

**THE STRATOTYPIC ILERDIAN REVISITED :  
INTEGRATED STRATIGRAPHY  
ACROSS THE PALEOCENE/EOCENE BOUNDARY**

**RÉVISION DE L'ILERDIEN STRATOTYPIQUE :  
STRATIGRAPHIE INTÉGRÉE  
DE LA TRANSITION PALÉOCÈNE/ÉOCÈNE**

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**ABSTRACT** - The Ilerdian is today one of the best known European marine stages. Data published after its definition and the ongoing research, have allowed the establishment of a detailed integrated stratigraphy. According to these data the Ilerdian extends from the alveolinid *A. cucumiformis* to *A. trempina* biozones; from the nummulitid *N. fraasi* to *N. involutus* biozones; from the small benthic foraminiferal *Angulogavelinella avnimelechi-Anomalinoidea rubiginosus* (BB1) (upper part) to *Cibicidoides subspiratus* (BB3) (lowermost part) biozones; from the planktic foraminifera *M. aequa* (lower part) to *P. wilcoxensis* (upper part) biozones; from the calcareous nannofossils *D. multiradiatus* (NP 9) (middle part) to the *D. binodosus* (NP 11) (uppermost part) biozones; from the dinoflagellate "W", *hyperacantha* to *W. unicaudalis* biozones; from the ostracod *E. isabonana* to *E. posterior* biozones; and in terms of magnetostratigraphy to Chrons C 24.1r, C 24.2 and C 24r. The Middle and Late Ilerdian overlap with the Ypresian but the Early Ilerdian spans a gap between the Thanetian and Ypresian that is not represented in any European marine classical stages.

**RÉSUMÉ** - L'Ilerdien est aujourd'hui un des étages marins européens les mieux connus. Les données publiées les années suivant sa définition et celles présentées ici permettent d'établir une stratigraphie intégrée très détaillée. Selon ces données l'Ilerdien s'étend : de la biozone d'alvéolinidés *A. cucumiformis* à celle à *A. trempina*; de la biozone de nummulitidés à *N. fraasi* à celle à *N. involutus*; de la biozone de petits foraminifères benthiques *Angulogavelinella avnimelechi-Anomalinoidea rubiginosus* (BB1, partie supérieure) à la biozone *Cibicidoides subspiratus* (BB3, partie basale); de la biozone de foraminifères planctoniques *M. aequa* (partie inférieure) à celle à *P. wilcoxensis* (partie supérieure); de la biozone de nannofossiles calcaires *D. multiradiatus* (NP 9, partie moyenne) à celle à *D. binodosus* (NP 11, partie supérieure); de la biozone de dinoflagellés "W", *hyperacantha* à celle à *W. unicaudalis*; de la biozone des ostracodes *E. isabonana* à celle à *E. posterior*; en termes de magnétostratigraphie aux Chrons C 24.1r, C 24.2 et C 24r. L'Ilerdien moyen et supérieur se superpose à l'Yprésien, mais l'Ilerdien inférieur couvre un intervalle entre le Thanétien et l'Yprésien qui n'est représenté par aucun étage marin classique européen.

**Key-words** : Ilerdian - Paleocene - Eocene - Chronostratigraphy - Biostratigraphy - Magnetostratigraphy - Integrated Stratigraphy - Spain.

**Mots-clés** : Ilerdien - Paléocène - Eocène - Chronostratigraphie - Biostratigraphie - Magnétostratigraphie - Stratigraphie Intégrée - Espagne.

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## INTRODUCTION

The aim of this paper is to restudy the Ilerdian Stage establishing an integrated stratigraphy across the Paleocene/Eocene boundary. Our conclusions are based on new data and on geological and paleontological data previously published from the Tresp section (stratotype) and Campo section (parastratotype).

The Ilerdian Stage was defined in 1960 by Hottinger and Schaub in the central south pyrenean basin (Spain), and in the ensuing years several papers were published showing a detailed biostratigraphy mainly based on microfossils (Hottinger 1960a, 1977; Gartner and Hay, 1962; Hillebrandt, 1965, 1975; Luterbacher, 1969, 1973; Ducasse, 1972; Caro, 1973; Ferrer *et al.*, 1973; Wilcoxon, 1973; Kapellos and Schaub, 1973, 1975; Schaub, 1966, 1969, 1973; Tambareau and Villatte, 1974; Tambareau, 1975; Le Calvez, 1975; Gaemers, 1978, etc.). Since then considerable progress has been made regarding the biostratigraphy and chronostratigraphy of the Paleogene. Several papers have also been published involving the Ilerdian (Schaub, 1981; Plaziat, 1981, 1984; Fomesu, 1984; L  t  , 1987; Eichenseer, 1988; Canudo, Molina and Sucunza, 1989; Sams  , Tosquella and Serra-Kiel, 1990; Tosquella, Sams   and Serra-Kiel, 1990; Pascual *et al.*, 1991; Canudo and Molina, 1992,...).

A revision of the basic data was necessary in order to position the Paleocene/Eocene boundary in relation to the Ilerdian Stage. A preliminary revision was presented at the 28th International Geological Congress in Washington, D.C. (Molina *et al.*, 1989); an integrated biostratigraphic study was carried out by means of several microfossil groups from some sections in the area of the Ilerdian stratotype. This study has been now enlarged to include the revision of other groups and the magnetostratigraphical data.

