifera*, and Late *postera* zones of the standard zonation) in the Palaeozoic record of the Stilo Unit (southern Calabria, southern Italy) indicates the existence of a stratigraphic gap during the early Famennian (*triangularis*, *crepida* and *rhomboidea* zones). In the studied section, this gap occurs above a thin, black, pelitic horizon that appears just on top of the uppermost sample dated as late Frasnian. The conodonts obtained from the beds underlying this black horizon are all highly pyritized, unlike the few Famennian conodonts found in the limestone bed immediately overlying this horizon, which is richer in organic matter. Both stratigraphic features (the black pelitic horizon and the gap in the conodont record) are interpreted as being related to the Upper Kellwasser Anoxic Event. These new data indicate that this important biotic crisis was also evident in the pelagic environments of the Palaeozoic succession of the Stilo Unit at the very end of the Frasnian.

Keywords Upper Kellwasser · Upper Devonian · Conodont biostratigraphy · Stratigraphic gap · Calabria

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Introduction

The Late Devonian is characterized worldwide by a serious biotic crisis, generally referred to as the Lower and Upper Kellwasser (KW) Events, located close to the Frasnian/Famennian (F/F) boundary. In the lithostratigraphic record related to pelagic environments, these events are usually reflected in peculiar lithofacies such as anoxic levels (Buggisch 1972; Sandberg et al. 1988; Schindler 1990; Riquier et al. 2006; Gereke 2007; Bond and Wignall 2008) and iron or phosphate-rich surfaces related to stratigraphic gaps (Geldsetzer et al. 1993; Racki 1998; Piecha 2002). These events have been interpreted as being connected to palaeoceanographic revolutions associated with changes in the oceanographic and climatic system (e.g., Joachimski and Buggisch 1993; Becker and House 1994; Joachimski et al. 2002; Chen and Tucker 2004; Racki 2005; Riquier et al. 2006) or possibly with bolide impacts (McLaren 1970; Sandberg et al. 1988, 1997, 2002).

In the Palaeozoic successions of the Western Mediterranean Alpine orogen, Upper Devonian strata have been recognized in several isolated outcrops, but the KW Events are poorly recorded, being detected only in the Carnic Alps (Wolayer Glacier Section; Kaiser et al. 2008 and references therein) and the Malaguide Complex of the Betic Cordillera

(Rodríguez-Cañero 1993). Upper Devonian strata are also present in Variscan outcrops within other neighboring chains, which were deformed to a lesser extent during the Alpine tectogenesis (Pyrenees, Iberian Chain, and Catalonian Coastal Ranges in Spain: García-Alcalde et al. 2002; and Sardinia: Corradini 2008). In the Wolayer Glacier Section, the Lower KW horizon is represented by several centimetres of black shales. Although there are no anoxic beds at the F/F boundary, the Upper KW Event can be detected by a positive carbon isotope excursion (Joachimski and Buggisch 1993; Bond et al. 2004). In the Malaguide Complex of the Betic Cordillera, the KW Events have been found as discontinuity surfaces with Fe-rich nodules and crusts, related to very narrow stratigraphic gaps that have been dated precisely by conodonts (Rodríguez-Cañero 1993).

Until now, only Famennian beds have been found in the Stilo Unit (near Bivongi) of the Calabria-Peloritani Terrane (southern Italy, Fig. 1), dated by means of conodonts (de Capoa-Bonardi 1970). The aim of this preliminary contribution is to report the first late Frasnian conodont associations found in Calabria, which neighboring black pelites are probably coeval to the Upper KW Event. We also report new associations that permit a precise recognition of several Famennian conodont biozones.

