

Integrated stratigraphy across the Paleocene/Eocene boundary at Campo, Spain

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The Campo section, located in the central South Pyrenean Basin, is the paratratotype of the Ilerdian, which is a regional stage very rich in different fossil groups, very expanded and well exposed. The Ilerdian is one of the best known European marine stages and constitutes one of the best examples of integrated stratigraphy (Molina et al. 1992). The biozonations based on larger foraminifera were established by Hottinger (1960) and Schaub (1966, 1981), on planktic foraminifera by Hillebrandt (1965), on ostracodes by Ducasse (1972), on dinoflagellates by Caro (1973), and on calcareous nannoplankton by Wilcoxon (1973). Since then many authors also studied and revised the biostratigraphy of these and other fossil groups, including small benthic foraminifera, and the magnetostratigraphy has been performed (Pascual & Pares in Molina et al. 1992).

The upper Ilerdian clearly overlaps with the lower Ypresian, but the lower Ilerdian covers the P/E boundary interval from the top of the Thanetian to the base of the Ypresian. The Thanetian in the Campo section consists of 80 m of limestones in which was identified the *Alveolina primaeva* and *Alveolina levis* Biozones, the *Deflandrea speciosa* and *Wetzeliella hyperacantha* (lower part) Biozones and the C26n and C25r (Serra-Kiel et al. 1994). Between the Thanetian and the Ilerdian there is a terrestrial interval of 6 m in which was identified an assemblage with *Stephanochara levis* of the *Sphaerochara edda* Biozone (Masseux & Tambareau 1978). The lower part of the Ilerdian paratratotype section at Campo is perfectly exposed on the north side of the road to Ainsa (Huesca province). A hiatus was identified at the base of the Ilerdian, with C25n missing (Molina et al. 1992; Serra-Kiel et al. 1994).

The Ilerdian section studied consists of 100 m of limestones, 200 m of marls with limestones and sandstones interbedded, and 100 m of dark grey marls (Fig. 1). The upper part of the Ilerdian is mainly composed of dark grey marls. The total thickness of the Ilerdian paratratotype is 1000 m and the Ypresian is about 1800 m. In order to revise the planktic foraminifera and calcareous nannoplankton biozonations and to analyze the carbon and oxygen stable isotopes we sampled in detail the lower 400 m of the Ilerdian at Campo. The *Alveolina* Limestones and the Riguala Marls constitute the Serraduy Formation which characterize the lower and middle Ilerdian.

Planktic foraminifera are absent in the basal 100 m of *Alveolina* Limestones because of the shallow and restricted environment of deposition. Planktic foraminifera are frequent in the overlying 300 m, increasing its abundance toward the top of the Riguala Marls. Hillebrandt (1965) recognized the *G. subbotinae-marginodentata* Biozone and the *G. lensiformis* Biozone. The absence of *Morozovella velascoensis*, a very significant index fossil for the P/E boundary interval, is due to the inner shallow oceanic environment. Its absence is a negative criterion that can not be used since other significant index fossils used in the Molina et al. (1999) subzonation are present and allow us to recognize the *M. gracilis* Subzone, the *A. berggreni* Subzone, the *A. sibaiyaensis* Subzone, and the *P. wilcoxensis* Subzone, which are

subdivisions of the *M. velascoensis* or P5 Zone of Berggren et al. (1995). Another significant index fossil is *Igorina broeder-manni* which appears at meter 230. Its first appearance occurs just after the *M. velascoensis* last appearance (Molina et al. 1999) and allows us to approximately place the corresponding level of the *M. velascoensis* Chronozone in the Campo section.

Calcareous nannofossils are present throughout the section but they are poorly preserved and not very abundant in the basal 100 m of limestones. A previous study on the calcareous nannofossil content was performed by Wilcoxon (1973) who recognized in the lower part of the Campo section the *D. multiradiatus* Biozone, the *M. contortus* Biozone, and the *D. binodosus* Biozone. The nannofloral assemblages are mainly characterized by the presence of *D. multiradiatus*, *C. eodela*, *T. pertusus*, *C. pelagicus*, *S. moriformis*, *Z. bijugatus*, and pentoliths. The co-occurrence of *D. multiradiatus* and large size of *C. eodela* suggest a NP9 Zone of Martini (1971). Fasciculiths are absent throughout the section and a dramatic reduction in diversity occurs in a sandstone interval just at the top of NP9. Rare and scattered *R. bramlettei* (= *R. cuspis* of some other authors) are present from just above the sandstone interval and at this level the NP9/NP10 zonal boundary is placed. This boundary, according to Aubry et al. (this volume), should be placed 30 m above at the first occurrence of *R. contortus*. Six meters above the NP9/NP10 zonal boundary *sensu* Monechi et al. (this volume) few specimens of *R. bramlettei* var. T (= *T. bramlettei* of several authors) and *D. diastypus* have been recognized. The first occurrence of the latter species defines the base of the CP9 Zone of Okada & Bukry (1980). An increase in the total abundance and diversification of the nannoflora have been observed in the upper part of the interval studied, allowing to recognize the main P–E transition events up to the NP11 Zone.

