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MESOZOIC AND CENOZOIC SEQUENCE STRATIGRAPHY OF EUROPEAN BASINS

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ABSTRACT: Under the auspices of the "Mesozoic-Cenozoic Sequence Stratigraphy of European Basins" project (MCSSEB) an attempt was made to construct a state-of-the-art biochronostratigraphic record of depositional sequences in European basins for the Mesozoic and Cenozoic. A well-calibrated regional biochronostratigraphic framework is seen as an essential step towards an eventual demonstration of synchroneity of sequences in basins with different tectonic histories. The Mesozoic sequence stratigraphic and biostratigraphic records for the project (MCSSEB) are calibrated to the Gradstein et al. (1994) temporal scale. The Cenozoic record is calibrated to the Berggren et al. (1995) scale. The primary calibration in the Mesozoic between temporal and standard stratigraphy is based on ammonite biostratigraphy. This calibration was facilitated by the integration of the composite ammonite zonation of the "Sequence Stratigraphy of European Basins" project with the standard stratigraphy, magnetostratigraphy and radiometric data for the Triassic through lower Cretaceous intervals in the Gradstein et al. (1994) time scales. The Triassic through lower Cretaceous composite ammonite zonation in Gradstein et al. (1994) includes the highest resolution, zonal or subzonal, ammonite subdivisions available from tethyan as well as boreal areas in Europe. For the upper Cretaceous, Gradstein et al. (1994) calibrated their temporal scale with the Cobban et al. (1994) ammonite record from the Western Interior Basin in the United States, which is well correlated with $^{40}Ar/^{39}Ar$ dates from bentonites incorporated in the Obradovich (1993) and Gradstein et al. (1994) time scales. Calibration of the upper Cretaceous Western Interior Basin ammonite record with the European succession is relatively well understood for the Cenomanian through Santonian Stages but largely unresolved for the Campanian and Maastrichtian Stages. An incomplete ammonite record in the type areas in Europe and the lack of calibration between zonations of "cosmopolitan" fossil groups such as planktonic foraminifera, calcareous nannofossils and endemic ammonites in North America as well as Europe prevent adequate correlation. Calibration in the Cenozoic between temporal and standard stratigraphy is based on an integrated framework of magnetostratigraphy, planktonic foraminifera and calcareous nannofossils and selected radiometric ages. Subsequent calibration of sequences, strontium isotope ratios ($^{87}Sr/^{86}Sr$), oxygen isotope events, and additional fossil groups from oceanic, near shore and non-marine environments, was carried out by a large number of coordinators and contributors.

INTRODUCTION

The chronostratigraphic charts presented in this paper are the result of an initiative by Peter Vail and Thierry Jacquin in 1990 to analyze and document depositional sequences in European basins and to record their stratigraphic position relative to a state-of-the-art temporal framework accurately calibrated to a biostratigraphic framework. The "Mesozoic-Cenozoic Sequence Stratigraphy of European Basins" project started officially with a meeting in Dijon France organized by Jacquin, de Graciansky, and Vail, in May 1992. Sequence interpretations for a large number of European basins were presented at poster sessions in Dijon. Papers in this volume, many of them based on the Dijon posters, form an integral part of the sequence documentation for the chronostratigraphic charts.

Work on the detailed chronostratigraphic charts for the Mesozoic and Cenozoic began eighteen months before the Dijon Meeting, in December 1990 in Paris with a planning meeting attended by a large number of specialists in a wide range of biostratigraphic disciplines from several European countries. At the Paris meeting, all specialists present were invited to participate in the calibration of fossil groups representing non-marine, shallow- and deep-water depositional environments to a revised temporal framework. Invitations were extended to specialists not present at the Paris meeting to complement the expertise in fossil groups essential to the construction of a stratigraphic framework and to the calibration of sequences. Progress was reviewed at workshops in Paris in May and December 1991 and a preliminary biochronostratigraphic framework calibrated to the Haq et al. (1987) time scale was presented at the Dijon Conference in 1992. After completion of the Gradstein et al. (1994) Mesozoic time scale and the Berggren et al. (1995) Cenozoic time scale, all biostratigraphic, isotope stratigraphic and sequence stratigraphic entries were recalibrated to the new time scales.

SEISMIC STRATIGRAPHY/SEQUENCE STRATIGRAPHY

Mitchum et al. (1977) described the depositional sequence as a basic unit for stratigraphic analysis with chronostratigraphic significance. They defined the depositional sequence as follows: "*A depositional sequence is a stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative conformities.*" This definition adds the concept of the "correlative conformity" to the unconformity-bounded sequence in the sense of Sloss (1963). Adding the "correlative conformity" to the sequence definition is essential to allow application of sequence stratigraphy in areas of continuous deposition. Even though Mitchum et al. (1977) discussed the chronostratigraphic significance of their sequence, they defined the sequence as a lithologic unit ("*A depositional sequence is determined by a single objective criterion, the physical relations of the strata themselves*)." They stopped,

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however, short of defining a sequence chronostratigraphic unit even though they defined a geochronologic unit sechron as: "*the maximum interval of geologic time occupied by a given depositional sequence, defined at the points where the boundaries of the sequence change laterally from unconformities to conformities along which there is no significant hiatus.*"

Here we simplify the lithologic definition of the sequence by Mitchum et al. (1977) as follows: A *depositional sequence* is a lithologic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities and their correlative conformities.

We also define the chronostratigraphic unit or sequence chronozone as follows: A *sequence chronozone* comprises all strata deposited globally during the timespan of a sequence measured at the correlative conformity where the bounding unconformities become conformable. A sequence chronozone can thus be viewed as a chronostratigraphic unit which includes all rocks deposited globally during the elapsed time between successive falls in relative sea level.

The geochronologic unit sechron defined by Mitchum et al. (1977) could be simplified as: A *sechron* spans the total interval of geologic time during which a sequence is deposited.

Sequences and subsequences of Sloss (1963), equivalent to megasequences and supersequence sets of Haq et al. (1987, 1988) are major tectono-eustatic units shaped by plate tectonic events that affect longer term eustatic sea level. Even supersequence boundaries of Haq et al. (1987, 1988), correlate well with times of major changes in plate spreading rate and direction (Ross, 1995). Higher frequency (3rd-order) sequences of Mitchum and Vail (1977), Haq et al. (1987, 1988) are shaped primarily by the interaction of sea-level changes with sediment supply, against the backdrop of basin subsidence. Subsidence/uplift is controlled by complex local and regional tectonic factors and is expected to differ from place to place; eustasy, however, represents a global signal. The higher frequency of a glacio-eustatic signal holds promise for high-resolution global stratigraphic correlation, provided it's signal can be reliably deduced from the sediment record. The likely mechanism behind these higher frequency sea-level changes is, in the Eocene to recent interval, almost certainly glacio-eustasy (Miller et al., 1987, 1991a), Abreu et al. (this volume), Abreu and Haddad (this volume), Abreu and Anderson (in press). For higher frequency sea level changes prior to the Eocene, Abreu et al. (this volume) postulate the possibility of glacial episodes during the Aptian and Maastrichtian although the Cretaceous and Paleocene glacial history remains largely unknown.

Sequence stratigraphy evolved from seismic stratigraphy (Vail et al., 1977), when the realization was made that packages of sediments observed on reflection seismic data could also be identified in wells and outcrop sections. Stratigraphers and sedimentologists seized on this opportunity that opened new dimensions to their respective disciplines. Stratigraphers sensed the enormous potential of a high frequency eustatic signal for global stratigraphic correlation and focussed on the chronostratigraphic position of the bounding surfaces. Haq et al. (1987) proposed a chronostratigraphic record of Mesozoic and Cenozoic sequences, mostly based on the temporally well-constrained classic stage type and reference sections in Europe. This record expanded on the Vail et al. (1977), uppermost Triassic to Pleistocene, chronostratigraphic record of depositional sequences identified on seismic sections and dated with available well control.

Sedimentologists focussed on modelling sediment response to changes in relative sea level (Jervey, 1988; Posamentier et al., 1988, Posamentier and Vail, 1988). Sarg (1988) and Van Wagoner et al. (1990) describe facies evolution in a sequence stratigraphic context for carbonate and siliciclastic depositional environments respectively. Mitchum (1977) and Van Wagoner et al. (1988) summarized definitions and terminology related to sequence stratigraphy.

The principal focus of this paper is to revisit the stratigraphic aspects of sequence stratigraphy and provide a chronostratigraphic record of sequence boundaries to complement the Haq et al. (1987) sequence record with new data provided by the contributors to the "Mesozoic-Cenozoic Sequence Stratigraphy of European Basins" project.

Sequence Boundaries and Correlative Conformities

Terrigenous sediments transported offshore accumulate relatively close to the basin margin and are shaped in packages (sequences or systems tracts) bounded by surfaces (sequence boundaries) as a response to the principal variables of sediment supply, subsidence and eustasy. Farther offshore the influence of terrigenous sedimentation decreases and a more pelagic, but not necessarily continuous, sedimentation dominates in which the sequence and systems tract packages and their bounding surfaces are often not well expressed and sequence boundaries become correlative conformities. In any given section a sequence boundary may be deduced from changes in lithofacies across physical surfaces (subaerial-erosional truncation surfaces and flooding or transgressive surfaces of onlap) and from vertical facies relationships (downward shift) Van Wagoner et al. (1990). In basinal settings, where changes in lithofacies are subtle, sequence boundaries or their correlative conformities may be identified from biotic analysis, well logs and/or geochemical analyses. In theory, the chronostratigraphic position of a sequence boundary is determined at the point where the bounding unconformity becomes conformable. The chronostratigraphic position can only be determined by comparing its stratigraphic position with other well-calibrated stratigraphic disciplines either biostratigraphy, magnetostratigraphy, chemostratography or preferably, a combination of those disciplines. In practice, the correlative conformity may not be recognizable in outcrop and the stratigraphic position of a sequence boundary is determined by choosing a section where lowstand deposits are developed, and the sequence boundary is identified within a biostratigraphic zone of a fossil group with high-stratigraphic resolution. Comparing the stratigraphic position of a sequence boundary in different settings in different basins will eventually reveal the stratigraphic position of the correlative conformity.

In outcrops along slowly subsiding margins with moderate sedimentation rates, prevalent in many basins of western Europe, the most often recognized surface is the combined sequence boundary and subsequent flooding (transgressive) surface. Most standard stage type sections located in passive-margin settings, have a transgressive surface as their lower boundary. However, the lowstand portion of the sequence and unknown portions of the previous highstand and transgressive deposits are missing in that position, but should be present farther down-dip in the basin. In the North Sea Basin for example, transgressive deposits and highstand deposits are found along the basin margins and lowstand deposits are concentrated in the deeper parts of the basin. When ocean drilling established a composite stratigraphic record for the Cretaceous and Cenozoic, hiatuses in the onshore standard record were the source of considerable debate on the placement of stage boundaries. Currently, the Global Boundary Stratotype Section and Point (GSSP) effort by the Commission on Stratigraphy is underway to define stage boundaries in settings where sedimentation is continuous across stage boundaries.

1987 CHRONOSTRATIGRAPHIC SEQUENCE RECORD

The stratigraphic record of Mesozoic and Cenozoic depositional sequences, calibrated to a temporal framework presented by Haq et al. (1987), is based on the sequence stratigraphic premise that deposition is controlled by the principal variables of subsidence/uplift of the basin floor, sediment supply and eustasy (Hardenbol et al., 1981; Jervey, 1988). Subsidence/uplift, controlled by tectonics on a plate tectonic to basinal scale, and sediment supply, controlled by tectonics and climate, is expected to differ between basins or even parts of the same basin. Eustasy, on the other hand, whether caused by volume changes of oceanic basins or by sequestering of water in the form of continental ice and in inland seas and lakes, is controlled by tectonics and climate as well, but its effects are global. This global effect, recognizable in the rock record, represents a synchronous stratigraphic signal. Haq et al. (1987) presented a stratigraphic record of hundred nineteen Mesozoic and Cenozoic sequences and their relative onlap calibrated to a temporal scale which expanded on the Vail et al. (1977), uppermost Triassic to Pleistocene, chronostratigraphic record of depositional sequences. Haq et al. (1987) identified considerable more sequences in outcrop than were identified by Vail et al. (1977) from seismic records. Sequence resolution is a function of local sedimentation rates but is often lower on seismic records than in outcrop sections deposited at similar rates. In general, sequence resolution increases in the direction of depocenters. Establishing the temporal position of sequence boundaries identified from seismic records requires well control in sediments conducive to reliable chronostratigraphic analysis.

Haq et al. (1987) placed shifts in coastal onlap and changes in sea level in three categories of relative magnitude: major, medium and minor (determined from seismic and outcrop records). Short-term sea-level changes derived from relative onlap and magnitude were expressed within an envelope of long-term sea-level change. The long-term sea-level envelope was then calibrated to its highest position of about 260 m in the early Turonian (Kominz, 1984; Pitman, 1978) and modern sea level at 60 m (which assumes no icecaps). In addition, sequences were tentatively ordered in a hierarchical system of 1st-order megasequences nearly identical to the sequences proposed for the North American craton by Sloss (1963, 1988), and 2nd-order supersequences which are subsequences of Sloss (1963, 1988). Second-order supersequences sets and 3rd-order sequences do not have Sloss (1963, 1988) equivalents. Sequences with lowstand submarine fans were indicated as type 1 and all others as type 2 sequences.

Most sequences in the Mesozoic record of Haq et al. (1987) were calibrated to the temporal scale through first-order calibrations to ammonite biostratigraphy. The limited number of radiometric dates in the Mesozoic, prior to the upper Cretaceous, are often not precisely calibrated to ammonite zones but to sub-stages. To subdivide stages, ammonite zones within a stage were allotted equal duration. Few of the other fossil groups on the Mesozoic portion of the Haq et al. (1987) record represent first-order correlation with ammonite zones. Sequences in the Cenozoic portion of Haq et al. (1987) were calibrated to the temporal scale through first- and second-order calibrations with an integrated framework of planktonic foraminifera and calcareous nannofossils.

To facilitate the calibration of sequences to the temporal framework, Haq et al. (1987) focused on extensively studied and biostratigraphically documented stage type and reference sections in Europe. Many type sections are selected in deposits laid down in shallow-marine environments and facies changes across sequence boundaries are rather well expressed, although lowstand deposits are often absent.