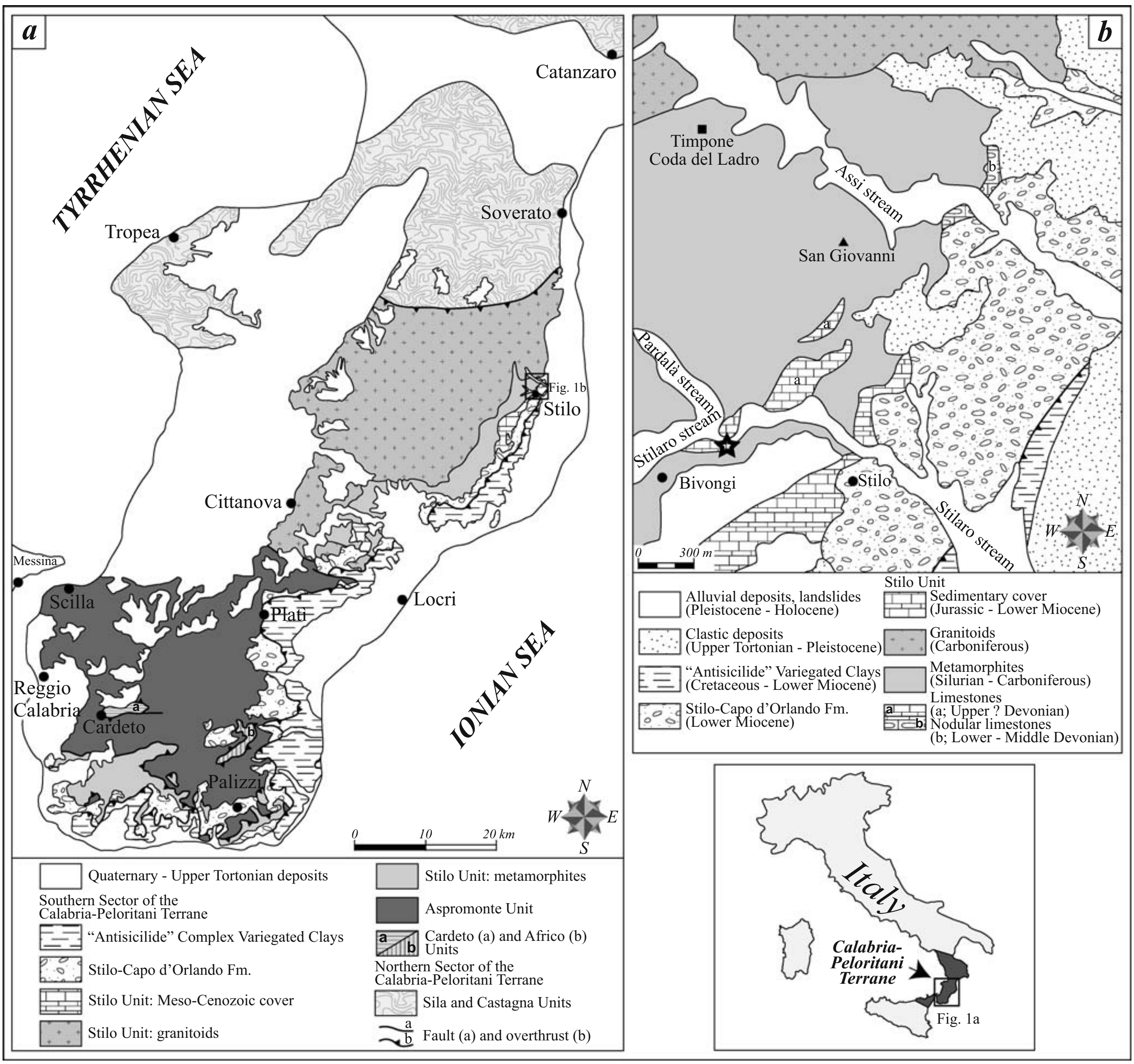


Fig. 1 **a** Geological sketch map of southern Calabria; **b** geological map of the study area (the *star* indicates the location of the section studied)

Lastly, we demonstrate for the first time in Calabria the existence of a stratigraphic gap between the upper Frasnian and the Famennian.

Geological setting and stratigraphy

The studied Palaeozoic succession belongs to the Stilo Unit (Fig. 1), the highest tectonic unit of the Internal Zones of the Calabria-Peloritani Terrane (Bonardi et al. 2002 and references therein), an arc-shaped orogenic belt connecting the Apennine and the Maghrebian Chains. This terrane includes Alpine continental-crust nappes which override H-P ophiolite-bearing thrust sheets deriving from the Central-Western Tethys. The Southern Sector of the Calabria-Peloritani Terrane is made up only of continental crust nappes and tectonic slices overriding the Monte Soro Unit, similar to the Maghrebian Flysch Basin.