Stable isotopes were never analyzed before and the position of the carbon isotope excursion (CIE) around the sandstone was only supposed. The carbon stable isotopes clearly show negative values beginning at the sandstone interval which corresponds to the planktic foraminifera *A. berggreni* Subzone and to the NP9/NP10 zonal boundary. The shift maintains high negative values throughout the *A. sibaiyaensis* Subzone. Due to the high rate of sedimentation at Campo this shift, lasting 15 m, represents one of the most expanded marine records of the CIE known to date. Furthermore, from meter 215 to 270 values remain very low; this fact could be due to several alternative causes. Similar extended falls in $\delta^{13}\text{C}$ have been observed in neritic sections in the Middle East (Schmitz et al. 1996), reflecting early Eocene long-term high input of organic matter to the sediments. Diagenetic alteration or slumping are other possible explanations for the extension of the CIE at Campo.

In conclusion, the detailed sampling of the lower part of the Campo section allows us to precisely place the CIE in relation to the many P–E transition events recorded in the lower part of the Ilerdian paratratotype. The expanded interval in which the excursion occurs shows no carbonate dissolution contrary to what

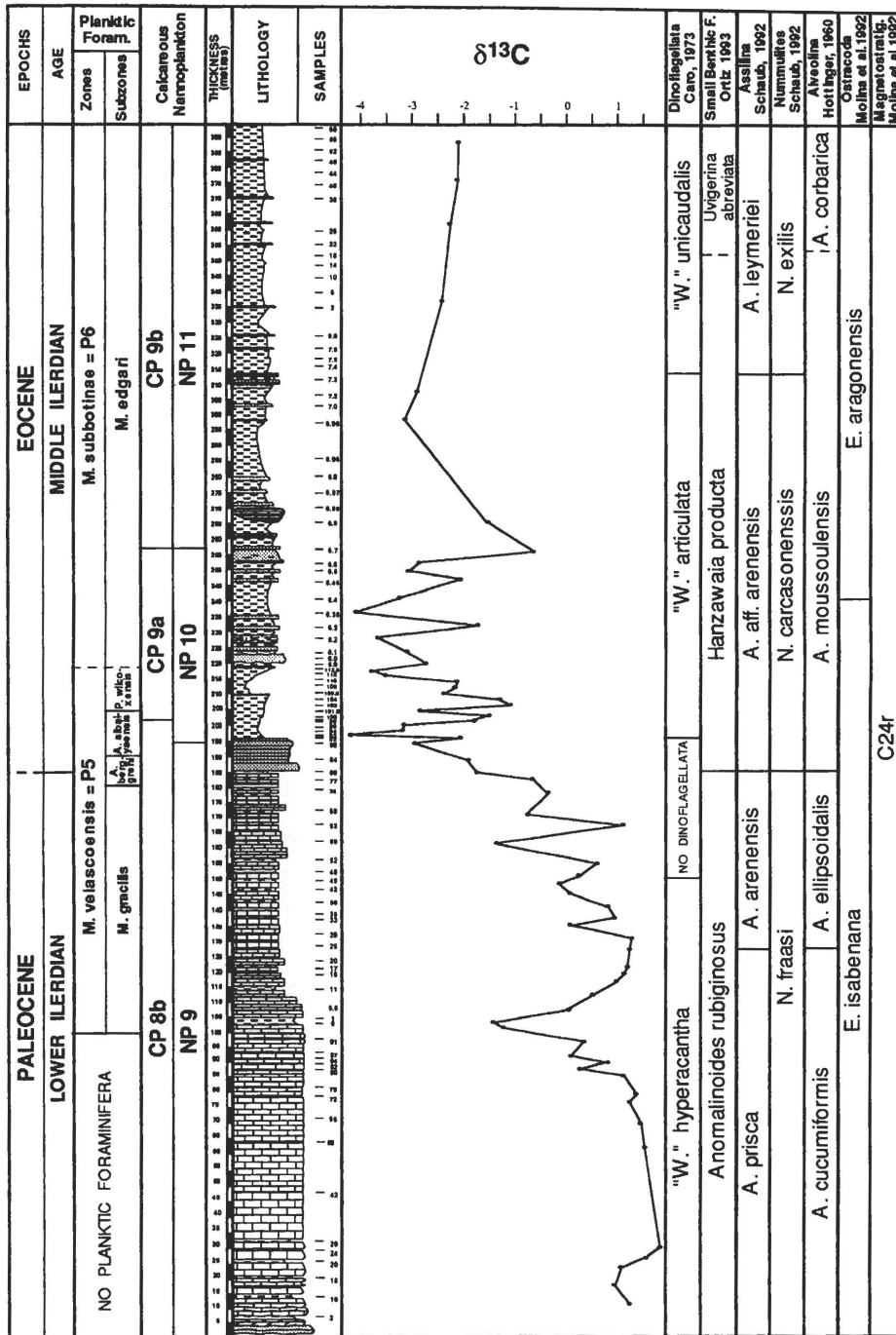


Fig. 1. Multiparameter stratigraphy across the lower and middle Ilerdian in the Campo section. Carbon isotopes have been measured on whole-rock samples.

happens in bathyal and abyssal sections. The lithology of this interval is quite distinctive from below and above and is composed of a 10 m basal interval of sandstones and 90 m of marls with some thick limestone strata interbedded in which red algae and corals are abundant as a consequence of the strong increase in temperature. In coincidence with the base of the CIE several evolutionary events can

be observed in different fossil groups, which reflect what happened in the neritic environments at this critical level, which is placed 200 m above the Thanetian. The suggested marker for the base of the Ypresian *Tribrachiatus digitalis* first occurs 35 m above the base of the CIE compared with 1800 m of Ypresian sediments in the Campo section.

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