MESOZOIC-CENOZOIC CHRONOSTRATIGRAPHIC CHARTS

Temporal Framework

Developments in geochronology since the publication of the Haq et al. (1987) Mesozoic-Cenozoic time scale, such as new $^{40}Ar/^{39}Ar$ dates for the upper Cretaceous of the North American Western Interior Seaway (Obradovich 1993) and the selection and dating of a boundary stratotype (GSSP) for the Eocene-Oligocene boundary, rendered all published time scales out of date, at least to some extent. For the Cenozoic, a new integrated time scale (Berggren et al., 1995) was made available for the calibration of the Cenozoic bio- and sequencechronostratigraphic record. In order to incorporate new $^{40}Ar/^{39}Ar$ dates (Obradovich 1993) for the upper Cretaceous and integrate new magnetostratigraphic and bio-stratigraphic calibrations, a separate time scale effort was initiated which resulted in an improved Mesozoic time scale (Gradstein et al., 1994).

Cenozoic Time Scale

The Cenozoic time scale (Berggren et al., 1995) integrates an extensive DSDP/ODP record on magnetostratigraphy, planktonic foraminifera and calcareous nannofossil biostratigraphy and standard stratigraphy with selected radiometric dates to produce a well-calibrated temporal framework (see appendix). Sequences are positioned relative to the Berggren et al. (1995) temporal framework primarily with calcareous nannofossils and planktonic foraminifera (Chart 2). The calibration of fossil groups to this integrated framework (Chart 3) is not documented in this volume and is the responsibility of the coordinator(s) for that particular fossil group. Manuscripts with biostratigraphic documentation submitted by coordinators are or will be published in the Bulletin de la Société Géologique de France: Larger Foraminifera (Cahuzac and Poignant, 1997; Serra-Kiel et al., 1988 in press). Brief summaries submitted by several coordinators are, because of space constraints, included in an appendix.

Mesozoic Time Scale

The Mesozoic time scale (Gradstein et al., 1994) integrates standard stratigraphy, magnetostratigraphy and ammonite biostratigraphy with high-temperature radiometric dates to produce an updated temporal framework (see appendix). The composite ammonite zonation of Gradstein et al. (1994) is, except for the upper Cretaceous, based on highest resolution zonal or subzonal subdivisions from tethyan and boreal areas provided by coordinators for ammonite biostratigraphy of the Sequence Stratigraphy of European Basins Project. For the upper Cretaceous, Gradstein et al. (1994) used the high-resolution ammonite zonation of the Western Interior Seaway Basins in North America (Cobban et al., 1994; Obradovich, 1993) because the $^{40}Ar/^{39}Ar$ radiometric dates of Obradovich (1993) were directly calibrated to the North American ammonite record. Calibration of the North American ammonite record to the standard stages and the European ammonite record remains tentative. Sequences are calibrated to the Gradstein et al. (1994) temporal framework primarily with ammonites (Charts 4, 6, 8).

Calibration of fossil groups, provided by coordinators, to the temporal framework of Gradstein et al. (1994) is not documented in this paper. The provided information is plotted on (Charts 5, 7, 8). Some coordinators submitted manuscripts with biostratigraphic documentation; these will be, or are already published in the Bulletin de la Société Géologique de France: Jurassic calcareous nannofossils (De Kaenel et al., 1996), Cretaceous benthic foraminifera (Magniez-Jannin, 1995), Jurassic dinoflagellates (Riding and Ioannides, 1996), Mesozoic-Cenozoic charophytes (Riveline et al., 1996), Cretaceous planktonic foraminifera (Robaszynski and Caron, 1995) and Triassic ammonoids (Mietto and Manfrin, 1995). Jurassic Brachiopods (Almeras et al., 1994) appeared in Geobios. Cariou and Hantzpergue (1997) coordinated an effort of the "Groupe Français d'Étude du Jurassique" to improve stratigraphic calibration of many of the same fossil groups addressed in this study. Summaries submitted by several coordinators are included in an appendix.

Sequence Record

The primary objective of this volume is to provide a state-of-the-art stratigraphic record of sequences identified as part of the Mesozoic-Cenozoic Sequence Stratigraphy of European Basins project. Independent records of sequences in tethyan and boreal basins calibrated to their respective ammonite zonations are summarized on the Mesozoic sequence chronostratigraphic charts from the base of the Triassic through the Turonian (Charts 4, 6, 8). Even though a comparable number of sequences were identified in the tethyan and boreal basins, synchroneity can only be demonstrated with the help of independent stratigraphic tools. In the Jurassic, ammonite records between boreal and tethyan basins considered for this project are much better calibrated than in the Triassic or lower Cretaceous. As a result, sequence records for boreal basins resemble those for tethyan basins closely in most of the Jurassic but the agreement is not as close in the Triassic. The lower Cretaceous interval shows major gaps in the sequence record because fewer papers were submitted while the calibration between boreal and tethyan ammonite zonations is much more tentative.

Jacquin and de Graciansky (this volume) identify four "Major Transgressive-Regressive Cycles" (MTR cycles) in the Mesozoic e.g., Eastern Tethys Cycle (Triassic), Ligurian and North Sea Cycles (Jurassic) and North Atlantic/Biscay Cycle (Cretaceous). Boundaries between MTR cycles do not coincide with system or series boundaries. In the Cenozoic, two additional unnamed MTR cycles are identified but not named. MTR cycles reflect the response of the western portion of the Eurasian plate to major plate tectonic phases in the opening of the Atlantic Ocean (Ziegler, 1990). These major tectonic phases affect the volume of ocean basins and hence global sea level and thus produce synchronous tectono-eustatic MTR cycles which are essentially identical for tethyan and boreal basins. Differences in sediment supply or correlation problems between tethyan and boreal ammonite zonations could explain the offset of the start of the regressive phase, as is the case in the middle Triassic, lower and upper Jurassic.

Jacquin and de Graciansky (this volume) also introduce the concept of "Transgressive-Regressive Facies Cycles" (TRF cycles), which describe sediment response to basin forming events resulting from regional and more local tectonic activity. The resulting tectono-eustatic effects are still producing a number of synchronous TRF cycles across Europe, but exceptions caused by local tectonics are rather ubiquitous as suggested by the numerous differences between boreal and tethyan basins on the sequence chronostratigraphic charts. Gianolla and Jacquin (this volume) describe the evolution of the principal TRF cycles (1 to 4) in Triassic basins from the Alps to the Barentz Sea. Jurassic TRF cycles (4 to 6) are documented by de Graciansky et al. a, b (this volume), TRF cycles (7 to 10) by Jacquin et al. (this volume). Lower Cretaceous TRF cycles (11 to 15) are summarized from European basins by Jacquin et al. (this volume). Triassic (Chart 8), Jurassic (Chart 6) and Cretaceous (Chart 4) sequence chronostratigraphic charts carry the Major Transgressive-Regressive Cycles proposed by Jacquin and de Graciansky (this volume) although their numbering system is not used on the charts. Their Transgressive-Regressive Facies Cycles are included on the Triassic, Jurassic and lower Cretaceous charts as well. TRF cycles in the Cenomanian, Turonian and Maastrichtian are based on outcrop records in northwestern Europe and the tethyan area, whereas Coniacian through Campanian TRF cycles are based on the Gulf Coast outcrop record (modified from Young, 1986). TRF cycles on the Cenozoic sequence chronostratigraphic chart are based on outcrop records of stage type areas in Europe.

As in Haq et al. (1987), sequences and subsequent flooding events are placed in three categories of relative magnitude: major, medium and minor. No attempt was made to organize sequences in a hierarchy of different orders of cyclicity even though some of the authors in this volume mentioned a hierarchy in their individual papers. A better understanding of the underlying mechanism and an independent measure of magnitudes are required before any hierarchical classification is justified. No distinction is made between Type 1 and Type 2 sequences, because local subsidence cannot be easily distinguished from the eustatic signal. Submarine fans are identified for essentially all sequences in the Paleocene and lower Eocene of the central North Sea Basin (Neal et al., this volume). Since no effort was devoted to quantification of falls and rises in relative sea level, no attempt was made to revise the coastal onlap curve and the derived eustatic curves of Haq et al. (1987, 1988). The new Mesozoic-Cenozoic stratigraphic record (except middle Eocene to recent) of sequences (Chart 1) is placed in the long term eustatic envelope of Haq et al. (1987). The middle Eocene to recent sequence record is placed in a short term oxygen isotope record of Abreu et al. (this volume). Below the middle Eocene short term eustasy is not indicated since no new quantitative information is available. Qualitative indications of magnitude (minor, medium and major) of sea level falls and rises are used instead. For comparison with the long term Mesozoic-Cenozoic eustatic envelope of Haq et al. (1987) a curve of inundated continental area (Ronov 1994) is shown on Chart 1. In addition, a long term eustatic curve based on oxygen isotopes for the Albian to recent interval (Abreu et al. this volume), is added in Chart 1.

The sequence stratigraphic entries on the new charts include a composite stratigraphic record of 221 sequence boundaries in the Mesozoic and Cenozoic. Haq et al. (1987) listed 119 sequences for the same interval. The increase in the number of sequences reflects the increase in the number of investigators as well as the number of basins studied, especially in the Triassic and the Jurassic where the number of sequences identified more than doubled. The number of sequences in the Cretaceous nearly doubled, even though few studies addressed the lower Cretaceous interval. In the upper Cretaceous (Coniacian through Campanian) sequence boundaries identified in boreal and tethyan basins could not be calibrated reliably to the temporal framework. Instead, for the Coniacian through lower Maastrichtian interval, a record of sequence boundaries from North America is included on the chart which could be calibrated to the North American ammonite zones included by Gradstein et al. (1994) in their Mesozoic time scale. Sequences of Haq et al. (1987) in the Coniacian through lower Maastrichtian interval were also based on the North American record and were tentatively calibrated to the standard stages. The increase in the number of sequences in the Cenozoic was smaller because parts of the Cenozoic were not re-studied as part of this project, and the Cenozoic was already studied in more detail by Haq et al. (1987). For comparison, sequences of Haq et al. (1987) are included on the charts calibrated to the new chronostratigraphic record.

Individual sequence boundaries are identified on the new charts by the first two to four letters of the name of the stage in which the sequence boundary is identified and numbered from old to young. For example, Ce1 represents the first sequence boundary in the lower Cenomanian and is situated within the *mantelli* ammonite zone. The next sequence boundary is Ce2 in the uppermost *dixoni* ammonite zone. The Cenomanian deposits below Ce1 are in sequence Al11 which has its lower bounding sequence boundary in the uppermost *dispar* ammonite zone in the Albian. If additional sequence boundaries were to be identified later between sequence boundaries Ce1 and Ce2 those could be identified as Ce1.1, Ce1.2, an additional sequence boundary below Ce1 could be identified as Ce0, etc.

Calibration of Sequence Boundaries, Bio-zonations and Isotope Data

Calibration of sequence boundaries to a temporal framework requires a stratigraphic discipline with a high resolution. Ammonite biostratigraphy represents the best calibrated, highest resolution stratigraphic discipline in the Mesozoic interval of the European basins studied. Ammonites are ubiquitous in the sedimentary record of many European basins and are extensively studied. Ammonite subdivisions are also well calibrated to the standard stages because they were traditionally included in their definition. Therefore, sequence boundaries on the Mesozoic charts are calibrated to ammonite zones or subzones and can be calibrated from basin to basin as long as the same ammonites are present. Unfortunately, ammonite assemblages differ from basin to basin as a function of the biogeographic provinces in which the basins are located. Calibration of ammonite zonations for different biogeographic provinces is a cooperative process and is still in progress. To preserve apparent differences in stratigraphic position of sequence boundaries between boreal and tethyan basins, all sequence boundaries, from the base of the Triassic to the top of the Turonian, are calibrated separately to ammonite records for boreal and tethyan provinces. In intervals with good agreement in ammonite calibration between boreal and tethyan provinces (Sinemurian through middle Oxfordian and Cenomanian through Turonian), sequence boundaries agree better than in intervals where differences in ammonite calibration are more pronounced (Triassic, upper Oxfordian through Tithonian and much of the Cretaceous). Other factors affecting agreement in sequence calibration are geographic distance between basins, the number of available studies (lower Cretaceous), the way ammonite zones are defined, hiatuses in shallow-water sections and the decision whether an ammonite appearance or disappearance is biozonal or chronozonal.

Synchroneity of sequence boundaries can only be demonstrated in the presence of high-resolution stratigraphic methods. In field observations, sequence boundaries can be positioned either within or at the boundary between ammonite zones. Those positioned at zonal boundaries are especially subject to further scrutiny of the completeness of the stratigraphic record at that location. Cenomanian sequence boundary Ce3 appears to fall between the *Mantelliceras dixoni* and *Acanthoceras rhotomagense* ammonite zones on the platform in the type area of the Cenomanian in France. The sequence boundary coincides, however, with the transgressive surface, and the lowstand deposits are not present on the platform. In basins where a lowstand is developed the sequence boundary occurs in the uppermost dixoni ammonite zone in the boreal realm (Robaszynski et al., this volume). However, in a tethyan realm (Robaszynski et al., 1993), the genus *Mantelliceras* persists to the sequence boundary but the first representatives of the genus *Acanthoceras* appear later in the lowstand deposits. The interval without *Mantelliceras* nor *Acanthoceras* was placed in a new *Cunningtoniceras inerme* zone and sequence boundary Ce3 was placed at the base of that zone. The evolutionary appearance of the planktonic foraminifer *Rotalipora reicheli* just below or just above the Ce3 sequence boundary and its disappearance close to the subsequent maximum flooding surface in sections in Tunisia, northwestern and southeastern France provides additional biostratigraphic evidence that sequence boundaries in this example are synchronous.

Calibration of the upper Cretaceous sequence boundaries identified in European basins to the temporal framework and to the North American ammonite record is relatively well understood for the Cenomanian and Turonian Stages but proved to be a challenge for the Coniacian through lower Maastrichtian interval. Western Interior seaway ammonite assemblages are mostly endemic and have very few counterparts among the European upper Cretaceous ammonites. The incomplete ammonite record in the type areas and the lack of calibration between the North American ammonite record and "cosmopolitan" fossil groups such as planktonic foraminifera and calcareous nannofossils, precludes the calibration of sequence boundaries identified in European basins in the Coniacian through Campanian interval. A record of North American sequence boundaries identified in the Gulf Coast area and calibrated to Western Interior seaway ammonite zones is included instead.