The Stilo Unit is made up of a Palaeozoic metapelitic basement, several kilometers thick, intruded by Late Variscan granitoids, which is unconformably overlain by a Meso-Cenozoic sedimentary cover mainly composed of shallow-water carbonates (Amodio-Morelli et al. 1976). The metapelitic succession, with decreasing metamorphic degree upwards, includes limestone horizons bearing Palaeozoic fossils (Acquafredda et al. 1994). Lower Devonian metalimestone lenses bearing orthoceratids and conodonts represent the oldest dated layers in the Stilo basement (Navas-Parejo et al. 2009). Younger Devonian beds, formed by laterally discontinuous and usually grey limestone containing dacryoconarids (Afchain 1970) and conodonts (de Capoa-Bonardi 1970; Gelmini et al. 1979; Bouillin et al. 1987). Famennian limestones sometimes occur as reddish nodular limestones, resembling that of coeval beds with griotte lithofacies that outcrop widely in the Montagne Noire (Feist 1985) and Pyrenees (Majesté-Menjoulas et al. 1984). In the area between Stilo and Bivongi (Fig. 1b), the upper part of the basement is formed by a thin horizon of a black chert layer below a thick succession of presumably metapelites and metarenites of Carboniferous age.

The stratigraphic section analyzed in the studied area is the same as that previously dated by de Capoa-Bonardi (1970). It is located along the road (SP 95) from Bivongi to Monasterace, on a bend near the Vina bridge, downwater of the confluence of the Pardalà stream and the Stilaro stream (Fig. 1b). The 8-m-thick succession (Fig. 2) is made up of thin- to medium-bedded grey limestones with thin pelitic partings. The bedding of the slightly deformed succession is regular and shows no evidence of tectonic omission. The base of the section emerges from the alluvial sediments of the Stilaro stream and starts with a 50-cm-thick interval composed of thin-bedded grey limestones, followed by a 20-cm-thick, black clayey horizon with millimeter- to centimeter-thick intercalations of grey limestones. The thin pelitic interval is overlain by 20-cm-thick grey limestones. The uppermost part of the section is nearly 7 m thick and made up exclusively of dark-grey to bluish, thin- to medium-bedded limestones which are slightly nodular and bioturbated in places.