## THE ILERDIAN STAGE

The Ilerdian was first proposed as a new stage by Lukas Hottinger and Hans Schaub in 1960 (manuscript deposited on September 12th 1959; published in *Eclogae geologicae Helveticae*, 53-1, pp. 453-479). On page 456 they stated that they chose the sequence with very good outcrops in the Tresp basin in the L  rida province (N Spain) as the type sequence, and they named this stage Iler-

dian from the latin form of L  rida (*vide* Plaziat, 1981b). They justified the creation of the Ilerdian on the fact that in the Paris basin there are no *Nummulites* or other larger foraminifera underlying the Cuisian. The Sparnaecian, which is a continental stage, was regarded as being unsuitable for the Paleogene chronostratigraphic standard scale.

The stratotype was designated by Schaub in 1969, and published in *M  m. B.R.G.M.*, 69, pp. 259-266. The type section is the Tresp section (L  rida province) and is exposed along the road from Tresp to Puente de Monta  ana, with the lower limit at 21.4 km and the upper limit at 13.2 km. Schaub (1969) also stated that the Campo section might be the parastratotype of Ilerdian. In 1974 there was a proposal (motion) at the meeting on the Ilerdian Stage in Paris (organized by the Soci  t   g  ologique de France and the International Working Group on Paleogene Stratigraphy) designating the Campo section (Huesca province) as the parastratotype, with the lower limit at 0.34 km on the Campo to Ainsa road and the upper limit at 58.8 km on the Graus to Campo road (Bignot, 1975).

The Ilerdian Stage was biochronostratigraphically defined by Schaub (1969) based on the biozonation of larger Foraminifera. Later, Schaub (1981) synthesized previous works and developed a more detailed biozonation which is the one we use in this paper:

### Late Ilerdian:

*Alveolina trespina*, *Nummulites involutus* and *Assilina adrianensis* Biozones.

### Middle Ilerdian:

*Alveolina corbarica*, *Nummulites exilis* and *Assilina leymeriei* Biozones.

*Alveolina moussoulensis*, *Nummulites robustiformis* and *Assilina* aff. *arenensis* Biozones.

### Early Ilerdian:

*Alveolina ellipsoidalis*, *Nummulites fraasi* and *Assilina arenensis* Biozones.

*Alveolina cucumiformis*, *Nummulites fraasi* and *Assilina prisca* Biozones.

Geologically, the type sections of Tresp and Campo are located in the Tresp-Graus basin, in an overthrust unit named the Central South Pyrenean Unit, that moved some 30 km southwards (Seguret, 1972). The sedimentation is syntectonic but the sliding was so gentle that the only tectonic effects are some slumping in the Campo section,

which is not a major problem since the section is about 700 meters thick and it is located in the Middle Ieridian.

The Ieridian was created as a Stage of the Mediterranean Paleogene and is used by many geologists of southern Europe, mainly specialists in benthic foraminifera. The main reason why it has not been accepted as an international Standard Stage is because its primitive definition was based only on biostratigraphical criteria from larger foraminifera; the Tremp section (stratotype) is not very rich in planktic foraminifera. This problem is solved in the Campo section (parastratotype). Furthermore, because of the richness and variety of different groups of fossils and the recent studies in magnetostratigraphy, etc., the Ieridian can now be placed very precisely in the geologic time-scale.

### THE TREMP SECTION (STRATOTYPE)

The section is very well exposed along the road from Tremp to Puente de Montañana, from the hamlet of Claret and nearly to the pass in the Montllobar mountain; the accessibility is excellent and the section should be preserved in the future thanks to its location in open and mainly uncultivated country.

The Ieridian stratotype section, which lithostratigraphically belongs to the Ager Formation (Luterbacher, 1969), is 830 m thick and lies between the continental formations of Tremp and Montañana. The lower limit is perfectly exposed on the north side of the road, one kilometer from Claret, overlying the continental deposits (Garumnian facies) of the Tremp Formation. The Ager Formation is a transgressive-regressive megasequence that begins with 140 m of a very shallow clastic facies, alternating with lagoonal or bay deposits, mainly marls with littoral molluscs and *Alveolina* limestones. It is followed by a more open marine facies of 170 m of *Turritella* and *Pattalophyllia* marls, which also yields *Nummulites*, *Operculina*, etc. The deepest water facies is composed of 400 m of marls, very rich in larger foraminifera that also contain planktic microfossils. The upper part of the Ager Formation is composed of 50 m of shallow marine facies with *Alveolina* and marine molluscs, overlain by 70 m of estuarine lagoonal and fluvial deposits.