Stratigraphic calibration of sequence boundaries in the Cenozoic presents a very different challenge. Planktonic foraminifera and calcareous nannofossils are the fossil groups best suited for long-distance calibration. Both groups prefer low latitude and relatively deep water paleoenvironmental settings. Many of the basins studied for the MCSSEB project represent rather shallow, middle latitude basins (North Sea Basin, Pannonian Basin) in which the record of planktonic foraminifera and calcareous nannofossils is incomplete. Tethyan basins such as the Piedmont Basin in northern Italy and the western Pyreneen and Tremp basins in northern Spain provided a more complete record.

Oxygen and Strontium Isotopes

Chemostratigraphy is evolving rapidly into an independent discipline in stratigraphy. Strontium isotope data from published sources are included on the Cenozoic, Cretaceous and Jurassic Sequence Chronostratigraphic charts (Charts 2, 4, 6) to provide an additional discipline for stratigraphic calibration. Oxygen isotope data are included on the Cenozoic and Cretaceous charts (Abreu et al., this volume) and represent an additional approach to determine the stratigraphic position and magnitude of sea-level changes, especially if the case can be made that the observed fluctuations in the Paleogene and Cretaceous isotope records reflect changes in ice volume (Abreu et al., this volume).

Strontium isotope values calibrated to other chronostratigraphic records are available from the literature for the Jurassic through Cenozoic interval. Unfortunately, there are too few stratigraphically well-constrained strontium isotope data for the Triassic to justify including them on the Triassic chart (Chart 8). Strontium isotope ratios on the Jurassic chart (Chart 6) are derived from Jones et al. (1994a, b). These data are precisely located in standard ammonite zones in measured sections in Great Britain, so that they could be readily calibrated to the chronostratigraphic framework on the chart. Data for the lower Cretaceous interval, derived from Jones et al. (1994b) and calibrated to boreal ammonite zones in Great Britain, cannot be calibrated as precisely owing to the tentative nature of the correlation between boreal ammonite zones and tethyan standard zones on the chart. Strontium isotope data in the upper Cretaceous are primarily from the work of McArthur et al. (1994) in the Western Interior of North America. These data are calibrated to Western Interior ammonite zones which are included on the chart. Precise positions within zones are not available and data are averaged by ammonite zone and plotted at the midpoint of the zone. These upper Cretaceous data are supplemented in the upper Campanian and Maastrichtian with data derived from magnetostratigraphically-constrained ODP sites from the work of Barrera (1994), Barrera et al. (in press) and Sugarman et al. (1995). Cenozoic data for the Paleocene and lower Eocene are from Hess et al. (1986). Data for the Lutetian to the present are from Miller et al. (1988), Oslick et al. (1994), Mead and Hodell (1995) and Farrell et al. (1995). These data are derived from ODP sites and the original calibration to calcareous nannofossil biostratigraphy, oxygen isotope stratigraphy or magnetostratigraphy was recalibrated to the temporal framework on the Cenozoic Sequence Chronostratigraphic chart (Chart 2) as appropriate.

Strontium ratios on all three charts are adjusted to a single standard where NIST-987 is 0.710250.

The Cenozoic Sequence Chronostratigraphic chart (Chart 2), includes a composite smoothed oxygen isotope curve for the entire Cenozoic compiled from Abreu and Haddad (this volume) and Abreu and Anderson (in press). The composite smoothed isotope curves of Abreu and Haddad (this volume) and Abreu and Anderson (in press), simulate a sea-level curve from the Cretaceous-Tertiary boundary to the recent.

The Cretaceous Sequence Chronostratigraphic chart (Chart 4) includes a smoothed (7 points least square method) isotope record based on bulk rock samples from Cenomanian through lower Campanian outcrops in England (English Chalk) and Italy (Gubbio) (Jenkins et al., 1994) and an upper Campanian to Maastrichtian record from central Tunisia (Abreu et al., this volume). The Cretaceous chart also includes an Aptian through Maastrichtian isotope record of deep water benthic foraminifera compiled from published data (Abreu et al., this volume).

Composite oxygen isotope curves from the Aptian to the present (Abreu et al., this volume) show the lightest values in the lowermost Turonian and a gradual change towards the heavier values of the Quaternary. The long-term trend in the upper Cretaceous and Cenozoic oxygen isotope record towards more positive values is explained by progressive cooling and glaciation at the poles (Savin et al., 1975). Rather than a continuous process, the long-term cooling seems to be made up of several shorter-term steps in the isotope values that can be related to changes, either in ice volume or in bottom water temperatures (Abreu et al., this volume; Abreu and Anderson in press). The long-term evolution in the oxygen isotope values mimics the change in long term sea level proposed by Haq et al. (1987). Higher frequency shifts in the oxygen isotope record are proposed as proxy indicators for glaciation and sea-level fluctuations. Abreu and Haddad (this volume) demonstrate a strong stratigraphic relationship between higher frequency shifts in the oxygen isotope record and sequences proposed from the rock record. Oxygen isotope curves may well provide an independent method for stratigraphic calibration of major eustatic changes (Miller et al., 1987) and demonstrate synchroneity of depositional sequences on different continents.

CENOZOIC SEQUENCE CHRONOSTRATIGRAPHIC RECORD

The Cenozoic in Europe consists of two "Major Transgressive-Regressive Cycles" (Chart 2) controlled by steps in the opening of the Atlantic Ocean (Ziegler, 1990). The opening of the Atlantic (Reykjanus) and the failed rifting of the North Sea resulted in a major transgressive phase in the upper Paleocene and lower Eocene. The middle Eocene through lower Oligocene represents an overall regressive phase. A second transgressive episode from the upper Oligocene to the middle Miocene is related to the opening of the North Atlantic. The Neogene from the middle Miocene to the present is mainly regressive. Basin-forming events in the Cenozoic of Europe are controlled by episodes in the opening of the Atlantic Ocean and the resulting compression between Europe and Africa. Eight "Transgressive-Regressive Facies Cycles" are identified from outcrop records of stage type areas in Europe (the regressive early Paleocene is still part of the late Cretaceous "Major Regressive Cycle" and the late Maastrichtian "Regressive Facies Cycle").

Eleven papers on the Cenozoic sequence stratigraphic record submitted for publication in this volume permit a substantial revision of the Haq et al. (1987) record in the Paleocene through lower Eocene, the Oligocene through middle Miocene and the Plio-Pleistocene intervals. The middle through upper Eocene and the upper Miocene are unchanged from Haq et al. (1987). The Paleocene to lower Eocene stratigraphic record of sequences is as the Haq et al. (1987) record based on the southern onshore North Sea Basin sections in southern England and Belgium (Neal et al., this volume; Vandenberghe et al., this volume) with seismic stratigraphic support from the offshore central North Sea basin. The Oligocene through lower Miocene sequence record is now calibrated to the Pannonian and Piedmont Basins (Vakarcs et al., this volume Gnaccolini et al., this volume) whereas Haq et al. (1987) based their record for this interval primarily on the southern North Sea Basin (Belgium) and the Aquitaine Basin (France). The middle Miocene record is also calibrated to the Piedmont and Pannonian Basins (Vakarcs et al., this volume; Gnaccolini et al., this volume) whereas Haq et al. (1987) is primarily based on the Piedmont Basin record. The Plio-Pleistocene record is as Haq et al. (1987), calibrated to the Calabrian and Sicilian deposits in Italy supplemented with offshore Gulf of Mexico data. Sequences at or near stage boundaries are identified with both stage prefixes to allow for future changes in the definition of stage boundaries as a result of the ongoing Global Boundary Stratotype and Point (GSSP) effort of the International Commission on Stratigraphy (ICS). Introductions to the Neogene (Vandenberghe and Hardenbol, this volume) and Paleogene (Neal and Hardenbol, this volume) summarize the papers submitted for the Cenozoic chapter of this volume and represent the principal documentation for the Cenozoic sequence chronostratigraphic record.

CRETACEOUS SEQUENCE CHRONOSTRATIGRAPHIC RECORD

The Cretaceous in western Europe is characterized by one Major Transgressive-Regressive Cycle named the North Atlantic/Biscaye Cycle, (Jacquin and de Graciansky, this volume). The earliest Cretaceous (Berriasian) represents the continuation of the regression that started near the Kimmeridgian/Tithonian boundary. The onset of the opening of the North Atlantic (Ziegler, 1990) marks the beginning of an overall transgressive phase that continues until the early Turonian and is followed by an overall regression that lasted into the early Cenozoic. Transgressive-Regressive Facies Cycles (TRF cycles) which describe sediment response to basin-forming events of a more local significance punctuate these Major Transgressive-Regressive Cycles (MTR cycles). Jacquin et al., (this volume) describes five TRF cycles (11 to 15) in the lower Cretaceous portion of the (North Atlantic/Biscaye, MTR cycle, (Jacquin and de Graciansky, this volume). TRF cycles in the upper Cretaceous are discussed below.

Upper Cretaceous Sequences

The upper Cretaceous introduced by Hardenbol and Robaszynski (this volume) summarizes the sequence stratigraphic information contained in five papers submitted for this part of the volume. The chronostratigraphic record of sequence boundaries in the upper Cretaceous is well calibrated in the Cenomanian and Turonian. Cosmopolitan ammonite assemblages in the Cenomanian and Turonian facilitate calibration between basins in different paleogeographic settings. As a result the record of sequence boundaries is better calibrated in the Cenomanian and Turonian than in any other Cretaceous interval. Cenomanian and Turonian deposits in western Europe suggest two Transgressive-Regressive Facies Cycles. The first TRF cycle begins at the Albian/Cenomanian boundary and includes the early Cenomanian. The second TRF cycle starts close to the base of the middle Cenomanian and includes the remainder of the Cenomanian and the entire Turonian. Cenomanian and Turonian sequences and TRF cycles on the Cretaceous chart (Chart 4) are based on records for tethyan and boreal areas described in Robaszynski et al. (this volume), Robaszynski et al., 1990, 1993.

The chronostratigraphic record of sequence boundaries in the Coniacian through Maastrichtian interval of European sections is poorly established. In contrast to the Cenomanian and Turonian the stratigraphic record of sequence boundaries for the Coniacian through Maastrichtian interval is the least calibrated of the entire Mesozoic-Cenozoic chronostratigraphic framework. Reliable first-order calibration between Campanian and Maastrichtian standard stages and biostratigraphic zonations, based on more cosmopolitan groups such as ammonites, planktonic foraminifera and calcareous nannofossils, are essentially non-existent. Even second- and third-order calibrations are scarce. Campanian/Maastrichtian strata in the boreal type areas of western Europe are mostly shallow-water deposits and do not contain diagnostic planktonic foraminifera and calcareous nannofossils. Outcrops are scattered over wide areas and assembling a composite section is problematic. Ammonites are scarce in outcrop and most of our current understanding is from a compilation of historical ammonite information from museum collections (Kennedy 1986). Ammonites suggest the lower and lower upper and perhaps the uppermost Campanian to be present. However, there seems to be no record for deposits between *Bostrychoceras polyplocum* and *Nostoceras hyatti* which in North America spans a period of 6–7 my.

The Coniacian through Maastrichtian record of sequence boundaries and TRF cycles on Chart 4 are, because of these unresolved uncertainties in the calibration of European biostratigraphic zonations with the Gradstein et al. (1994, 1995) temporal scale, based on a North American record. North American sequences identified along the Gulf Coast in Texas and Arkansas are calibrated to the North American ammonite zones of Cobban et al. (1994). Sequences in the Coniacian through lowermost Maastrichtian interval are based on a tentative sequence-stratigraphic interpretation of outcrop sections described in published records from the Gulf Coast areas in Texas and Arkansas (Young, 1986; Kennedy and Cobban, 1993a, b, c; Cobban and Kennedy 1992a, b, 1993, 1994). Most Maastrichtian sequences (Ma2 to Ma5) are interpreted from outcrops in the area of the Maastrichtian stratotype.

Coniacian through lower Campanian sequences are identified in the Austin area of central Texas. Young (1986) describes three significant transgressions onto the San Marcos platform in central Texas e.g., near the Santonian/Campanian boundary, upper Dessau Formation; middle Campanian, Pecan Gap Formation, and lower upper Maastrichtian, upper Corsicana Formation. These transgressions and two additional transgressions, one in the early Coniacian (onlap of Austin Chalk) and one in the upper Campanian (Bergstrom Formation) which yield no evidence of covering the San Marcos platform, are carried on the chart as Transgressive-Regressive Facies cycles.

The base of the Austin chalk onlaps Turonian strata, and the earliest Coniacian is not present in the Austin area. The transgressive base of the Austin Chalks is the base of the Atco Formation. The basal sequence boundary may actually be in the uppermost Turonian = Tu4. Other sequences in the Austin area are: base of the Vinson Formation = Co1, base Jonah Formation = Sa1, base Dessau Formation = Sa2, base upper Dessau Formation = Sa3, base Burditt Formation = Cam1 and base Sprinkle Formation = Cam2, Young (1986). The stratigraphic position of the sequences identified in the Austin area remains tentative because of uncertainties in the calibration of Young's ammonite zonation with Cobban's Western Interior ammonite zonation.

Lower Campanian to lowermost Maastrichtian sequences are based on well dated surfaces described in a series of papers on ammonite-bearing deposits in north eastern Texas and Arkansas by Kennedy and Cobban (1993a, b, c) and Cobban and Kennedy (1992a, b, 1993, 1994). The deposits described are obvious transgressive deposits associated with major flooding surfaces from which much of the ammonite record in the Gulf coast area is reported. The ammonite localities are: Roxton Formation = Cam2 (Cobban and Kennedy, 1992), North Sulpher River = Cam3 (Cobban and Kennedy, 1992), Wolfe City Sand Formation = Cam4 (Cobban and Kennedy, 1993a), Pecan Gap Formation = Cam5 (Cobban and Kennedy, 1994), Annona Chalk Formation at Okay = Cam6 (Kennedy and Cobban 1993), Annona Chalk Formation at Yancy 1 = Cam7 and Yancy 2 = Cam8 (Kennedy and Cobban, (1993a), Saratoga Formation = Cam9 (Kennedy and Cobban, 1993) and Nacatoch Formation = Ma1 (Cobban and Kennedy, 1995).