Conodont biostratigraphy

Frasnian

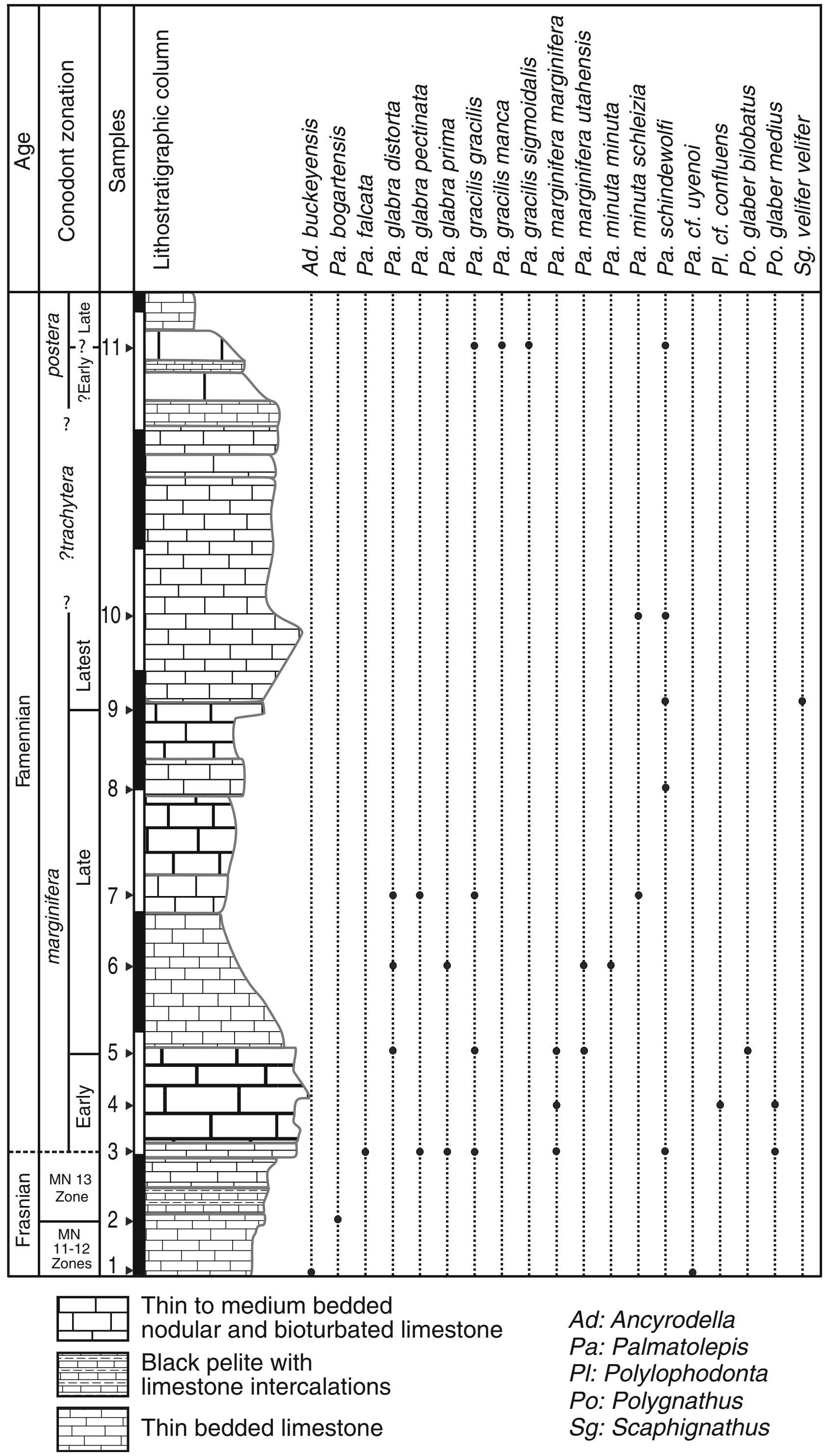
The zonation we apply to the Frasnian part of this section was proposed by Klapper (1989) for the predominantly carbonate, conodont successions in the Montagne Noire. The correlation with the Frasnian standard conodont zonation (Ziegler and Sandberg 1990) was provided by Klapper and Becker (1999). The lowermost bed of the section (sample 1, Fig. 2) contains *Ancyrodella buckeyensis* Stauffer, 1938 (Fig. 3, photos 1 and 2), which ranges from the *punctata* Zone to the Late *rhenana* Zone (equivalent to the MN 5 Zone and to the uppermost MN 12 Zone of Klapper 1989). This sample also provided two broken Pa elements, which we assign tentatively to *Palmatolepis uyenoi* Klapper, 2007 (Fig. 3, photos 3 and 4). The occurrence of this species identifies the MN 11–12 zones.

The index conodont species of the MN 13 Zone, *Palmatolepis bogartensis* (Stauffer, 1938) (Fig. 3, photo 5), appears in sample 2. The black pelite interval can be seen just above this bed. All the conodont specimens recovered from the upper Frasnian horizons lying below the black pelite interval are pyritized whilst the samples taken from the limestone bed lying immediately above it are not. Unfortunately, the few conodont fragments obtained in the overlying bed cannot be determined and so do not allow accurate dating.

Famennian