The larger foraminifera of the Ieridian Stratotype (Tremp section), as well as those from other nearby sections with which stratigraphic correlation can be established, have been studied by several authors (Hottinger, 1960a; Luterbacher, 1969, 1970,

1973; Gaemers, 1978a; Schaub, 1981). Recently, Samsó, Tosquella and Serra-Kiel in Pascual *et al.*, (1991) have recognised the following *Alveolina* biozones established by Hottinger (1960a, 1960b): *A. cucumiformis* Biozone at the bottom of the section, and *A. corbarica* Biozone and *A. trempina* Biozone at the top of the section. The following *Nummulites* Biozones established by Schaub (1981) have been recognized: *N. robustiformis* Biozone, *N. exilis* Biozone and *N. involutus* Biozone. Finally, the following *Assilina* Biozones also established by Schaub (1981) have been recognized: *As. aff. arenensis* Biozone, *As. leymeriei* Biozone and *As. adrianensis* Biozone. The assemblages of *Alveolina* and nummulitids (*Nummulites*, *Operculina*, *Assilina*) determined in this paper are shown in figure 1. The top of *Alveolina cucumiformis* Biozone and the *Alveolina ellipsoidalis* Biozone can be drawn in the stratotype if the nearby sections of Puigmasana and Mur of Hottinger (1960a) and Guardia de Tremp and Puigercós of Gaemers (1978a, 1978b) are considered. The *Alveolina moussoulensis* Biozone is not found in the whole area, but it can be drawn in figure 2 by correlation with the *N. robustiformis* Biozone. Related with *N. frausi*, *As. prisca* and *As. arenensis* Biozones, which according to Schaub (1981) characterised the Early Ieridian, have been recognized by this author in the Alsina, Llimiana, St. Esteve and Areny sections of Ferrer *et al.*, (1973), and in the Estorm section of Hottinger (1960a), spanning the *A. cucumiformis* and *A. ellipsoidalis* Biozones.

The small benthic foraminifera were studied in the Tremp section by Ferrer *et al.* (1973) and Le Calvez (1975) but no zonation or biostratigraphical distribution was attempted for these shallow water assemblages. New data from the Tremp section (Ortiz and McDougall, 1991) subdivides the assemblages into two zones which approximate the Paleocene, BB1, and early Eocene, BB2, bathyal biozones of Berggren and Miller (1989). A third zone could be questionably recognized (BB3, lowermost part). Application of Berggren and Miller (1989) biozonation can only be used with caution as most age diagnostic species are missing from these shelf assemblages. The boundary between biozones BB1 and BB2 is placed in the lower part of *Pattalophyllia* Clay, where the Paleocene species *Cibicidoides hyphalus* occurs with early Eocene species. Assemblages lower in the section include the Paleocene species *Anomalinoides rubiginosus*, *Cibicidoides aleni*, *Pullenia coryelli*, *Bulimina trigonalis*, and *Spiroplectamina thaneteana*. Early Eocene species present in the lower part of *Pattalophyllia* Clay and higher in the section include *Cibicidoides eoceanus*, *Uvigerina abbreviata*, and *Hanzawaia producta*. A