Maastrichtian sequences Ma 2 to Ma 5, based on outcrop data from the type area of the Maastrichtian Stage in The Netherlands and Belgium are calibrated to belemnite zones which are also poorly calibrated to the Gradstein et al. (1994) time scale.

Lower Cretaceous Sequences

Two papers concerning the lower Cretaceous were submitted for publication in this volume. To complement the documentation for the sequence stratigraphic record of the lower Cretaceous, Jacquin et al. (this volume) provide an overview of sequences and Transgressive-Regressive Facies cycles comprised in the transgressive phase of the Cretaceous Major Transgressive-Regressive cycle. Jacquin et al. (this volume) describe sequences in TRF cycles (numbered 11 to 15), from the northern North Sea to southern Italy. These TRF cycles represent sediment response to eustatic events caused by regional tectonic events superimposed on major intra-plate reorganizations. Jacquin et al. (this volume) summarize the lower Cretaceous sequence record in the context of his Transgressive-Regressive Facies cycles. Hoedemaeker (this volume) describes sequences in the Berriasian-Barremian interval in southeastern Spain. Ruffell and Wach identify several sequences in the Albo-Aptian of southern and eastern England.

JURASSIC SEQUENCE CHRONOSTRATIGRAPHIC RECORD

The Jurassic in Europe is characterized by two Major Transgressive-Regressive Cycles (Jacquin and de Graciansky, this volume). The transgressive portion of the first cycle (Ligurian Cycle) begins in the uppermost Norian Stage (upper Triassic) becomes regressive near the base of the middle Toarcian in the lower Jurassic and ends at the base of the upper Aalenian in the middle Jurassic. The transgressive portion of the second cycle (North Sea Cycle) begins in the middle Jurassic and becomes regressive near the top of the Kimmeridgian in the upper Jurassic and ends in the earliest Cretaceous (uppermost Berriasian). De Graciansky et al. a, b (this volume) and Jacquin et al. (this volume) describe Transgressive-Regressive Facies cycles (4 to 10) in the Jurassic. The number of TRF cycles and differences in the stratigraphic position of their bounding surfaces in tethyan and boreal basins reflect differences in sediment response to regional and more local tectonic activity. The record of individual sequences in the Ligurian MTR cycle (TRF cycles 4 to 6) is discussed in de Graciansky et al. (this volume) and for the North Sea MTR cycle (TRF cycles 7 to 10) boreal and tethyan basins is discussed in Jacquin et al. (this volume). Sequence stratigraphic interpretations for Jurassic Basins in Great Britain include Stephen and Davies (this volume) for the Moray Firth Basin, van Buchem and Knox (this volume) for the Cleveland Basin in Yorkshire and Hesselbo and Jenkyns (this volume) for the Wessex, Bristol Channel, Cleveland and Hebrides Basins. Gygi et al. (this volume) summarizes sequence stratigraphic interpretations in the Oxfordian and lower Kimmeridgian of northern Switzerland. Sequence stratigraphy of rift related basins in tethyan settings are by Leinfelder and Wilson (this volume) for the Lusitanian Basin in Portugal and Dumont (this volume) in the western Alps in southeastern France.

TRIASSIC SEQUENCE CHRONOSTRATIGRAPHIC RECORD

Sequence stratigraphic interpretations of Triassic deposits in European basins include contributions from the Dolomites and Lombardy in the Southern Alps, the Western Southern Alps, Northern Calcareous Alps, Paris Basin, SE France, Germany and SW Barentz Sea. Sequence interpretations in the different basins are calibrated either to a boreal (coordinator Van Veen), or a tethyan ammonoid biozonation (coordinators Mietto and Manfrin). Gianolla and Jacquin (this volume) summarized the contributions and calibrated the various sequence interpretations to these boreal and tethyan ammonoid biochronozones. Jacquin and de Graciansky (this volume) identify a Major Transgressive-Regressive Cycle starting low in the Triassic and ending in the uppermost Norian (Eastern Tethys Cycle) where a second MTR cycle (Ligurian Cycle) begins that continues to the upper Aalenian in the middle Jurassic. Gianolla and Jacquin (this volume) identify four TRF cycles (cycles 1 to 4) and 22 depositional sequences in Triassic basins from the Alps to the Barentz Sea. The lowermost TRF cycle (cycle 1) of Gianolla and Jacquin (this volume) may still be part of the Permian MTR cycle. Sequences carried on Chart 8 are discussed in Gianolla et al. (this volume) and Skjold et al. (this volume). Gianolla and Jacquin (this volume) summarize and calibrate all papers submitted for the Triassic chapter of this volume.

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CENOZOIC	
Planktonic Foraminifera	W. A. Berggren
Calcareous Nannofossils	M.-P. Aubry
Dinoflagellates	G. L. Williams, H. Brinkhuis, J. Bujak, S. Damassa, P. A. Hochuli, L. de Verteuil, D. Zevenboom
Ostracoda	J.-P. Colin, P. Carbonel, O. Ducasse, C. Guernet, Y. Tambareau
Larger Foraminifera	J. Serra-Kiel, L. Hottinger, B. Cahuzac, A. Poignant
Radiolarians	J. P. Caulet, A. Sanfilippo
Charophytes	J. Riveline, *J. P. Berger, M. Feist, I. Soulié-Märsche*
Mammals	J. J. Hooker, F. F. Steininger
Foraminifera North Sea	F. M. Gradstein
Diatoms	J. Barron
Oxygen Isotopes	V. S. Abreu
Strontium Isotopes	M. B. Farley (with assistance of C. Wu), K. E. Miller
Sequences	J. Hardenbol, J. E. Neal, N. Vandenberghe, G. A. Vakarcs, P. R. Vail
CRETACEOUS	
Ammonites	J. Thierry, J. M. Hancock, Ph. Hoedemaeker, F. Amédro, L. G. Bulot, W. A. Cobban
Belemnites	R. Combemorel, W. K. Christensen
Planktonic Foraminifera	F. Robaszynski, *I. Premoli-Silva, M. Caron*
Calcareous Nannofossils	K. Von Salis
Dinoflagellates	J.-C. Foucher, E. Monteil
Ostracoda	J.-P. Colin
Larger Foraminifera	M. Bilotte, A. Arnaud-Vanneau
Smaller Foraminifera	F. Magniez-Jannin
Charophytes	J. Riveline, *M. Feist*
Inoceramids	A. V. Dhondt
Radiolarians	P. de Wever
Calpionellids	J. Remane
Rudists	J.-P. Masse, J. Philip
Calcareous Algae	J.-P. Masse
Oxygen Isotopes	V. S. Abreu
Strontium Isotopes	M. B. Farley
Sequences	Th. Jacquin, J. Hardenbol, P. R. Vail
JURASSIC	
Ammonites	J. Thierry, *D. Contini, R. Mouterde, M. Rioult, S. Elmi, C. Mangold, E. Cariou, D. Marchand, R. Enay, F. Atrops, P. Hantzpergue, J. R. Geysant, M. Corña, J.-L. Dommergues, C. Meister, L. Rulleau*
Belemnites	R. Combemorel
Calcareous Nannofossils	K. Von Salis, J. Bergen, E. De Kaenel
Dinoflagellates	N. S. Ioannides, J. Riding, *E. Monteil, L. E. Stover*
Ostracoda	J.-P. Colin, *A.-M. Bodergat*
Larger Foraminifera	B. Peybernes
Smaller Foraminifera	C. Ruget, *F. Nicollin*
Brachiopods	B. Laurin, *A. Bouillier, Y. Almeras*
Charophytes	J. Riveline, *M. Shudack, C. Martin-Closas, M. Feist*
Radiolarians	P. de Wever
Calpionellids	J. Remane
Strontium Isotopes	M. B. Farley
Sequences	Th. Jacquin, P.-C. de Graciansky, P. R. Vail
TRIASSIC	
Ammonoids	P. Van Veen, P. Mietto, S. Manfrin
Calcareous Nannofossils	K. Von Salis
Dinoflagellates	P. A. Hochuli, *P. Van Veen, J. Riding*
Spores/Pollen	P. A. Hochuli, G. *Warrington, P. Van Veen, J. O. Vigran*
Ostracoda	J.-P. Colin
Larger Foraminifera	B. Peybernes
Charophytes	J. Riveline, *W. Bilan*
Conodonts	B. Vrielynck
Radiolarians	P. de Wever
Sequences	Th. Jacquin, P. Van Veen, P. Gianolla, P. R. Vail

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APPENDIX to: Hardenbol J., Thierry J., Farley, M. B., Jacquin Th., de Graciansky P.-C. and Vail P. R. Mesozoic and Cenozoic Sequence Chronostratigraphic Framework of European Basins

CENOZOIC ERA

GEOMAGNETIC POLARITY TIME-SCALE

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A new geomagnetic polarity time-scale for the late Cretaceous and Cenozoic (Cande and Kent, 1992: CK92) was based on an analysis of magnetic anomaly profiles from the world's ocean basins. It is the first time since Heirtzler et al. (1968) published their time-scale that the relative widths of the magnetic polarity intervals for this entire interval have been systematically determined from magnetic profiles. A composite geomagnetic polarity sequence was derived based primarily on data from the south Atlantic where anomaly spacings were constrained by a combination of 9 finite rotation poles and averages of 61 stacked profiles distributed over the 9 finite rotation pole intervals. Fine scale information was derived from magnetic profiles on faster spreading ridges in the Pacific and Indian Oceans and inserted into the south Atlantic sequence. Based on the assumption that spreading rates in the south Atlantic were smoothly varying but not necessarily constant, a time-scale was generated by using a spline function to fit a set of 9 age calibration points plus the zero-age ridge axis to the composite polarity sequence. The selected tiepoints (see also Berggren et al., 1992) reflect a preference for those data which can be tied to the magnetic anomaly sequence via marine magnetobiostratigraphic correlations and constraints from biostratigraphic correlation of sediments overlying oceanic basement.

The new time-scale has several significant differences from previous time-scales. For example, Cron C5n is ~0.5 my older and Chrons C9 through C24 are 2–3 my younger than in the chronologies of Berggren et al. (1985) and Harland et al. (1990). Many additional anomalies that may represent reversals of the global geomagnetic field were also identified, for example, between Anomalies 3A and 4A. On the other hand, an essentially continuous pattern of small scale anomalies or tiny wiggles was documented between Anomalies 24 and 27 that appear to be an "earth-filtered" record of short period (2 to 20 ky) intensity variations of the dipole field. This type of dipole field behavior, previously recognized within Anomaly 5 and between Anomalies 12 and 13, may have characterized the geomagnetic dynamo throughout the Cenozoic (Cande and Kent, 1992b).

Geomagnetic polarity chron nomenclature is based on the long-standing numbering scheme (sometimes with lettered additions) for magnetic lineations in which prominent anomalies (generally positive and corresponding to predominantly normal polarity) have been designated from 1 (youngest) to 34 over the Cenozoic and to the younger end of the Cretaceous Quiet Zone or Cretaceous Long Normal. A chron corresponds to the interval from the younger boundary of the eponymous anomaly to the younger boundary of the preceding anomaly and has the prefix C. (e.g., Chron C3A). However, each of these chrons is usually divided into the two constituent intervals of predominantly normal and reversed polarity which are designated by adding to the chron name the suffix n for normal polarity and r for the preceding reversed polarity interval (e.g., Chron C3An and Chron C3Ar). When these polarity chrons are further subdivided into shorter polarity intervals they are referred as subchrons and identified by appending, from youngest to oldest, a .1, .2, etc. to the polarity chron name, and adding an n for a normal polarity interval or an r for a reversed polarity interval (e.g., Chron C3An.1r). Finally, the designation -1, -2, etc. is used following a chron or subchron name to denote apparently very short polarity intervals corresponding to the tiny wiggles which, upon calibration, convert to durations of less than 30 ky. In view of their uncertain origin, these globally mapped geomagnetic features are referred to as cryptochrons and have not been included in any of these charts.

Cande and Kent (1995) generated an adjusted geomagnetic reversal chronology for the late Cretaceous and Cenozoic using the same tiepoints and anomaly distances as CK92 except in two instances: a) a consensus age of 65 Ma (rather than 66 Ma in CK92) was used for the Cretaceous/Paleocene boundary in Chron C29r; and b) a tiepoint at 5.23 Ma for the older boundary of Subchron C3n.4n was used rather than 2.60 Ma for the younger boundary of Chron C2An. The latter modification allowed the direct incorporation of the astrochronologically calibrated polarity time scale for practically all of the Pleistocene and the Pliocene that was developed by Shackleton et al. (1990) and Hilgen (1991) and thereby avoided the promulgation of separate time-scales over this interval (see discussion in Berggren et al., 1995a). The revised geomagnetic polarity time scale (CK92/95, or sometimes just CK95) was used as the chronological framework for the integrated Cenozoic time scale of Berggren et al. (1995b).

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PLANKTONIC FORAMINIFERA

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Calibration of planktonic foraminiferal datum events/zonal boundaries to the GPTS has been made essentially using the same DSDP and ODP sites/holes as reviewed below by Aubry. All datum events compiled in Berggren et al. (1985) have been reviewed and updated as well as all datum events identified and correlated to magnetostratigraphy in the 10 year interim to 1995. A major advance has been made in the compilation, and calibration, of Pliocene-Pleistocene datum events. The Achilles heel of this scheme remains, as for the calcareous nannoplankton, the middle Eocene, where lack of continuous, temporally complete stratigraphic sections precludes accurate magnetobiostratigraphic correlations. The Paleogene planktonic foraminiferal zonation follows that established by Berggren and Miller (1988); the Miocene zonal scheme is taken from Berggren et al. (1995), and the Pliocene Pleistocene is taken from Berggren et al. (1995b).

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CALCAREOUS NANNOFOSSILS

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The magnetobiostratigraphic/chronologic framework presented here draws from the recent revision to the Cenozoic time scale by Berggren et al. (1995a) for the Paleocene to Miocene and by Berggren et al. (1995b) for the Pliocene and Pleistocene. Progress in Cenozoic magnetobiostratigraphic correlations has been uneven since the publication of the work of Berggren et al. (1985a,b), and the number of sections reliable for magnetobiochronologic calibration remains very small, even for the Neogene. This is largely due to the lack of quality of magnetobiostratigraphic correlations in many sections, due to poor recovery in some, and to the ambiguity or insufficient quality of the magnetic polarity signal in others. We are just recognizing that the deep sea record is less complete than once thought and that unconformities may account for discrepancies previously attributed to diachrony (Aubry, 1995). As a consequence, temporal interpretation of stratigraphic sections must be conducted to establish that the sections used to calibrate datums to magnetochronology are continuous.