We apply the standard conodont zonation of Ziegler and Sandberg (1990) to the Famennian interval of the section. The first indisputable Famennian conodonts, obtained from the limestones overlying the black pelite bed, are included in sample 3, located about 50 cm above sample 2 (Fig. 2). These limestones have provided *Palmatolepis marginifera marginifera* Helms, 1959 (Fig. 4, photo 1). This is the defining subspecies for the base of the Early *marginifera* Zone and ranges to the Latest *marginifera* Zone. Sample 3 also contains *Polygnathus glaber medius* Helms and Wolska, 1967, which ranges from the Early to the Late *marginifera* zones. *Palmatolepis marginifera utahensis* Ziegler and Sandberg, 1984 (Fig. 4, photo 3), the index subspecies for the Late *marginifera* Zone, first occurs in

Fig. 2 Lithostratigraphic column and conodont species distribution throughout the section



sample 5. Sample 7 contains, among other species, *Palmatolepis glabra pectinata* Ziegler, 1962, whose upper range is the Late *marginifera* Zone. The occurrence of *Scaphignathus velifer velifer* Beinert, 1971 in sample 9 indicates the Latest *marginifera* Zone (Fig. 4, photo 4). We could not find any index taxa either for the *trachytera* zones or for the Early *postera* Zone in sample 10. Sample 11, however, has provided *Palmatolepis gracilis manca* Helms, 1963 (Fig. 4, photo 8), which is the key subspecies for the base of the Late *postera* Zone. Consequently the interval between samples 9 and 11 cannot currently be definitively assigned to any zone.