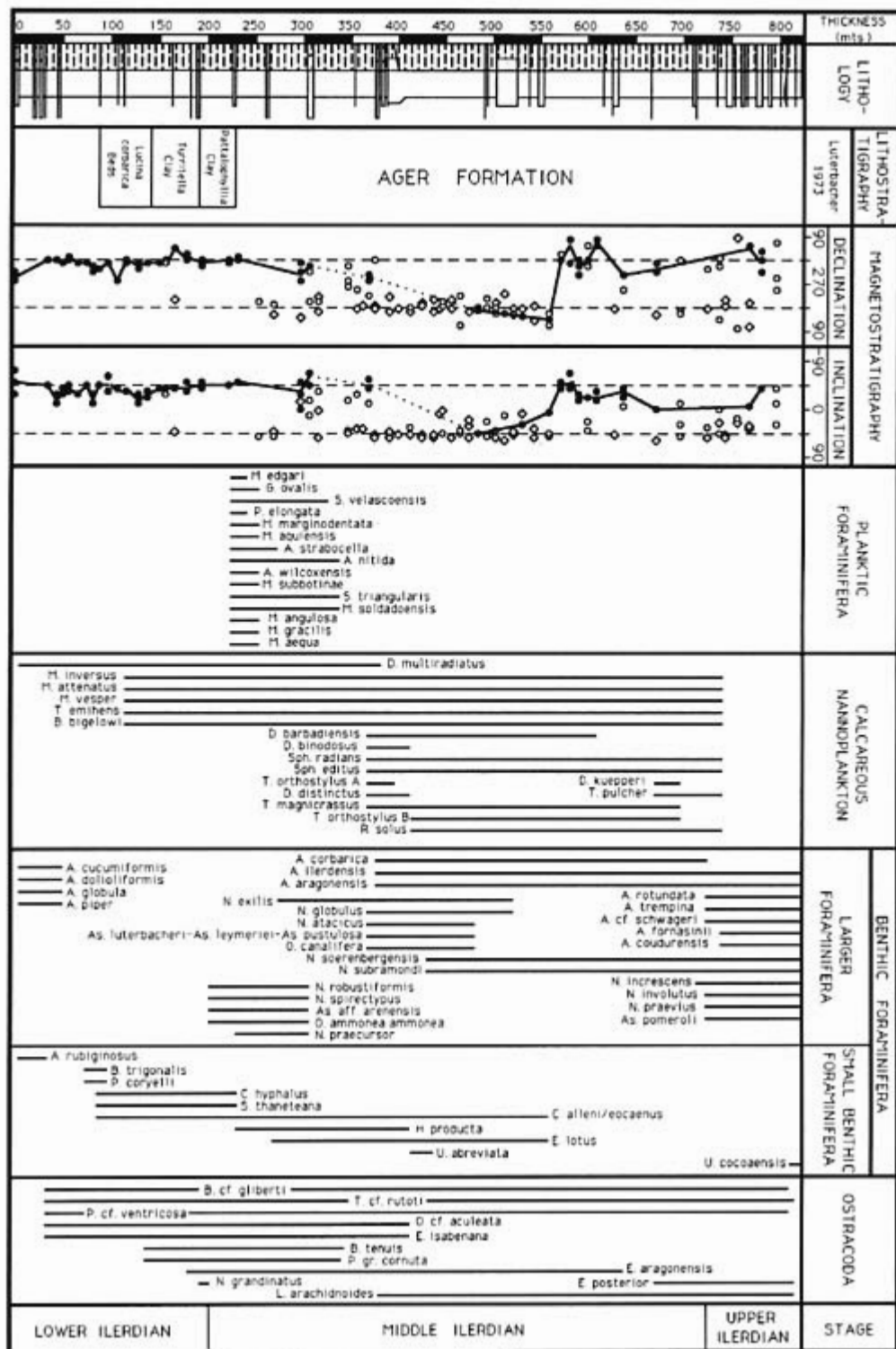


FIG. 1. — Lithostratigraphy, magnetostratigraphy and stratigraphic range of the most significant studied microfossils in the Tresp section (Ilerdian stratotype). Lithostratigraphie, magnetostratigraphie et distribution stratigraphique des microfossiles plus significatifs de la coupe de Tresp (Stratotype de l'Ilerdien).

third biozone is questionably recognized in the upper part of the section with the appearance of *Uvigerina cocoaensis*. This species first occurs in planktic foraminiferal zone P9 (Boersma, 1984), but benthic foraminifera in this and subadjacent samples are not age diagnostic.

The planktic foraminifera were studied by several workers (Gartner and Hay, 1962; Hillebrandt, 1965; Luterbacher, 1969; Ferrer *et al.*, 1973; Blow, 1979), but they are frequent only in the middle part of the section. Hillebrandt (1965) indicated the presence of *Pseudohastigerina eocaenica*, which is a junior synonym of *Pseudohastigerina wilcoxensis*. This species which was not found by Luterbacher (1969) or by us, is probably very scarce due to unfavorable environmental conditions. Furthermore, by correlation with Campo, Zumaya and other sections we discovered the real cause, which is that *Pseudohastigerina* appears later in the Pyrenees than in low latitudes, and by that time the paleoenvironment in Tresp was too shallow for *Pseudohastigerina wilcoxensis* to live in. According to our study the middle part of the stratotype contains the following association of planktic foraminifera: *Morozovella edgari*, *Morozovella gracilis*, *Morozovella marginodentata*, *Morozovella aequa*, *Morozovella lacerti*, *Morozovella subbotinae*, *Muricoglobigerina esnehensis*, *Muricoglobigerina aquiensis*, *Muricoglobigerina angulosa*, *Muricoglobigerina soldadoensis*, *Subbotina finlayi*, *Subbotina patagonica*, *Subbotina triangularis*, *Planorotalites elongata*, *Acarinina wilcoxensis*, *Acarinina strabocella*, *Acarinina nitida* and *Globanomalina ovalis*. This assemblage could correspond to the *G. marginodentata* Biozone of Hillebrandt (1965), to the upper part of *G. velascoensis* Biozone of Bolli (1966) and Toumarkine and Luterbacher (1985), to the P6a Biozone of Berggren and Miller (1988) and to the upper part of the *Morozovella aequa* Biozone of Canudo and Molina (1992). Nevertheless, if *Pseudohastigerina wilcoxensis* is absent because of the ecology, this interval could also correspond to the *M. edgari* Biozone of Toumarkine and Luterbacher (1985), the P6b Zone of Berggren and Miller (1988) and the *Pseudohastigerina wilcoxensis* Biozone of Canudo and Molina (1992). The planktic foraminifera biozonation of the lower and upper parts of the stratotype, which are very poor in this kind of microfossils, can be deduced by correlation with the parastratotype.

The calcareous nannofossils were studied by Wilcoxon (1973) who only recognized the *Marthasterites contortus* and *Discoaster binodosus* Biozones through the Illerdiian stratotype. Kapellos and

Schaub (1973, 1975) established the correlation with the larger foraminifera biozonations, and by resampling the base and the top of the section they also recognized the *Discoaster multiradiatus* and the *Tribrachiatulus orthostylus* (= *Marthasterites tribrachiatulus*) Biozones respectively. The different assemblages allow recognition of the NP 9 (confirmed by correlation with the parastratotype), NP 10, NP 11 and possibly NP 12 of the Martini (1971) biozonation. In the Tresp section the index *D. lodoensis* of the NP 12 Biozone is absent, but this biozone could be also recognized by the presence of *D. kueperi* and *T. pulcher*. Nevertheless, by correlation with the parastratotype the NP 12 Biozone is very questionable in the upper part of the Tresp section.

The dinoflagellates are scarce and were studied by Caro (1973) who established three biozones ("*Wetzeliella*" *hyperacantha*, *Wetzeliella articulata* and *Wetzeliella unicaudalis*) for the middle part of the Tresp section.

The ostracoda were studied by Carbonnel (1975) and Tambareau (1975) and recently by Lété (1987). Two biozones were established: *Echinocythereis isabonana* Biozone (Early Illerdiian) and *Echinocythereis aragonensis* Biozone (Middle and Late Illerdiian). According to the new data of this paper the *Echinocythereis posterior* Biozone is defined for the uppermost part of the Tresp section (base with the first occurrence of this species, top with its disappearance). However, because the *Echinocythereis* are rare near the defined limits these boundaries fall lower in the Tresp section.