The calibration of Paleogene datums herein relies primarily on DSDP Holes 384 (Aubry in Berggren et al., 1995a), 527 (Shackleton et al., 1984) and 577 (Monecchi et al., 1985) for the Paleocene; on DSDP Holes 516 (Berggren et al., 1983a; Wei and Wise, 1989), 522,523 (Poore et al., 1982,1983), 527,528 (Shackleton et al., 1984), 530 (Steinmetz and Stradner, 1984), 550 (Aubry et al. 1995; Berggren and Aubry, 1995), ODP Holes 689,690B (Wei and Wise, 1990), 703A (Wei, 1991), 744 (Wei and Thierstein, 1991), 748 Aubry, (1992), and on the Contessa Highway, Massignano and Bottacione sections (Napoleone et al., 1983; Coccioni et al., 1988; Monecchi and Thierstein, 1995; Nocci et al., 1986; Premoli Silva et al.,1988) for the Eocene; on DSDP Holes 516F (Berggren et al., 1983a; Wei and Wise,1989), 522, (Poore et al.,1982), 558, 563 (Miller et al., 1985), ODP Hole 703A (Wei, 1991), 774A (Wei and Thierstein, 1991), 748A (Aubry,1992; Wei et al., 1992), and the Massignano section (Premoli Silva et al., 1988) for the Oligocene; and on DSDP Holes 558, 563 (Miller et al., 1985; Wright and Miller, 1993), 608 (Gartner,1992; Olafsson,1991), 516 (Berggren et al.,1983b), ODP sites 844, 845, 848, 852 and 853 (Raffi and Flores, 1995; Raffi et al., 1995) and the Buff Bay section, Jamaica (Aubry,1993 Berggren,1993 and Miller et al., 1994) for the Miocene. The reader is referred to Berggren et al., (1995a,b) for the details on magnetobiostratigraphic correlations in these sections. The calibration of Pliocene and Pleistocene calcareous nannofossil datums in Berggren et al. (1995b) is based on the studies of Backman and Shackleton (1983), Backman and Pestiaux (1987), Berggren et al. (1983). It appears there remain two main problematic stratigraphic intervals. Middle Eocene datums are poorly tied to the magnetic reversal pattern due to the lack of continuously recovered and (temporally) complete sections. Upper middle and lower upper Miocene datums (NN7-NN10 zonal interval) are unsatisfactorily tied to the magnetic polarity pattern because of unprecedented inconsistent correlations between calcareous microfossil (calcareous nannofossil and planktonic foraminifera) datums and magnetozones in different sections (see also Aubry, 1997). For this reason, two sets of magnetobiostratigraphic correlations are given for the NN7- NN10 zonal interval. Oligocene diachrony between high and mid-low latitudes is now well-established as a result of drilling in he Southern Ocean, and this is reflected in the magnetostratigraphic correlations as well.

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DINOFLAGELLATES

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The diversity of Tertiary dinoflagellates makes them ideal zonation microfossils for most marine deposits: the one exception is in abyssal sediments where the organic-walled species are rare. The increasing climatic differentiation between tropical and polar regions during this time, however, is reflected in the increasing provinciality of the assemblages. Consequently, any plots of the first appearance datums(FADs) and the last appearance datums (LADs) must include information on the source.

The most detailed studies of Tertiary dinoflagellate assemblages are based on the type sections of Europe, where there is calibration with the foraminiferal and nannofossil zonations. This is especially true of the Paleogene. The Miocene dinoflagellate assemblages from the type sections, however are poorly preserved when compared to other regions. For this reason, much of the data for this epoch has been derived from sections in the Salisbury embayment, eastern United

States of America. The Pliocene-Pleistocene records are primarily European and North Atlantic.

Our compilation has benefited from several comprehensive reviews of Tertiary biostratigraphy. These include Costa and Manum(1988), Powell (1992), Stover et al. (1996), Williams and Bujak (1985) and Williams et al. (1993). Costa and Manum(1988) and Powell (1992), published Paleocene-Miocene zonations for northwest Europe, with reference sections from surface and subsurface locations in Denmark (especially Jutland), southern England (primarily the Isle of Wight), France, Belgium, Germany, the North Sea and the North Atlantic Basin (Rockall Plateau and Bay of Biscay).

Many of the horizons plotted for the individual epochs are based on original research. In the Paleocene, a few of the FADs and LADs are based on the El Haria section, Tunisia, where there is continuous deposition across the Cretaceous/Tertiary boundary. Brinkhuis and Leereveld (1988) and Brinkhuis and Zachariasse (1988) describe the dinoflagellate assemblages from this section and correlated them with the planktonic foraminiferal zonation of Blow (1969) and the calcareous nannofossil zonation of Martini (1971). Northwest European Paleocene assemblages have been described by Hansen (1977,1979); Heilmann-Clausen (1985,1988); Hultberg (1986) and Powell et al. (1996).

The Eocene FADs and LADs for southern England are derived from Bujak et al. (1980), de Coninck (1990), plus personal knowledge of the Hampshire Basin sequences. Ranges of dinoflagellates from southern European sections are from Brinkhuis and Biffi (1992). This paper fills a gap in our knowledge of Priabonian assemblages.

The major source of Oligocene data has been Stover and Hardenbol (1994), Benedek and Müller (1974) and Brinkhuis et al. (1992). Stover and Hardenbol (1994) studied the dinoflagellates from the type and other sections of the Boom Clay of Belgium. The Boom Clay provides the lithostratigraphic basis for the lower Oligocene Rupelian Stage. Control in the late Oligocene is also based on Brinkhuis et al. (1992) who studied sections from the Piedmont and Marche basins in Italy. This paper also provided control for the early Miocene.

Miocene dinoflagellate FADs and LADs are based primarily on de Verteuil and Norris (1992,1994,1996). De Verteuil studied the diverse assemblages from the Chesapeake Group of the Salisbury Embayment, a basin occupying the coastal areas of New Jersey, Delaware, Maryland and Virginia and extending out into the North Atlantic. The surface and subsurface sections are keyed to the planktonic foraminiferal zonation and the calcareous nannofossil zonation. Zevenboom (1995) examined Oligocene-Miocene surface sections of central and northern Italy and wells from the Netherlands. Other important papers utilized were Powell (1986a, 1986b, 1986c).

The former paucity of data on Pliocene dinoflagellates is being rectified through such studies as Head (1992,1994), Head et al. (1989a), de Vernal and Mudie (1989b,1992) and Mudie et al. (1990). These studies have been the basis for the plots of FADs and LADs.

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OSTRACODES

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During the last two decades, numerous detailed studies undertaken on Cenozoic European ostracode faunas have provided a good understanding of the stratigraphical distribution of a great number of species. In many cases planktonic foraminifera, nannoplankton and larger foraminifera (*Nummulites, Alveolina*) zones have been proposed.

Paleogene

For the Paleogene of northwestern Europe, the most comprehensive study can be found in the works of Keen (1977, 1978). This author proposes a 14-fold ostracode zonation for the marine environment based on the distribution in the Paris Basin, Belgium and England. Each zone is tentatively correlated with planktonic foraminifera and nannoplankton zones often through Nummulite zones. This author also proposes a brackish and a freshwater ostracode zonation.

For the southern North Sea Basin, additional information is provided on the stratigraphic value of Oligocene ostracodes by the works of Gramann and Spiegler (1986), Uffenorde (1986); and Uffenorde et al. (1979) who proposed bio-ecostratigraphical zonations.

For southern Europe, our data essentially come from the Aquitaine Basin and the Pyrenees (Ducasse, 1969; Tambareau, 1972; Ducasse et al., 1985). For the Pyrenees, good correlations have been established with larger foraminifera.

Neogene

Data on Neogene ostracodes from northern Europe are scarce. The most comprehensive works are those of Uffenorde (1986); and Uffenorde et al. (1979) on Miocene ostracodes from the southern North Sea Basin.

In southern Europe, important works have been carried on the Miocene ostracodes from the Aquitaine Basin (Carbonel, 1985), the Miocene and Pliocene of the Rhône Valley by Carbonnel (1969), Carbonnel and Ballesio (1982) and Carbonnel and Martini (1976), and the Miocene -Pliocene on the central and eastern Mediterranean Basin by Sissingh (1976,1982). This last author subdivided the middle Holocene to Holocene interval into 19 ostracode zones characteristic for the successions in brackish, infralittoral, circalittoral to upper bathyal and deeper environments. Carbonel and Jiricek (1977) proposed tentative correlations based on ostracode bioevents between the Rhône Valley and the paratethys.

The stratigraphic distribution of Plio-Pleistocene ostracodes is fairly well known in southern Europe, essentially in Italy by the various works of Colalongo (1968), Colalongo et al. (1972), Colalongo and Russo (1974) and in the eastern Mediterranean Basin (Sissingh, 1976,1982). Correlations with planktonic foraminifera are generally well established.

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LARGER BENTHIC FORAMINIFERA (NEOGENE)

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Larger Foraminifera commonly occur in the Oligo-Miocene shelf facies of tropical seas. A biozonation scheme based on these forms mainly concerns the southern European basins, from southwestern France (Aquitaine) to Turkey; it takes into account a latitudinal thermal gradient indicative of a progressive cooling evidenced from Oligocene to Quaternary. Two remarks are to be made: the FAD and LAD of species are certainly not synchronous everywhere,—age assignments of some levels such as Mediterranean Chattian and Aquitanian are uncertain. We have followed the same numbering system of the SB biozones (Shallow Benthic Foraminifera) as for the lower Tertiary (see Serra-Kiel et al., this volume). The Eocene-Oligocene boundary is marked by many disappearances (*Discocyclinidae, Nummulites* spp. as *N. retiatus, B. vonderschmitti*, etc.; Barbin, 1988) and first occurrences (*N. vascus, N. fichteli, O. complanata*, etc.). Numerous taxa are still observed in the Oligocene (with a noticeable species diversity in the Chattian); then a decrease occurs during the lower Miocene and finally Larger Foraminifera become nearly extinct at the end of the Miocene.

1[st] **biozone** (zone SB 21): Rupelian. Index fossils: *N. vascus, N. fichteli.*

N. bouillei (already known in the Priabonian) is present; likewise in the earliest Rupelian, *N. germanicus* in the northern area and *N. incrassatus* in the southern one. The first occurrence of *B. pygmea* (rather rare) and *B. bulloides* (Aquitaine, Italy) is noticed. The genera *Spiroclypeus, Heterostegina, Operculina* (Hottinger, 1977), *Praerhapydionina* (*P. delicata*), *Austrotrillina* (Adams, 1976), *Halkyardia* (*H. minima*) already reported from the Eocene, and *H. maxima* occurring during that interval) and numerous *Neorotalia* are recorded in that zone and also in the following one.

2[nd] **biozone** (SB 22): Rupelian (*pars*), Chattian (*pars*). Index fossils: *N. vascus, N. fichteli*, Lepidocyclinids.

The late Rupelian sees the appearance of Lepidocyclinids (first in the southern domain), accompanied by *Nummulites* (the two index species, and *N. bouillei*) *E. formosoides* (*E. dilatata* lineage) and *N. praemarginata* (N. *morgani-tournoueri* lineage) appear in the first subzone (SB 22A, upper Rupelian) whose top sees the last occurrence of *B. bulloides*.

In the second subzone (SB 22B), the first *Cycloclypeus* (*C. droogeri*, then *C. mediterraneus*: Matteucci and Schiavinotto, 1985; Drooger and Laagland, 1986; Laagland, 1990) appear in the Mediterranean towards the base of the Chattian. *N. vascus* becomes extinct in the upper part of that zone.

3[rd] **biozone** (SB 23): Chattian. Index fossils: *Miogypsinoides.*

It is characterized by the development of the *Miogypsinoides* anagenetic lineage (*M. complanatus, formosensis, bantamensis, lateralis*: Drooger, 1963; Cahuzac, 1984), and at the bottom by the appearance of *C. eidae* and *P. escornebovensis* (Cahuzac and Poignant, 1993a). Larger Foraminifera are abundant and diversified from throughout Aquitaine and the whole Mediterranean area and some taxa are known up to Germany and the Paratethys (*N. morgani*, Miogypsinidae). *N. bouillei* is still present in many areas (Mediterranean, Aquitaine up to the peri-Armorican domain: Cahuzac and Poignant, 1988)

The assemblages also include *S. blanckenhorni, G. assilinoides, Heterostegina* spp., *O. complanata, V. aquitanica, B. pygmaea, B. inflata, P. delicata, Austrotrillina* spp. (e.g. *A. paucialveolata*); *M. septentrionalis* seems to be restricted to the upper part of the zone (Germany, Aquitaine, Italy: de Bock, 1976). The last, rather rare *N. fichteli* and *H. maxima* die out in the lower part of the zone (Cahuzac and Poignant,1993a). *N. morgani* and *E. dilatata* are frequent and the latter is said to disappear towards the Oligo-Miocene boundary in many areas; *Eulepidina* has been frequently reported from the Aquitanian, although quite often deposits dated as Aquitanian by authors are known to be Chattian in age.

4[th] **biozone** (SB 24): Aquitanian. Index fossils: unispiralled *Miogypsina* (*gunteri* group).

The distributional pattern changes due to several disappearances at the top of the Chattian and as a result Larger Foraminifera are reduced both in number and diversity. This zone is characterized by the *M. gunteri-tani* lineage. Some other species are also present: *N. morgani, P. escornebovensis, O. complanata, Heterostegina* spp., likewise *M. dehaartii* at the base. The first "*Miolepidocyclina*" (*M. socini* group: de Bock, 1977) appear during that interval.