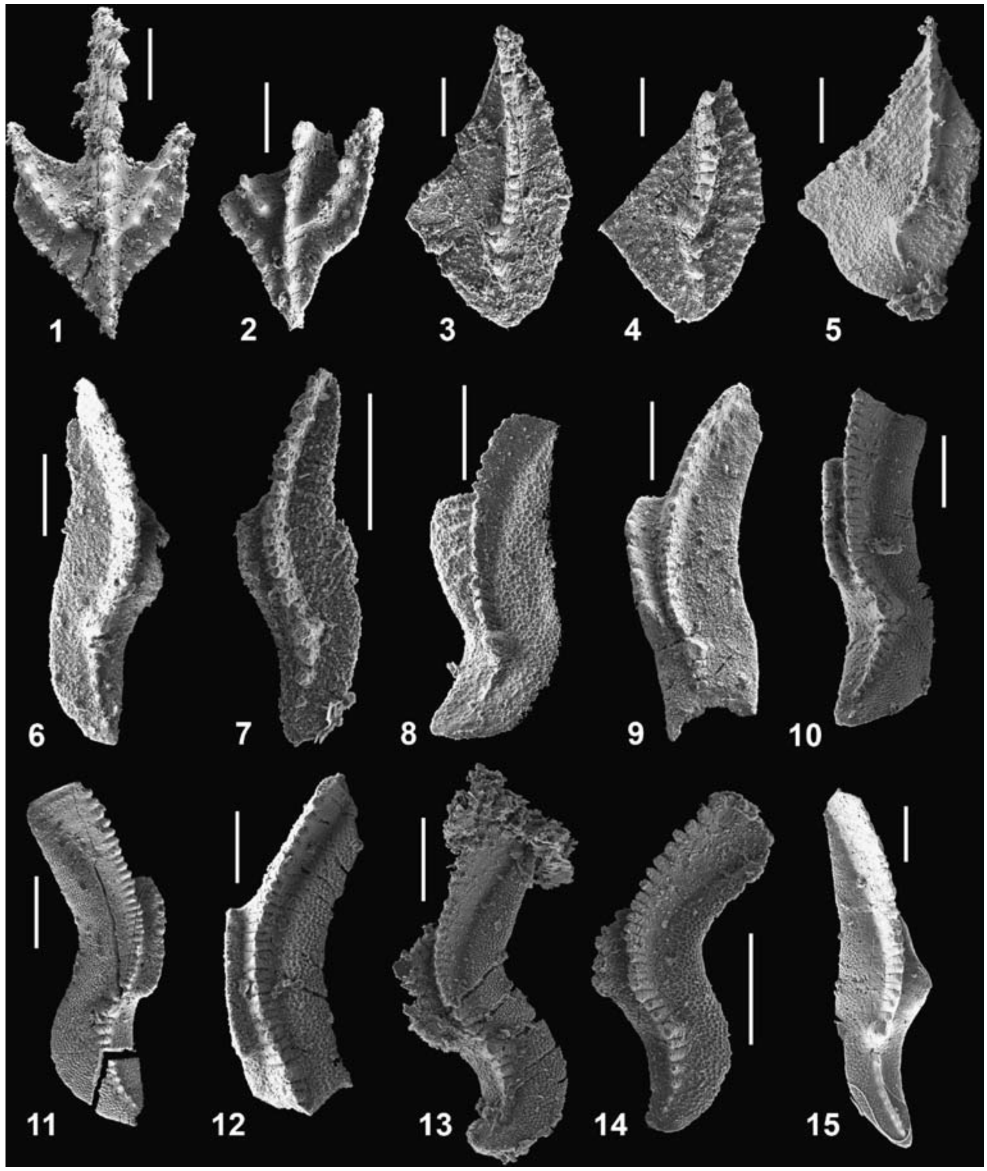


Fig. 3 All photographs are upper view of Pa elements. All conodont specimens are deposited in the Departamento de Estratigrafía y Paleontología (University of Granada). *1, 2 Ancyrodella buckeyensis* Stauffer, 1938: *1* specimen 06P-1-1; *2* specimen 06P-1-9. *3, 4 Palmatolepis cf. uyenoi* Klapper, 2007: *3* specimen 06P-1-5; *4* specimen 06P-1-6. *5 Palmatolepis bogartensis* (Stauffer, 1938): specimen 06P-2-1. *6–8 Palmatolepis glabra prima* Ziegler and Huddle, 1969: *6* specimen 06P-3-1; *7* specimen 06P-6-14; *8* specimen 06P-6-10. *9, 10 Palmatolepis glabra pectinata* Ziegler, 1962: *9* Specimen 06P-3-4; *10* Specimen 06P-7-5. *11–14 Palmatolepis glabra distorta* Branson and Mehl, 1934: *11* specimen 06P-6-6; *12* specimen 06P-5-10; *13* specimen 06P-6-13; *14* specimen 06P-7-4. *15 Palmatolepis falcata* (Helms, 1959): specimen 06P-3-15. All *scale bars* are 200 µm;

Discussion

The late Frasnian KW Crisis includes 2 of the 20 Devonian anoxic events recognized worldwide (Schindler 1993; House 2002). The Lower KW Event occurred near the base of the Late *rhenana* Zone. The Upper KW Event started during the *linguiformis* Zone and ended at or after the F/F boundary. In many stratigraphic sections, both the Lower and the Upper KW Events are observed as anoxic horizons (Sandberg et al. 1988; Paris et al. 1996; Riquier et al. 2005, 2006; Girard and Renaud 2007; Bond and Wignall 2008; among many others).

In recent years, many authors have been studying the processes, timing and causes of both KW Events. According to Girard and Renaud (2007), both KW Events were global and synchronous. The Upper KW Event coincides with a brief but widespread and intense anoxic period that is recognized worldwide usually by the presence of thin black shale horizons associated with one of the most important mass extinctions of the Phanerozoic record and with shifts in many geochemical indicators, among them stable isotopes, associated with changes in conodont biofacies (Buggisch 1972; Lottmann et al. 1986; Sandberg et al. 1988; Schindler 1990; Riquier et al. 2006; Bond and Wignall 2008; among others). In some sections of the Alpine Mediterranean region (the Wolayer Glacier Section in the Carnic Alps, in particular), the faunal extinction event is not related to the presence of any anoxic-event bed, although the marked shifts usually present in geochemical indicators have also been recognized there (Joachimski and Buggisch 1993; Kaiser et al. 2008). Most authors interpret the widespread anoxic conditions at that time as the consequence of the expansion of deep anoxic waters spreading over continental margins and platforms (McGhee 1996) due to the sinking of denser