The molluscs are sometimes abundant and data were published by De Renzi (1967, 1975) who considered their biostratigraphy, correlating them with the European Eocene molluscan faunas.

The magnetostratigraphic record of the Tresp section is characterized by a long reversed polarity zone interrupted by one normal period (Pascual *et al.*, 1991). Comparing the obtained magnetic polarity with the paleontological data it is suggested that the boundary between the *Morozovella aequa* and the *Pseudohastigerina wilcoxensis* Biozones (Canudo and Molina, 1992), is located stratigraphically below of the normal period. This boundary approximately coincides with the ones between *M. velascoensis* and *M. edgari* (Berggren *et al.*, 1985), *M. velascoensis* and *M. subbotinae* s.l. (Cavelier and Pomerol, 1986), NP 9 and NP 10 (Berggren *et al.*, 1985), P6a and P6b (Berggren and Miller, 1988) and P6 and P7 (Blow, 1979). According to the reference scales, the first normal interval after the mentioned boundary corresponds to the polarity Chron 24.2.



Thus the normal polarity interval found in the Illeridian stratotype could be the 24.2. Then, the lower and upper reversed intervals of the section are respectively the 24.1r and the 24r. The position of these polarities in the Illeridian stratotype are: Chron 24.1r is in the Late Illeridian and the top of the Middle Illeridian, Chron 24.2 is in the Middle Illeridian and Chron 24r is in the lower part of the Middle Illeridian and Early Illeridian.

### THE CAMPO SECTION (PARASTRATOTYPE)

The Campo section crops out along the Esera river about 2 km south of the village of Campo. The bottom of the Illeridian parastratotype is perfectly exposed on the north side of the road to Ainsa beginning at 0.34 km, while the Middle Illeridian outcrops west of the hamlet of Navarri, and the Late Illeridian may be observed along the road from Campo to Graus, near the village of Murillo de Liena (Schaub, 1966, 1973, 1981; Kapellos and Schaub, 1973, 1975).

Underlying the parastratotype are sediments of marine facies of the Middle Thanetian with *Alveolina* (*Glomalveolina*) *primaeva*, *Fallotella alavensis*, *Operculina heberti*, and of the Late Thanetian with *A. (G.) levis*, *Operculina azilensis* and *Assilina yvettae* (Hottinger, 1960a; Hottinger and Schaub in Hottinger et al., 1964; Schaub, 1966, 1981; Tambareau and Villatte, 1974; Robador et al., 1990). There is a brief non-marine intercalation that contains charophytes, between the Late Thanetian and the first Illeridian sediments.

The Early Illeridian (*Alveolina cucumiformis*, *Alveolina ellipsoidalis* Biozones) and the lowermost Middle Illeridian (*Alveolina moussoulensis* Biozone) is composed of 150 m of limestones that in the upper part alternate with marls. The rest of the Illeridian is made up of more than 550 m of silty marls that were interpreted as a regressive sequence from lower slope deposits, succeeded by prodelta to offshore and delta-front type sedimentation to the top of the Illeridian (Mutti et al., 1972). Overlying the progradation of silty marls to coarse sands are deposits with nummulitid rich layers that characterize the *Alveolina oblonga*, *N. planulatus* Biozones and *A. dainelli*, *N. praelevigatus* Biozones. The lithostratigraphy of this area has been recently revised by Samsó (1988) and Tosquella (1988), who established a subdivision of the classical formations previously recognized in the basin.

The larger foraminifera were studied by Hottinger (1960a, 1977), Schaub (1966, 1973, 1981), Tambareau and Villatte (1974). Recently, Samsó et al. (1990), Tosquella et al. (1990), and Robador et al. (1990) have recognized as the previous authors the *A.(G.) primaeva* and *A.(G.) levis* Biozones (Thanetian), the *A. cucumiformis* and *A. ellipsoidalis* Biozones (Early Illeridian), the *A. moussoulensis* and *A. corbarica* Biozones (Middle Illeridian) and the *A. oblonga* and *A. dainelli* Biozones. Corresponding to nummulitids they have recognized the *Assilina yvettae* Biozone (Late Thanetian), the *N. fraasi*, *As. prisca* and *As. arenensis* Biozones (Early Illeridian), the *N. robustiformis*, *N. exilis*, *As. aff. arenensis* and *As. leymeriei* Biozones (Middle Illeridian), the *N. planulatus* and *As. plana* Biozones, and the *N. praelevigatus* and *As. laxispira* Biozones. However, they do not find the association that characterizes the Late Illeridian (*A. trempina*, *N. involutus* and *As. adrianensis* Biozones), because this zone of the section is very poor in larger foraminifera due probably to the great depth of the paleoenvironment at that moment. All species determined by these authors are indicated in figure 3.