5[th] **biozone** (SB 25): Burdigalian. Index fossils: plurispiralled *Miogypsina.*

The *M. globulina-intermedia-mediterranea* lineage is the essential element of the Burdigalian. *A. howchini* (Italy, Turkey) and *P. escornebovensis* are recorded in the lower part of the zone just as *M. burdigalensis-negrii* (Mediterranean, Aquitaine; Adams et al., 1983; Cahuzac and Poignant, 1993b). *N. tournoueri* still persists, and disappears according to the different areas at the latest towards the N6-N7 boundary (Drooger, 1979; Adams, 1992). At this limit, *M. cushmanni-mediterranea* just appears in the southernmost basins (Portugal, Spain, Italy: Wildenborg, 1991). The co-occurrence of the latter with *B. melo* group is not reliable anywhere in the European basins, in which *Miogypsina* does not reach zone N8.

6[th] **biozone** (SB 26): Middle -Upper Miocene. Index fossils: *Heterostegina, Borelis.*

The taxa diversity strongly diminishes. *H.* spp. (for instance *H. granulatatesta*, occurring in the Langhian, Papp and Küpper, 1954) and *B. melo* group, are the only rather common Larger Foraminifera. *B. melo curdica* seems to occur first in N8, while the last *B. melo melo* reach the lower Messinian in some areas of the Mediterranean (Bizon et al., 1973). In that interval, *Planorbulinella* spp., *D. italica* are observed, just as the last *Operculina* in the Tortonian (Mediterranean; Drooger, 1979; Adams, 1992), and some *Neorotalia* in the mid- Miocene.

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LARGER BENTHIC FORAMINIFERA (PALEOGENE)

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The shallow benthic foraminiferal biozones (SB) presented on Chart 3 are, in part the result of the project "Early Paleogene Benthos" (IGCP Project 286). These SB biozones cover the Paleocene and Eocene time span from the eastern shores of the Atlantic (Paris-Pyrenean Basins) to Assam (India). Basically, they are derived from species ranges as observed in many outcrop sections in the Pyrenees, Swiss Alps (Schlieren- and Gürnigelflysch and various sections in the Helvetic units), northern Italy (Verona, Vicenza), Adriatic and Gargano platforms, Crimean Peninsula and Haymana Basin (central Anatolia).

The integrated numbered biozonations with the prefix SB is independent from the standard plankton zonations, but correlated with them. It is directly correlated with sedimentary sequences (Pujalte et al., 1994) and with magnetostratigraphic data (Serra-Kiel et al., 1995; Burbank et al., 1992; Bentham 1992) in the Pyrenean area.

Each SB is defined by first and last appearances of different taxa, mainly alveolinids and nummulitids. Therefore the SB biozones 3 through 20 are very similar to the well-known *Alveolina* biozones of Hottinger (1960) and the Nummulites biozones of Schaub (1981).

Smaller and larger foraminifera in SB 1 and SB 2 are characteristic of very shallow facies types. The three columns differentiated in biozones SB 3 to SB 20 correspond from left to right to the larger foraminiferal associations characteristic of the shallowest to the deepest euphotic zones. Thus, the first column (left) corresponds to the alveolinids, including the genera *Glomalveolina* and *Alveolina* according to Hottinger (1960), Drobne (1977), Hottinger and Drobne (1988), and the genera *Malatyna* and *Praebullalveolina* according to Sirel and Açar (1982,1983). The second column corresponds to the nummulitids (*Ranikothalia, Assilina, Nummulites* and *Heterostegina*), based on Hottinger (1977), Herb (1978) and Schaub (1981). In this column, the biozone SB 18 is characterized according to the biostratigraphic data in Ferrer (1971b) and to the magnetostratigraphic record in Burbank et al. (1992). The third column corresponds to orthophragminids (*Discocyclina, Nemkovella, Asterocyclina* and *Orbitoclypeus*), based on Less (1987, 1993) and Less and Kovács (1996).

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DIATOMS

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Although separate Miocene to Quaternary diatom zonations exist for the North Pacific, low latitudes, and Southern Ocean (Barron, 1985), only the North Pacific zonation is provided, because it is the most widely applicable zonation in outcrop areas where calcareous microfossil biostratigraphy is poorly developed (i.e., in higher latitude regions of the North Pacific). Barron and Gladenkov (in press) and Gladenkov and Barron (in press) give the most recent review of the Miocene to Quaternary North Pacific diatom zonation and provide the first detailed calibration to magnetostratigraphy for the Miocene. Many of the Miocene zones can also be used effectively in the high-latitude North Atlantic and Norwegian Sea as well as in the Southern Ocean.

For the Paleogene, a middle to low latitude diatom zonation is supplied, because it is the most widely applicable zonation and can often be used at higher latitudes. The Oligocene to late early Eocene zones are those of Fenner (1984) with secondary calibration to the magnetostratigraphy mainly through the correlation with calcareous nannofossil zones suggested by Fenner and Mikkelsen (1990). The base of the *Triceratium kanayae* zone, however, is placed in the middle part of calcareous nannofossil subzone CP 12a based on Barron's unpublished studies of DSDP Hole 390A. The only direct correlation to magnetostratigraphy for these zones is for the bases of the *Rocella gelida* and *R. vigilans* zones which are taken from Gladenkov and Barron (in press).

The early Eocene to early Paleocene zones are those of Fourtanier (1991) who also provides correlation to calcareous nannofossil zones and limited calibration with magnetostratigraphy at ODP Site 752. In order to fill out the diatom zonation for the Cenozoic, an earliest Paleocene zone, the *Hemiaulus rossicus -Trinacria heibergiana* assemblage zone is included, in part after Strelnikova (1990). Here, this basal Cenozoic zone is informally recognized as the interval from the last occurrence of *Gladius* spp. at the Cretaceous/Tertiary boundary to the first occurrence of *Hemiaulus periterus*.

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MESOZOIC ERA

GEOMAGNETIC POLARITY TIME-SCALE

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Introduction

The Mesozoic portion of the magnetic polarity time scale was compiled from selected publications. Magneto-biostratigraphic studies published prior to 1993 were compiled by Ogg (1995). A version of that magnetic polarity scale with modifications derived from publications through early 1994 was incorporated in the Mesozoic time scale of Gradstein et al (1994,1995) after rescaling to the durations of ammonite zones or subzones. In cases where the ammonite-zonal control is less complete (e.g., Sinemurian), then the observed pattern is scaled within the stage. This Gradstein et al (1994) version has been used on the chronostratigraphic charts of this volume. The following review briefly summarizes revisions of the compilation of Ogg (1995) incorporated on the chronostratigraphy charts and indicates a few additional magnetostratigraphy studies of late 1994 through 1996 that are not included on the charts.

The magnetic polarity time scale for the Mesozoic is well-documented in the Cretaceous and latest Jurassic where the seafloor magnetic anomaly pattern provides a guide for scaling the polarity sequence. The polarity pattern is known in partial detail for two-thirds of the Triassic and Jurassic ammonite zones. The major stages with ill-defined, inadequately calibrated or unresolved magnetic polarity patterns are the Carnian, Rhaetian-Hettangian-Sinemurian, and late Bathonian-Callovian. This magnetic polarity time scale will continue to be enhanced with further high-resolution magnetostratigraphy research.

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CRETACEOUS PERIOD

GEOMAGNETIC POLARITY TIME-SCALE

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The calibration of the magnetic polarity scale to Cretaceous stage boundaries remains uncertain due to lack of agreement for placement of international stage boundaries by the Subcommission on Cretaceous Stratigraphy (e.g., Rawson et al.,1996). The magnetic time scale shown on the chronostratigraphic charts is according to pre-1993 "common usage" biostratigraphic markers for stage boundaries (reviewed in Ogg, 1995, and Gradstein et al., 1994).

There have not been any precise ammonite or nannofossil markers for the Valanginian/Hauterivian boundary in magnetostratigraphic sections, and the observed variability in a dinoflagellate marker for the boundary (last appearance datum of *Scriniodinium dictyotum*) brackets polarity zone M10Nr. However, Channell et al. (1994) have reported a possible occurrence of *Acanthodiscus radiatus* in an Italian section that would place the ammonite-defined Valanginian-Hauterivian boundary near the base of polarity zone M11n. The regional Purbeck stage of southern England has yielded a magnetostratigraphy consistent with an age assignment to polarity chrons M19r through M14r, indicating correlation to latest Tithonian through earliest Valanginian stages of the Tethyan realm (Ogg et al., 1994). The underlying Portland appears to span only polarity zones M21r through M19n, implying a middle and late Tithonian age correlation (Ogg et al., 1994).

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AMMONITE ZONATIONS

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Introduction

Ammonite biostratigraphy is a key element in the organization of Cretaceous stratigraphy. Ammonite zones and subzones are used to define most stage and substage boundaries. The current Cretaceous ammonite zonation, which is continuously improved, reflects an evolution towards a consensus scheme. The "Colloque sur le Crétacé" in Lyon, France (1963, published in 1965), the Symposium on Cretaceous stage boundaries held in Copenhagen, Denmark (1983, published in 1984), the International Symposium on Cretaceous Stage Boundaries in Brussels, Belgium (1995, published in 1996), the meeting on "Tethyan and boreal Cretaceous" Maastricht, the Netherlands (I.G.C.P. Project n° 362, 1995) and the 5th International Cretaceous Symposium in Freiberg, Germany, (1996), are important milestones in this process.

The zonations used on the Cretaceous Charts originate from the most recently published synthesis (Hancock, 1991, Bulot et al., 1992 and Hoedemaeker et al., 1993) or from publications devoted to specific

Cretaceous subsystems or stages (Robaszynski and Amédro, 1980; Hancock and Kennedy, 1980; Rawson, 1980; Owen, 1985 and Amédro, 1992). The zonation adopted here is a simplified scheme and very likely a provisional one. Certainly it will be modified and/or partly ratified during subsequent meetings on Cretaceous stratigraphy.

As in other Mesozoic systems, ammonite zones and subzones were selected in order to maximize the relative time resolution of the biostratigraphic reference framework, preserving the correlations between the faunal realms (boreal or northwestern Europe and Tethyan or southwestern Europe). For the Upper Cretaceous, special attention was given to recently proposed correlations between U.S.A. and Western Europe zonal schemes (Cobban, 1994; Hancock et al., 1994; Kennedy et al., 1992).The selection retains both the up-to-date species names and some obsolete or no longer used ones, in order that non-ammonite specialists would not be lost.

Different phylosophies for calibrating ammonite zonal schemes to stages were used for the lower and upper Cretaceous. In the upper Cretaceous, many radiometic data are correlated with ammonite zones in the U.S.A. (Obradovich, 1994; Gradstein et al., 1994); and the subdivision of each stage from Cenomanian to Maastrichtian reflects these data. In the lower Cretaceous, few radiometric data calibrated to ammonite data exist (Obradovich, 1994; Gradstein et al., 1994), and each stage from Valanginian to Albian was subdivided into zones or subzones of equal duration within its estimated limits. In the Berriasian, magnetic polarity data added an additional measure of duration by comparing with seafloor spreading profiles.

The International Symposium on Cretaceous Stage Boundaries in Brussels, Belgium 1995(published 1996), made recommendations for the selection of Cretaceous stage and many substage boundary stratotypes (GSSP). These Global Stratotype Section and Points depend primarily on the selected boundary markers. Most of these proposals require further investigation and ultimately the acceptance by the Commission on Stratigraphy. Recommendations made in Brussels postdate the preparation of the Cretaceous Charts and are thus not included. Differences with stage boundaries on the charts are small.

Proposed boundary markers:

Tithonian/Berriasian = Jurassic/Cretaceous = base Berriasella jacobi zone
Berriasian/Valanginian = base Calpionella zone E
Valanginian/Hauterivian = FAD Genus Acanthodiscus
Hauterivian/Barremian = base Spitidiscus hugii zone
Barremian/Aptian = base Magnetic Chron MO
Aptian/Albian = FAD Leymeriella schrammeni
Albian/Cenomanian = FAD Rotalipora globotruncanoides
Cenomanian/Turonian = FAD Watinoceras devonense
Turonian/Coniacian = FAD Cremnoceramus rotundatus
Coniacian/Santonian = FAD Cladoceramus unduloplicatus
Santonian/Campanian = LAD genus Marsupites
Campanian/Maastrichtian = FAD Pachydiscus neubergicus

UPPER CRETACEOUS AMMONITES (J. M. Hancock)

Ammonite zonations in use ten years ago for upper Cretaceous successions have already been changed in many details. The proposed scheme is mainly based on zonations established by Hancock and Kennedy (1980), Owen (1984, 1988a,b).

There is every expectation that the zonation shown on the Cretaceous charts will be modified further. The most up to date information since the completion of the charts, and thus not included on the charts, can be found in the proceedings of the "Second International Symposium on Cretaceous Stage Boundaries" in Brussels Belgium, (1995, published in 1996). Provisional basis for the stratigraphic correlation of the upper Cretaceous are still in discussion (Kennedy, 1994).

Improvements in recent years are dominated by the research of W. A. Cobban in the United States of America, C. W. Wright and W. J. Kennedy in the United Kingdom, the late J. Wiedmann in Germany, A.A. Atabekyan in Russia, M. Matsumoto in Japan, H. C. Klinger in South Africa, and until the 1970's the late M. Collignon in France.

Summary papers in recent years, already out of date, include Cobban (1994), Hancock (1991) and. Hancock, Cobban and Kennedy (1994). Some more recent developments are given by Amédro in Robaszynski et al., 1990, Chancellor et al. (1994), Kennedy and Cobban(1991), Kennedy, Cobban and Scott (1992), Thomel (1993), Ward and Kennedy (1993). Several of these papers are focused on correlations between Western Europe and the United States of America.

PRINCIPAL REFERENCE

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LOWER CRETACEOUS AMMONITES (Ph. J. Hoedemaeker).

Standard ammonite zonation for southern Europe.

The "Colloque sur le Crétacé inférieur" (B.R.G.M., 1965) accepted, albeit with minor changes, the old subdivisions of Kilian (1910). Since then the standard ammonite zonation for southern Europe (Tethyan) was drastically improved. In Digne, France (1990, IGCP Project 262), results of the investigations of Bogdanova (1978), Busnardo (1984), Company (1987), Delanoy (1990), Hoedemaeker (1982), Le Hégarat (1971), Kakabadze (1983), Owen (1979), Moullade and Thieuloy (1967), Thieuloy (1972, 1977, 1979), and other unpublished data were used to construct a consensus standard ammonite zonation for the Mediterranean region (Hoedemaeker and Bulot, 1990).