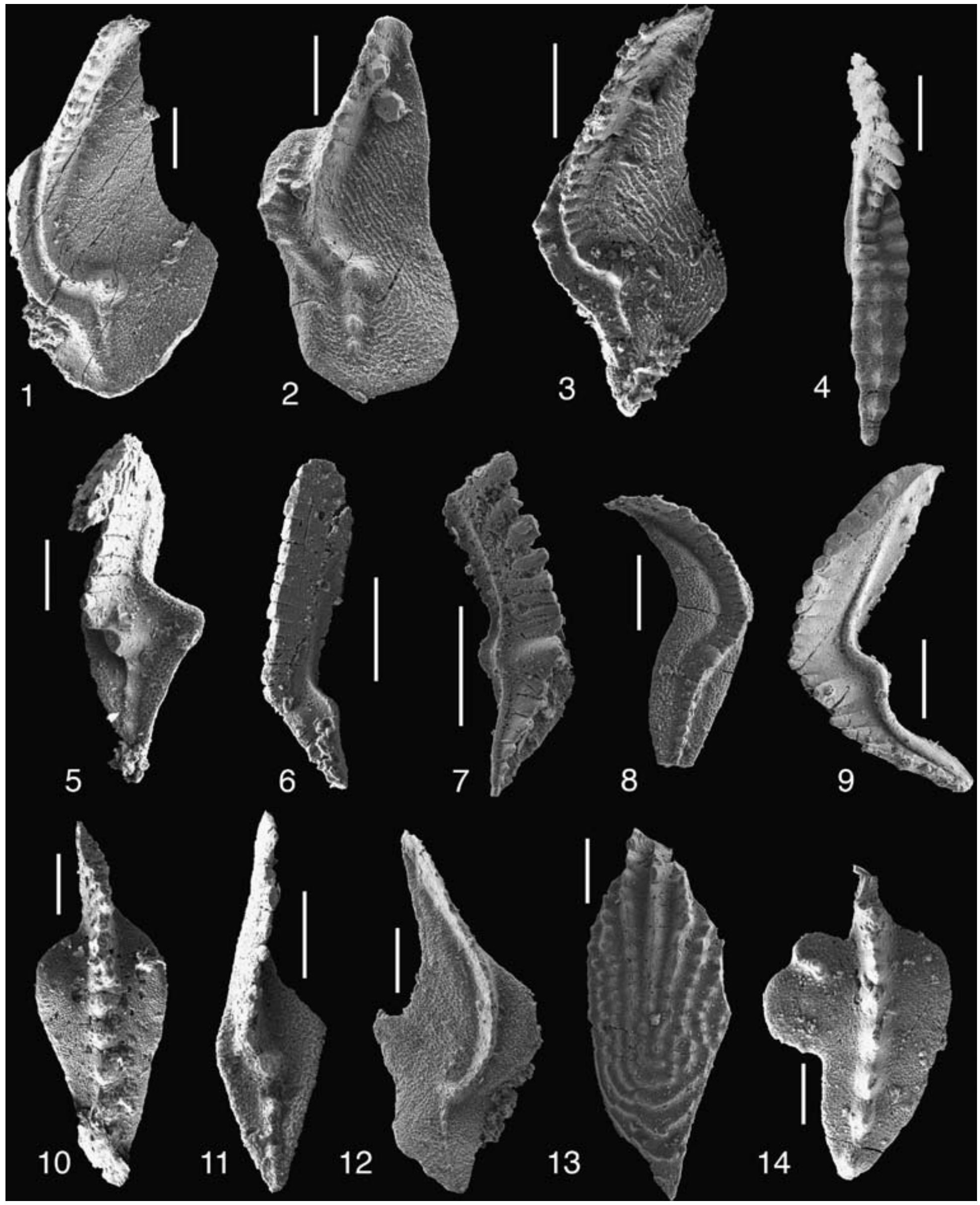


Fig. 4 All photographs are upper view of Pa elements. All conodont specimens are deposited in the Departamento de Estratigrafía y Paleontología (University of Granada). *1–2 Palmatolepis marginifera marginifera* Helms, 1959: *1* specimen 06P-3-8; *2* Specimen 06P-4-6. *3 Palmatolepis marginifera utahensis* Ziegler and Sandberg, 1984: specimen 06P-6-3. *4 Scaphignathus velifer velifer* Beinert, 1971: specimen 06P-9-3. *5 Palmatolepis minuta schleizia* Helms, 1963: specimen 06P-7-2. *6, 7 Palmatolepis gracilis gracilis* Branson and Mehl, 1934: *6* specimen 06P-5-1; *7* specimen 06P-7-6; *8 Palmatolepis gracilis manca* Helms, 1963: specimen 04A-3-16. *9 Palmatolepis gracilis sigmoidalis* Ziegler, 1962: specimen 04A-3-23. *10 Polygnathus glaber medius* Helms and Wolska, 1967: specimen 06P-3-7. *11 Palmatolepis minuta minuta* Branson and Mehl, 1934: specimen 06P-6-7. *12 Palmatolepis schindewolfi* Müller, 1956: specimen 06P-3-25. *13 Polylophodonta cf. confluens* (Ulrich and Bassler, 1926): specimen 06P-4-14. *14 Polygnathus glaber bilobatus* Ziegler, 1962: specimen 06P-5-5. All scale bars are 200 μm