Although the small benthic foraminifera in the Campo section indicate a slightly deeper paleoenvironment than at the Tremp stratotype, the bathyal biozonation of Berggren and Miller (1989) can only be used with caution, as most of the diagnostic species are not present in this section. Three zones are recognized which are equivalent to biozones BB1, BB2, and BB3 (Ortiz and McDougall, 1991). The boundary between biozone BB1 and BB2 occurs in the lower part of the Riguala Marls, where the Paleocene species *Anomalinoidea rubiginosus* occurs with the Eocene specimens transitional between *C. alleni* (Paleocene) and *C. eocaenicus* (Eocene). Paleocene species present lower in the section include *Cibicidoides hyphalus*, *Cibicides succedens*, *Spiroplectammina thanetana*, and *Tritaxilina indentata*. Species characteristic of the Early Eocene occurring higher in the section include *Turrilina brevispira*, *Loxostomoides applinae*, *Uvigerina abbreviata*, *U. batjesi* and *Hanzawaia producta*. Biozone BB3 is recognized by the first appearance of *Cibicidoides subspiratus* in the middle part of the lateral equivalent marls of Roda Sandstone Formation of the Campo section. Although this biozone was correlated with planktic foraminiferal zone P9 to P13 (Berggren and Miller, 1989), older occurrences of *Cibicidoides subspiratus* which are recorded under the name *Cibicides fortunatus* suggest the base of the biozone is equivalent to planktic foraminiferal zone P6c (uppermost part). Benthic foraminifera continue to appear higher in the section

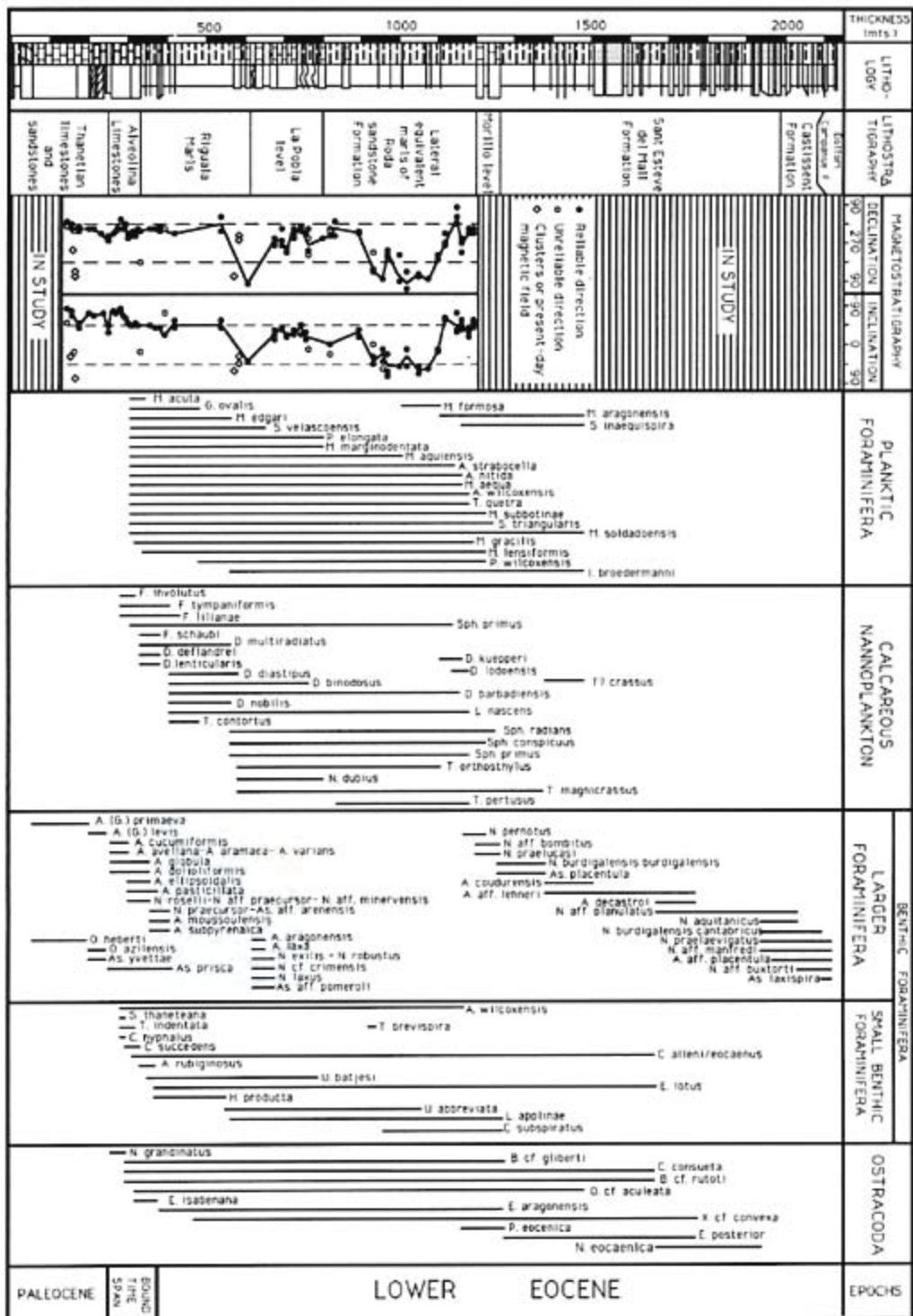


FIG. 3. - Lithostratigraphy, magnetostratigraphy and stratigraphical range of the most significant studied microfossils in the Campo section (Iberian parastratotype).

*Lithostratigraphie, magnetostratigraphie et distribution stratigraphique des microfossiles plus significatifs de la coupe de Campo (Parastratotype de l'Herdien).*

but age diagnostic species become increasingly rare as water depths decrease.