In Mula, Spain (1992, IGCP Project 262) agreement was reached on several improvements in the standard ammonite zonation for the Mediterranean region (Hoedemaeker et al., 1993). In Piobbico, Italy (1994, IGCP Projects 362 and 343), the " Mula zonation" was confirmed. This zonation is used on the Cretaceous chart with some additional subzones and horizons proposed subsequently. The scheme is also based on new data provided recently by Bulot et al. (1992, 1993a, b), Blanc et al. (1992, 1994), Bulot and Thieuloy (1993), Atrops and Reboulet (1994).

Standard ammonite zonation for northwestern Europe.

Lower Cretaceous standard ammonite zonations for northwestern Europe have not benefited as much from international agreement. The zonation on the chart is a mixture of German and English zones. The standard ammonite zonation for the Albian, mainly shaped by Spath (1923–1943), Breistroffer (1947) modified by Owen (1979, 1988a, 1988b) and Casey (1961), includes elements of the phyletic zonation constructed by Amédro (1980, 1992) and by Robaszynski and Amédro (1986). The zonation of the Aptian is the English one of Casey (1961). The zonation for the Barremian is in fact the German one introduced by Koenen (1902, 1908) updated by Kemper (1976). The Hauterivian zonation on the Cretaceous chart is based on the Speeton Clay succession (Rawson 1971) and accepted with minor modifications for Germany by Kemper (1976). The Valanginian zonation was developed for Germany by Kemper (1961, 1976, 1978), Kemper et al. (1981), Jeletzky and Kemper (1988), and Quensel (1988). The zonation for the uppermost Portlandian and Ryazanian is from Casey (1973) described in England and applied to Greenland by Birkelund et al. (1984). The Upper Volgian and Ryazanian zonations for Russia and Siberia have been in use for many years.

Tethyan—Boreal correlalions

Correlations between the tethyan and boreal ammonite zones for the Aptian and Albian are not particularly problematic as is the case in the uppermost Jurassic. However, correlations between tethyan and boreal zones for the Berriasian to Barremian stages are extremely tentative and based on very few genera and species the areas have in common due to extreme provinciality. Correlations for the Berriasian and Valanginian were published by Kemper et al. (1981) and Hoedemaeker (1987, 1991). Hauterivian and Barremian calibrations are from unpublished sources.

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IMMEL, H., 1979, Die Ammonitengliederung des mediterranen und borealen Hauterive and Barreme unter besonderer Berücksichtigung heteromorpher Ammoniten der Gattung Crioceratites Leveillé: Newsletters on Stratigraphy, v. 7, p. 117–120.

KEMPER, E., RAWSON, P. F., AND THIEULOY, J.-P., 1981, Ammonites of Tethyan ancestry in the early Lower Cretaceous of north-west Europe, Palaeontology, v. 24, Pt. 2, p. 251–311.

QUENSEL, P., 1988, Ammonitenfauna im Valangin-Hauterive Grenzbereich vom Mittellandkanal bei Pollhagen, Berliner Geowissenschaftlichen Abhandlungen, v. A 94, p.15–71.

PLANKTONIC FORAMINIFERA

ROBASZYNSKI, F., AND CARON, M., 1995, Foraminiféres planctoniques du crétacé: commentaire de la zonation Europe-Mediterranée: Bulletin de la Société géologique de France,166 (6), p. 681–692.

DINOFLAGELLATES, Boreal (northwestern Europe) Albian-Maastrichtian

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In spite of the available data, it is not yet possible to define a valid biozonation for the Albian-Maastrichtian interval of northwestern Europe. Therefore we have indicated on the chart the FADs for thirty taxa and the LADs for twenty eight taxa, those for which the accuracy is in doubt are dashed. In fact, it is often hard, or even impossible, to plot most dinoflagellate data from the literature correctly relative to the three most commonly used biostratigraphical scales of reference; ammonite zones for the Albian-Coniacian, belemnite zones for the Campanian-Maastrichtian and planktonic foraminifera zones for the Cenomanian-Campanian intervals. Moreover the calibration between biozonations mentioned in the literature and the standard reference scales on the chart is often hard to establish. Therefore, we have selected taxa for which appearance and (or) extinction times are confirmed by several authors, including those with small discrepancies.

For the Albian-Santonian interval, data are chiefly from the following papers, all relating to the Paris Basin: Davey and Verdier (1971, 1973, 1976); Fauconnier (1979); Foucher (1976, 1980 in Robaszynski et al. 1980, 1982); Foucher and Taugourdeau (1975) and Verdier (1975). For the Campanian-Maastrichtian interval, the dinoflagellate information was compiled from Foucher (1976); Foucher and Robaszynski (1977); Foucher in Robaszynski et al. (1985); Hansen (1977, 1979) and Wilson (1974) mostly based on studied sections in Belgium, Denmark, the Netherlands and France.

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DINOFLAGELLATES, Boreal: Berriasian-Aptian,Tethyan: Berriasian-Turonian

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All Cretaceous FADs and LADs are first-order correlations with boreal or tethyan ammonite zones, except for the Cenomanian-Turonian interval, where first-order correlations are with Planktonic Foraminifera zones. Boreal and tethyan FADs and LADs are presented on the charts in four columns. Only those publications documenting a selected bioevent are listed below.

Each bioevent (FAD, LAD or acme) is identified by a numerical age (my) and a bibliographic citation associated with that bioevent. These numerical biostratigraphic datums have been related to the boreal or tethyan ammonite zonations and subsequently correlated to the chronostratigraphy and absolute time scale of Gradstein et al. (1994, 1995); decimal numbers are intended only as a place holder to help determine the relative position of bioevents. Uncertain stratigraphic positions for zonal boundaries, FADs and LADs are shown with dashed lines. Taxonomy follows Lentin and Williams (1993).

REFERENCE

LENTIN, J. K., AND WILLIAMS, G. L., 1993, Fossil dinoflagellates: index to genera and species, 1993 edition: American Association of Stratigraphic Palynologists, Contributions Series, v. 28, p. 1–856.

Boreal Dinoflagellate Cysts

Upper Cretaceous Albian-Maastrichtian (see Foucher, in appendix).

Lower Cretaceous (Berriasian-Aptian)

Entries on chart: **FADs**, 124.23/ 124.14; **LADs**, 125.88/ 125.36/ 125.22/ 124.44/ 123.61/ 123.30

REFERENCE

HARDING, I. C., 1990, A dinocyst calibration of the European boreal Barremian. Palaeontographica, Abteilung B, v. 218, p. 1–76.

Entry on chart: **LADs**, 143.83

REFERENCE

RIDING, J. B., AND THOMAS, J. E., 1992, Dinoflagellate cysts of the Jurassic System, *in* Powell, A. J., ed., A stratigraphic index of dinoflagellate cysts: Chapman and Hall, London, p. 7–98.

Entries on chart: **FADs**, 140.04/ 139.49/ 138.54/ 137.64/ 136.89/ 136.46/ 136.32/ 136.17/ 135.92/ 135.84/ 132.50/ 132.22/ 131.90/ 131.55/ 130.96/ 130.24/ 130.18/ 129.79/ 129.71/ 129.05/ 128.46/ 128.02/ 126.95/ 126.8/ 124.82/ 124.23/ 124.14/ 120.98/ 120.00/ 119.02/ 118.42/ 118.05/ 117.07 /116.09/ 115.55/ 113.16/ 112.18; **LADs**, 140.75/ 140.04/ 139.07/ 138.54/ 136.99/ 136.49/ 136.46/ 136.39/ 136.30/ 136.13/ 135.90/ 135.70/ 132.18/ 131.90/ 131.34/ 130.24/ 129.79/ 129.71/ 127.14/ 127.03/ 125.88/ 125.52/ 124.82/ 124.61/ 123.61/ 122.76/ 122.55/ 120.98/ 119.02/ 118.05/ 117.53/ 116.09/ 115.11/ 114.08/ 112.18

REFERENCE

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Entries on chart: **FAD**, 136.62; **LAD**, 135.67

REFERENCE

MONTEIL, E., (unpublished), Palynological study of the Speeton Clay Formation, East Yorkshire, England.

Tethyan Dinoflagellate cysts

Upper Cretaceous

Late Albian Col de Palluel section, Vocontian Trough, southeastern France

Entries on chart: **FADs**, 101.59/ 101.14/ 100.91/ 100.05/ 99.90/ 99.62/ 99.46/ 99.30. **LADs**: 101.14/ 100.91/ 99.62/ 99.46/ 99.30

REFERENCE

DAVEY, R. J., AND VERDIER, J. P., 1973, An investigation of microplankton assemblages from latest Albian (Vraconian) sediments: Revista Espanola Micropaleontologia., v. 5, n° 2, p. 173–212.

Cenomanian-Turonian Vergons section, Vocontian Trough, southeastern France

Entries on chart: **FAD**, 92.08; **LADs**: 94.40/ 94.34/ 93.94/ 93.66/ 92.52

REFERENCE

COURTINAT, B., CRUMIÈRE, J. -P., MÈON, M., SCHAAF, A., 1991, Les associations de kystes de dinoflagellés du Cénomanien-Turonien de Vergons (Bassin vocontien, France): Geobios, v. 24, 6, p. 649–666.

Lower Cretaceous

Berriasian-Valanginian Broyon quarry, Berrias stratotype and Angles hypostratotype, Vocontian Trough, southeastern France

Entry on chart: **FAD**, 133.82

REFERENCE

MONTEIL, E., 1985, Les dinokystes du Valanginien du Sud-Est (Ardèche, France); Thèse 3° Cycle, Université Pierre and Marie Curie, Paris, n°. 85-46, 314 p.

Entries on chart: **FADs**: 136.52/ 136.42/ 136.04 /136.00/ 135.23/ 134.95/ 134.58/ 133.49

LADs: 136.93/ 136.51/ 137.47/ 136.08/ 135.92/ 135.06/ 134.20/ 133.97

REFERENCE

MONTEIL, E., 1992, Kystes de dinoflagellés index (Tithonique-Valanginian) du Sud-Est de la France. Proposition d'une nouvelle zonation palynologique: Revue de Paléobiologie, v. 11, 1, p. 297–306.

Entries on chart: **FADs**, 143.72/ 142.89/ 142.76/ 141.37/ 139.73/ 138.98/ 138.29/ 138.19/ 138.08/ 136.99; **LADs**: 141.48/ 141.37/ 138.70/ 139.73/ 138.19

REFERENCE

MONTEIL, E., 1993, Dinoflagellate cyst biozonation of the Tithonian and Berriasian of South East France. Correlation with the sequence stratigraphy: Bulletin Centres des Recherches Exploration-Production Elf-Aquitaine, v. 17, n° 1, p. 249–273.

Entries on chart: **FAD**, 133.39; **LAD**: 136.42

REFERENCE

MONTEIL, E., (unpublished), Palynological study of the Angles section, southeast France.

Hauterivian-Barremian Vergons section and Barremian stratotype, Vocontian Trough, southeastern France

Entry on chart: **FAD**, 127.03

REFERENCE

JARDINÉ, S., RAYNAUD, J. F., RÉNEVILLE P., DE, 1984, Dinoflagellés, spores et pollens, *in* Debrand-Passard, S., Courbaleix, S., Lienhardt, M. -J., "Synthèse Géologique du Sud-Est de la France": Mémoire B. R. G. M., Orléans, v. 125, p. 300–303.

Entries on chart: **FADs**, 131.68/ 131.77/ 129.61/ 129.54; **LADs**: 130.14/ 128.20/ 127.79/ 127.71/ 127.40

REFERENCE

LONDEIX, L., 1990, La distribution des kystes de dinoflagellés dans les sédiments hémipélagiques (Ardèche) et pélagiques (Arc de Castellane, S. E. de la France) en domaine vocontien, du Valanginien terminal au Barrémien inférieur. Biostratigraphie et relations avec la stratigraphie séquentielle: Thèse Université de Bordeaux I, n° 323, 275 p.

Entries on chart: **FAD**, 127.25; **LAD**: 131.72

REFERENCE

POURTOY, D., 1989, Les kystes de dinoflagellés du Crétacé inférieur de la Veveyse de Châtel-St-Denis (Suisse): Biostratigraphie et stratigraphie séquentielle: Thèse 3° Cycle, Université de Bordeaux I, n° 2245, 168 + 214 p.

Entries on chart: **FADs**,126.72/ 126.37/ 124.79/ 124.45/ 124.34/ 121.19; **LADs**: 126.66/ 126.07/ 122.86/ 122.28/ 121.74

REFERENCE

RENEVILLE, P., DE AND RAYNAUD, J.-F., 1981, Palynologie du stratotype du Barrémien: Bulletin Centres des Recherches Exploration-Production Elf-Aquitaine, v. 5, 1, p. 1–29.

Aptian(Bedoulian and Gargasian stratotypes, Vocontian Trough, southeastern France

Entries on chart: **FADs**, 120.24/ 117.17/ 117.12/ 115.90; **LADs**: 120.18/ 118.78/ 116.75/ 116.59/ 111.92

REFERENCE

JARDINÉ, S., RAYNAUD, J. F., RÉNEVILLE, P., DE, 1984, Dinoflagellés, spores et pollens; *in* Debrand-Passard, S., Courbaleix, S., Lienhardt, M. -J., "Synthèse Géologique du Sud-Est de la France": Mémoire B. R. G. M., Orléans, v. 125, p. 300–303.

Entries on chart: **LADs**, 120.98/ 120.75

REFERENCE

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OSTRACODES

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Cretaceous ostracodes have been extensively studied in Europe and numerous synthesis on their biostratigraphic value and distribution published (Babinot et al., 1978, 1982, 1983, 1985a,b; Damotte et al., 1981; Neale, 1978)

Upper Cretaceous

In the Boreal realm, ostracode datums can be correlated to a certain degree with ammonite zones in the Cenomanian, echinoids, inoceramid and belemnite zones in the Turonian to Maastrichtian interval (Neale, 1978; Clarke, 1983). Late Campanian and Maastrichtian ostracodes from the Netherlands (Maastrichtian stratotype) have been extensively studied by Deroo (1966).

In the Tethyan Realm, all the ostracode works have been undertaken in carbonate platform environments especially in southern France (Babinot, 1980; Babinot et al., 1985a), and Spain (Rodriguez-Lazaro, 1985) which very seldom contain ammonites. Correlation with standard ammonite-zones are therefore purely tentative.