and more saline waters (either colder or warmer, according to different authors: Geldsetzer et al. 1987, 1988; Wilde et al. 1988; Becker and House 1994; among others). These palaeoceanographic changes would have been triggered by a rapid fall in sea level after the Late Devonian highstand, related either to bolide impacts or to tectonic events (Sandberg et al. 1988, 2002; House 2002; Racki 1998; Averbuch et al. 2005; among others). Nevertheless, Bond et al. (2004) conclude that the Upper KW Event was an epicontinental seaway phenomenon caused by the upward expansion of anoxia from deep-basin environments. The black clay horizon is interpreted as being local evidence of anoxia in the stratigraphic record of the Stilo Unit. Nevertheless, the KW Events are not necessarily shown in the rock record at any site as anoxic (black shale) layers (e.g., Becker et al. 1991; Rodríguez-Cañero 1993; Riquier et al. 2005, 2006).

The thin black clay horizon observed in the section studied here, lying between well-dated Frasnian (sample 2) and Famennian (sample 3) beds (Fig. 2), is tentatively correlated to the Upper KW Anoxic Event. This thin black pelitic horizon appears in fact just above sample 2, which belongs to the MN 13 Zone. Its presence indicates that anoxic conditions developed in the succession belonging to the Stilo Unit at the end of the late Frasnian, whereas such conditions disappeared during the Famennian. This may explain why the Frasnian conodonts of the section studied are all pyritized below this horizon whilst those of the Famennian are usually not. Pyritization of the Frasnian conodonts during early diagenesis indicates burial under sulfidic conditions (Berner

1981) and confirms that the black pelitic horizon was deposited during the intense anoxic conditions commonly associated throughout the world with the Upper KW Event. Immediately after this anoxic event, the more or less complete reoxygenation of bottom waters would have made it more unlikely that sulfidic conditions could exist beneath the sediment–water interface, and so the conodonts deposited within the limestones postdating the anoxic event were rarely pyritized during early diagenesis associated with burial. The palaeoceanographic changes related to the development of widespread anoxic conditions might also explain why the lower Famennian *triangularis, crepida*, and *rhomboidea* zones are not recorded in the section studied. Nevertheless, the stratigraphic gap that affects the lower part of the Famennian must be confirmed after more detailed studies, as it was not possible to classify the scarce conodont fragments obtained from the few-decimetre-thick limestone beds immediately overlying the black pelitic interval. In brief, the evidence available supports the presence of the Upper KW Event beds in the Calabria-Peloritani Terrane, and this is the first record of this important event in the area.

In the Palaeozoic record of the Western Mediterranean Alpine orogen, the KW Crisis has until now only been recognized in the Carnic Alps and the Malaguide Complex of the Betic Cordillera. In this latter, an Upper Devonian conodont fauna was extracted from limestone lenses intercalated between Devonian-Carboniferous pelites and sandstones, including several Fe-rich horizons testifying to KW Events (Rodríguez-Cañero 1993). Although no KW anoxic horizon has yet been detected in the Malaguide Complex, sea-level oscillations have been detected by the analysis of conodont biofacies (Rodríguez-Cañero 1993), as it has also been described in other areas (Schindler 1993; Crick et al. 2002; Bond et al. 2004). Despite doubts concerning the significance of conodont biofacies analysis with regard to KW Events expressed in some recent papers (cf. Bond and Wignall 2008), this technique has also revealed the occurrence of oscillations in sea-level within the section studied (research in progress).

Concluding remarks

We describe for the first time the record of Frasnian beds and of a stratigraphic gap at the base of the Famennian in the Palaeozoic successions of the Calabria-Peloritani Terrane (Stilo Unit). These limestone beds, dated by means of conodonts, belong to the late Frasnian MN 11-12 and MN 13 zones, and to the Early, Late, and Latest *marginifera* and Late *postera* zones of the Famennian. The presence of a thin, black, clayey horizon rich in organic matter, located close to the F/F boundary in the Palaeozoic rocks of the Stilo Unit, could demonstrate the occurrence of the Upper KW Anoxic Event in the Calabria-Peloritani Terrane during the late Frasnian. These new findings and accurate biostratigraphic datings open possibilities for exploring in detail the incidence of the important Late Devonian palaeoceanographic events at the westernmost end of the Paleotethys.

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