The planktic foraminifera were studied by Hillebrandt (1965) who recognized three zones: *Globorotalia subbotinae-marginodentata* (G), *Globorotalia lensiformis* (H) and *Globorotalia formosa-Acarinina angulosa* (I) and established the correlation with the larger foraminiferal biozones. Recently the planktic foraminifera have also been studied by Molina *et al.* (1989), Canudo *et al.* (1989), and Canudo (1991; in press). In the Campo section the planktic foraminifera are more diversified and frequent than in the Tremp section. The first appearance of *Pseudohastigerina* has been found in higher horizons than those of Hillebrandt (1965). In the Illeridian of the Campo section the following biozones can be recognized: *Morozovella velascoensis*, *Morozovella edgari* and *Morozovella subbotinae* of Toumarkine and Luterbacher (1985), P6a, P6b and P6c zones of Berggren and Miller (1988) and *Morozovella aequa* and *Pseudohastigerina wilcoxensis* Biozones of Canudo and Molina (1992). The planktic foraminiferal record continues in the higher horizons which clearly belong to the Ypresian (*Morozovella aragonensis* Biozone of Canudo and Molina (1992); *Morozovella formosa formosa* Biozone of Toumarkine and Luterbacher (1985) and P7 Biozone of Berggren and Miller (1988).

The calcareous nannofossils were studied by Wilcoxon (1973) and Kapellos and Schaub (1975). They recognized the same biozones for the Illeridian: *Discoaster multiradiatus*, *Marthasterites contortus*, *Discoaster binodosus* and *Tribrachiatus orthostylus* (= *Marthasterites tribrachiatus*). Recently, the calcareous nannoplankton have been restudied (Molina *et al.*, 1989; Canudo *et al.* 1989). In the Illeridian and Ypresian interval the following zones of Martini (1971) have been recognized: NP 9 (upper part), NP 10, NP 11, NP 12 and NP 13.

The dinoflagellates were studied by Caro (1973) who recognized the following Illeridian-Ypresian biozones: "*Wetzelialla*" *hyperacantha* (upper part), *Wetzelialla articulata*, *Wetzelialla unicaudalis* and *Wetzelialla coleothrypta* (lower part). He discussed the stratigraphic value of these biozones indicating their relationship with zonations based on other groups of microfossils present in the Campo section.

The ostracoda were studied by Ducasse (1972) who established five zones in the Campo section, the Illeridian being composed of zones 2 to 5 (lower part). The revision carried out for this paper allows to recognize and modify the same biozonation that Carbonnel (1975) defined for the Tremp section. Perhaps owing to an ecological control and/or to

the chance of sampling, the index species level of appearance of the new *E. posterior* Biozone is found in stratigraphically higher levels than in Tremp section. Consequently, the biozonal boundary has been drawn with an oblique dotted line.

The magnetostratigraphy of the Illeridian parastratotype is marked, in the lower part, by a long reversed polarity period that comprises the upper part of the Thanetian limestones and sandstones, the *Alveolina* limestones and the Riguala marls. Comparing the obtained paleontological data with the reference scales suggests that the lower part of the section corresponds to Chron 25. The boundary between the Thanetian with the Illeridian *Alveolina* limestones is an unconformity characterized by the presence of a hardground followed by fluvial deposits. The absence of the normal anomaly 25n could be attributed to this gap. In the bottom of the La Pobla level a normal polarity direction within a problematic zone has been found. Although it is recommended that at least three reliable directions are used at one site to make sure of the polarity, this normal direction indicates that part of the La Pobla level could correspond to Chron 24.2. Above it there is a reversed period that continues into the lower part of the marls equivalents to the Roda Sandstone. The middle part of these marls corresponds to a normal polarity zone (Chron 24.1) and the uppermost samples studied show a reversed polarity zone that corresponds to Chron 23r.

## THE ILLERDIAN AND THE PALEOCENE/EOCENE BOUNDARY

According to the data summarized in figures 1-4, the chronostratigraphic position of the Illeridian can be precisely determined. The data obtained from its rich micropaleontological record have been used to establish the correlation between the biozonations for this time interval and this is a good example of integrated biostratigraphy.

The chronostratigraphical scales more frequently used (Berggren *et al.*, 1985; Cavelier and Pomerol, 1986; Aubry *et al.*, 1988) considered the Ypresian as the standard stage for the Early Eocene. According to biostratigraphical data published about the Ypresian (Aubry, 1983; Steurbaut, 1988) it comprised the calcareous nannofossil NP 10?, NP 11, NP 12, NP 13 and NP 14 (lower part) Biozones, and the Cuisian stage completely overlaps with the Ypresian, being a junior synonym.



In the Late Paleocene the Thanetian has been the more frequently used standard stage. According to Curry (1981) and Hamilton and Hoojatzadeh (1982) the stratotype belongs to NP 8 and the base of NP 9. Nevertheless, the NP 9 index form *Discoaster multiradiatus*, was not found by Aubry (1983) who believes that the greater part belongs to NP 8 and the non-fossiliferous extreme base may be older. The Selandian, which is another Paleocene stage, has been revised by Perch-Nielsen and Hasen (1981) who determined that its base may correspond to Zone NP 4 (upper part), which is much older than the Thanetian. The "Unfossiliferous Clay", that constitutes the top of the Selandian, by correlation based on indirect evidence could correspond to NP 9 (lower part). According to Cavalier and Pomerol (1986), the attribution of this latter formation (probably unconformable) to the Selandian remains debateable.

The Illeridian stage, in terms of calcareous nanofossils corresponds to NP 9 (upper part), NP 10 and NP 11 Biozones of Martini (1971). The extreme base of the Illeridian was mainly dated as the *Alveolina cucumiformis* Biozone, which is now correlated in the lower part of the planktic foraminifera *Morozovella aequa* Biozone of Canudo and Molina (1992). The top of the Illeridian was mainly dated by the *Alveolina trempina* Biozone, which is now correlated with the planktic foraminifera *M.formosa-M.lensiformis* (P6c) of Berggren and Miller (1988). Consequently, the Early Illeridian spans a gap between the Thanetian and the Ypresian that is not represented in any European marine classical stages. The Sparnacian and the Late Landenian, that seem to cover this interval, are both made up of continental facies and are unsuitable to be considered as standard stages. The Middle and Late Illeridian overlap with the Ypresian, since the calcareous nanofossils NP 10? and NP 11 Biozones has been recognized in both stages. This was also concluded by Bignot and Moorkens (1975) and by Cavalier and Pomerol (1986) who more precisely indicated that the dinoflagellata W2 Biozone was also recognized in the Middle Illeridian and in the base of the Ypresian.

The Paleocene/Eocene boundary is a problem since there is not yet a general agreement on its

position on the geologic time scale. In order to precisely place this boundary, the International Subcommission on Paleogene Stratigraphy has organized a Working Group to establish a Paleocene/Eocene Boundary Stratotype. The Paleocene/Eocene boundary used today has different placements depending on the speciality of the authors. For Mammalogists it must be located between the Paris basin Thanetian and Sparnacian, for specialists in larger foraminifera at the base of the Illeridian and for the majority of the specialists in planktic foraminifera at the *Pseudohastigerina* first appearance "datum", which is believed to occur at the base of the Ypresian.

To solve some problems Plaziat (1975) suggested moving the lower limit of the Illeridian down so as to include the *Glomalveolina levis* zone, so that it would correlate with the mammalian boundary. Nevertheless, it is not clear whether the major break in mammalian faunas coincides with the Thanetian/Sparnacian boundary or with the Thanetian/Illeridian boundary. By that time Pomerol (1975) proposed the placement of the Paleocene/Eocene boundary at the base of the Illeridian. According to Cavalier and Pomerol (1986) the P/E boundary based on a major break in mammalian faunas occurs practically at the base of the *Morozovella velascoensis* Zone (P5) and at the point where *Nummulites* and large flosculinized *Alveolina* appear, corresponding with other biostratigraphical, magnetostratigraphical and geochemical breaks. According to this proposal the P/E boundary could correspond with the Thanetian/Illeridian boundary.

The *Pseudohastigerina* "datum" has been used by some authors to define the Paleocene/Eocene boundary, which induced Plaziat (1981) to propose the lowering of the upper limit of the Illeridian (trying to adapt exactly the Illeridian to the range of the objectionable Sparnacian) to place it between the *A. moussoulensis* and *A. corbarica* Biozones. However, the *Pseudohastigerina* first appearance datum plane does not seem to be very isochronous and there are some taxonomic problems in discriminating between *Pseudohastigerina wilcoxensis* and its ancestor *Globanomalina ovalis*. Furthermore, it is not clear whether the first appearance of *Pseudohastigerina* coincides with the base of the Ypresian;

on the contrary, this genus seems to first appear in younger horizons.

Consequently, the different proposals regarding the position of the Paleocene/Eocene boundary need further study. At this stage, we propose to define a time interval called "Paleocene/Eocene boundary time span", which comprises from the base of the Ilerdian to the base of the Ypresian.

## CONCLUSION

The base of the Ilerdian is placed in the base of the *Alveolina cucumiformis* Biozone, in the base of *Nummulites fraasi* Biozone, in the base of *Assilina prisca* Biozone, in the upper part of *Angulogavelinella avnimelechi-Anomalinoidea rubiginosa* (BB1) Biozone, in the lower part of *Echinocythereis isabonana* Biozone, in the middle part of "Wetzeliella" *hyperacantha* Biozone, in the middle part of *Discoaster multiradiatus* (NP 9) Biozone, in the lower part of *Morozovella aequa* Biozone and in Chron 24r.

The top of the Ilerdian is placed in the *Alveolina trempina* Biozone, in the *Nummulites involutus* Biozone, in the *Assilina adrianensis* Biozone, in the lowermost part of *Cibicidoides subspiratus* (BB3) Biozone, in the lower part of *Echinocythereis posterior* Biozone, in the upper part of *Wetzeliella unicaudalis* Biozone, in the uppermost part of *Discoaster binodosus* (NP 11) Biozone, in the upper part of *Pseudohastigerina wilcoxensis* Biozone and in Chron 24.1r.

Consequently, the Ilerdian is today a very well defined Stage, represented by thick and relatively continuous marine sediments, excellently exposed and very rich in microfossils, being now one of the best known European stages. The Middle and Late Ilerdian overlap with the Ypresian but the Early Ilerdian spans a gap between the Thanetian and Ypresian that is not represented in any of the European marine classical stages.

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