Lower Cretaceous

In the Boreal Realm several authors have proposed zonations based on marine ostracodes for the lower Cretaceous. Correlations with ammonite zones are rather accurate. Of particular interest is the work of Bertram and Kemper (1971) and Kemper (1982) for the Albian-Aptian of Germany, Christensen (1974) for the Danish Embayment, Lott et al. (1985), Wilkinson (1988), Wilkinson and Morter (1981) and Hart (1973) for Great-Britain. Neale (1978) proposed a 8 fold zonation based on ostracodes for the lower Cretaceous of England.

For the Tethyan realm, ostracode datums were selected from the work of Babinot et al. (1985) on southern France. Correlations with ammonite zones are also rather accurate.

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LARGER BENTHIC FORAMINIFERA

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One of the objectives of IGCP 262 (Tethyan Cretaceous Correlation) was to develop biostratigraphic tools allowing precise correlations between all Tethyan areas. For this reason about 80 larger benthic foraminifera specialists agreed to collaborate and produce a general distribution of larger benthic foraminifers for the lower Cretaceous. Publication of their detailed results is in preparation. Calibration between ammonite zonations and benthic foraminifera distribution was available for the northern Tethyan region and, especially, in France and Spain where ammonites were found either in the trangressive deposits on the platforms or on the platform slopes. The important reference sections in France were sampled by Hubert Arnaud, and the ammonites were studied by Luc Bulot. For the Berriasian, the correlation between calpionellids and benthic foraminifera was done by Eric Blanc.

Northern Tethyan area (northern Mediterranean margin)

Data are from Portugal (Berthou), Spanish Pyrenees (Caus, Peybernès); French Pyrenees (Peybernès); Provence and Subalpine Chains (Masse and Anneau-Vanneau); Hungary (Bodrogi); Romania (Bucur, Dragastan); Slovenia-west Carpathians (Köhler and Salaj). From the base of the Valanginian to the lower Hauterivian platforms were drowned and deposition is dominated by marls, crinoidal-bryozoan limestones or oolithic limestones. Larger benthic foraminifers are usually missing in these types of environments.

Adriatic area

Data are from northern Italian areas, Karst, Gorizia, Venezia-Giulia (Longo Salvador, Pirini Radrazzani, Pugliese) and Friuli (Sartorio), central Italy (Arnaud-Vanneau) southern Italian areas Apulia-Apennines, (Sartorio and Gargano-Murge; Luperto-Sinni, Masse), Croatia, Dinaric Karst area, (Velic and Radoicic), Kosovo (Peybernès), Albania (Sadushi), Greece (Decrouez, Peybernès, Skoursis-Coroneou, Carras). From the base of the Albian to the middle Albian, carbonate platforms emerged and were karstified. Carbonate sedimentation took place on the platform margin. The larger benthic foraminifer commonly present in these lowstand systems tracts is Orbitolina (Mesorbitulina) texana.

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RIVELINE, J., BERGER, J. P., FEIST, M., MARTIN-CLOSAS, C., SHUDACK, M., AND SOULIE MÄRCHE, L., 1996, European Mesozoic-Cenozoic Charophyte biozonation: Bulletin de la Société géologique de France, v. 167 (3), p. 453–468.

CALPIONELLIDS

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There are only minor paleobiogeographic variations in the composition of calpionellid faunas. Regional differences in the relative frequencies of species or genera do exist: The genera *Calpionellopsis*, *Calpionellites* and *Calpionella elliptica* are more frequent in the southern part of the Mediterranean basin than in southeastern France. On the other hand, only in the central part of their domain, corresponding to the Mediterranean basin and Cuba, the succession of calpionellid faunas is documented completely. More marginal areas such as different parts of Mexico and the northeastern Caucasus were invaded by calpionellids in the Berriasian only.

Despite these regional differences, there is general consensus about the chronologic succession of the main events and their calibration with ammonite zones. Statements postulating a diachrony of calpionellid zonal boundaries are not supported by factual arguments. The standard zones of Rome 1971 (Allemann et al., 1971) and the standard subzones of the 1984 Sümeg meeting in Hungary (Remane et al., 1986) provide the basic frame for interregional correlations. Within this framework, various finer subdivisions have been developed: Remane (1963, 1964) for southeastern France, which is used on the chart, or the subdivisions by Pop (1974, 1994, 1997) for the Roumanian Carpathians and Cuba, Grün and Blau (1996, 1997) for the southern Alps, Lakova et al. (1997) for the Balkan, Rehakova (1997) for the western Carpathians.

Observations:

1. The occurrence of calpionellids in the basal Hauterivian was confirmed by Blanc (pers. comm. 1995) who discovered *Tintinnopsella carpathica* in a borehole in Neuchâtel. Together with the finds of calpionellids in the Hauterivian of the Slovak Carpathians this justifies the establishment of a Tintinnopsella Zone. The problem with this zone is, however, that both its boundaries are defined by extinction events so that it does not posses truly diagnostic species. In certain regions calpionellids disappear already in the Valanginian, or at least there are intervals without calpionellids from the middle Valanginian upward.

2. A subdivision of the Calpionellites Zone is possible due to the appearance of new species of *Calpionellites* shortly after *Ct. darderi*, but more data are necessary to be sure of the exact position of these events due to the rarity of these forms. Taxonomy of the various species may also still need some clarification

3. At the International Symposium on Cretaceous Stage Boundaries in Brussels, Belgium 1995, the Valanginian working group decided to equate the base of the Valanginian Stage with the base of the Calpionellites Zone, a proposal to become official with the definition of a boundary stratotype. The boundary formerly used by ammonite workers in France was at the base of the Otopeta Zone, corresponding to the base of the Praecalpionellites murgeanui Subzone or the middle of the Vocontian subzone D3.

4. The first appearance of *Tintinnopsella longa* in the upper part of Zone C, confirms the observation in the Vocontian Basin but the precise level may still be subject to further refinement.

5. There is a certain confusion as to the scope of a Calpionella elliptica Zone or Subzone. Its base should correspond to the first appearance of C. elliptica, in the uppermost Zone B but some authors have also used it as a synonym of Zone C of Remane (1963).

6. Calpionellids have originated in the central Tethys. Only there the transition from *Chitinoidella* can be observed. Several successive waves of faunal migration originate from the central Tethys region. In the eastern Sierra Madre of Mexico, calpionellids appear only in the lower part of zone B; in central Mexico they appear in Zone C (Adatte et al., 1996. Another important migration occurs in Zone D, (perhaps two closely spaced events), documented in the state of Oaxaca (Mexico) and the northeastern Caucasus (Remane, in press). It is of course very tempting to relate these faunal migrations to marine highstands. In any event, on the carbonate platform of the Jura mountains, marine transgressions could be dated by calpionellids as middle to higher Zone D and as Zone E and a carbonate platform in the northeastern Caucasus was drowned at the beginning of Zone D.

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RUDISTS

Upper Cretaceous

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During the late Cretaceous (Cenomanian to Maastrichtian) rudists extend widely on the shelf areas of southern Europe. According to the paleogeographical evolution of the western Tethyan area the rudist provinciality increases (Philip 1985). Two main rudistid provinces can be distinguished: the Periadriatic (Apulian) province and the western European province. Thus cosmopolitan species (recorded with asterisks on the chart) can be found in both provinces and constitute an accurate basis for correlations. Three rudist families contribute to the biozonation of the upper Cretaceous: *Caprinidae* (mainly for the Cenomanian), *Hippuritidae* (from the lower Turonian to the Maastrichtian), *Radiolitidae* for the entire upper Cretaceous).

Rudist biozones in the upper Cretaceous have in general been interpreted as coenozones, each zone separated by horizons where rudists are scarce or absent.

Calibration of the rudist zonation has been established mainly in the western European domain (southeastern France, northern Spain), areas where basinal facies, bearing ammonites or planktonic foraminifera, are interbedded with rudist carbonate banks. Strontium isotope calibration has been carried out only on the Campanian-Maastrichtian rudist beds of Bulgaria (Swinburne et al., 1992).

Cenomanian

In western Europe, the lowermost transgressive Cenomanian is characterized by the first appearance of *Ichtyosarcolites triangularis*, an eurytopic species represented both in carbonate and siliciclastic littoral facies (Philip 1978; Bilotte 1985). In the periadriatic area there is in general no hiatus between the Albian and the Cenomanian. The Cenomanian being characterized by the first appearance of genera like *Caprina*, *Neocaprina*, *Orthoptychus*, etc. (Polsak 1965; Carbone et al., 1971; Sliskovic 1971; Sirna 1982).

The upper Cenomanian coenozone contains cosmopolitan species (*Caprinula boissyi*, *Sauvagesia sharpei*) allowing correlations between western European and Periadriatic regions (Philip 1978; Iannone and Laviano 1980; Polsak et al., 1982).

Turonian

Due to complex paleogeographic events, a strong rudist renewal occurs at the Cenomanian-Turonian boundary (Philip and Airaud-Crumière 1991). In sections without hiatuses (i.e. Provence, Philip 1978) the first appearance of Hippuritids takes place in the lowermost Turonian.

In western Europe, Hippuritids (*Vaccinites*, *Hippurites*) provide a zonation of the Turonian calibrated to ammonite zones (Devalque et al., 1982; Platel 1982; Bilotte 1985), while in the periadriatic area the Turonian is poorly documented (Polsak 1962).

Coniacian and Santonian

In western Europe, three coenozones, well calibrated to ammonite zones, characterize this interval (Philip 1970; Pons 1977; Bilotte 1983, 1985; Floquet et al., 1982; Floquet 1990). In the periadriatic area only the Santonian displays rich and well differentiated rudist coenozone (Polsak 1965; Laviano and Sirna 1979).

Campanian and Maastrichtian

In western Europe and the periadriatic area, rudist coenozones are well exposed in this interval. A much debated problem concerns the Campanian- Maastrichtian boundary in the rudist carbonate platforms where ammonites are scarce. In western Europe, the appearance of *Hippurites radiosus* (Des Moulins) was either considered coeval with the base of the Maastrichtian (Philip and Bilotte 1983; Pons 1977; Platel 1987), or with the uppermost Campanian (Neumann et al., 1983). Lower Maastrichtian ammonites were described by Kennedy et al., (1986) above the *Hippurites radiosus* biostrome of Maurens in the Aquitaine Basin. The ammonite bearing layer of Maurens contains *Nostoceras hyatti* now considered as the uppermost zone of the Campanian (Kennedy et al., 1992). Cosmopolitan species of rudists occur in the upper Campanian-lower Maastrichtian of both southwestern Europe (Philip 1983) and the periadriatic area (Sladic-Trifunovic 1972 and 1979–80).

The uppermost Maastrichtian rudist coenozones are found in Sicily (Camoin 1983; Cestari and Sirna 1987), in the Dinarids (Pejovic 1987; Plenicar et al., 1992) and in Limburg (Philip and Bilotte 1983).

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RUDISTS

Lower Cretaceous

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Investigations on rudists, as biostratigraphic markers have demonstrated the chronologic value of these bivalves. As members of the shallow water carbonate platform biota lacking ammonites and pelagic indices, rudist biostratigraphy is less precise and well calibrated than those of deep water organisms. Nevertheless, studies performed during the last decades have improved their biostratigraphic resolution at stage, substage or even ammonite zone level.

The lower Cretaceous Rudist stratigraphic distribution is mainly known from western Europe where these typical mesogean fauna is recorded subcontinuously throughout the whole corresponding time interval. The periadriatic record (Apulian domain) is more limited and essentially documented for the Aptian-Albian interval (Masse 1976, 1992, 1995). Three main periods are to be distinguished:

Berriasian to Barremian

The dominant groups are the requienids and the monopleurids. Among the requienids only one genus; *Matheronia* is recorded in the Berriasian-Valanginian while this taxon is followed by *Requenia* and *Lovetchenia* during the Hauterivian. *Toucasia* appears in the upper Hauterivian. Primitive caprinids (*Pachytraga*) are recorded in the Hauterivian both in European and some African areas; some conical to tubular shell monopleurids such as *Agriopleura* and *Petalodontia* develop in the Barremian.

Lower Aptian

Advanced caprinids develop near the Barremian-Bedoulian Boundary and spread rapidly in different areas with a distinctive biogeographic distribution. Thus during the lower Aptian; *Offneria* and *Praecaprina* are known both in western Europe and periadriatic regions, with distinctive species assemblages whereas *Caprina* seems to be restricted to western Europe.

At the same time caprotinids and monopleurids are also increasing in diversity with some generic provincialism, e.g. *Himeraelites-Glossomyophorus* and *Bicornucopina* are restricted to the periadriatic domain.

Among the requienids, *Matheronia* is found in western Europe while *Lovetchenia* is recorded in the periadriatic area.

Upper Aptian-Albian

Caprinids record a mass extinction in the whole peri-Mediterranean area at the lower-upper Aptian boundary.

Thus the upper Aptian and Albian are marked by the development of radiolitids (*Eoradiolites—Praeradiolites*) and Polyconitids (*Horiopleura—Polyconites*) recorded in the whole Mediterranean area; *Sellaea*, a typical Arabo-African Albian Taxon, is only present in the periadriatic area. The uppermost Albian is marked by the first appearance of advanced radiolitids (*Durania*) and the restoration of caprinids (i.e. *Caprina*).

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CALCAREOUS ALGAE

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As components of the warm shallow Tethyan Cretaceous biota, dasycladale algae are mainly restricted to the present perimediterranean domain where distinct European and Apulian (i.e. periadriatic) assemblages are found. A number of taxonomic works and regional syntheses, performed during the two last decades now permit to have a comprehensive overview on the chronological distribution and the paleogêography of this group.

Western Europe

With data from southern France, Spain and Switzerland, a synthetic biostratigraphy has been proposed dealing with 27 genera and 44 species (Masse, 1993). The chart only takes into account the most representative taxa. Two major breaks are recorded corresponding with: (1) the mid Valanginian turnover when the majority of Berriasian-Valanginian species disappear, followed by a slow progressive restoration of the species diversity during the Hauterivian and a diversity peak during the late Barremian and early Aptian and (2) the mid Aptian turnover marked by a mass extinction event with a limited recovery during the late Aptian-Albian.

Periadriatic domain

Luperto-Sinni and Masse (1993) summarized the wealth of data obtained from authors working in Italy, Croatia, Bosnia-Herzegovina and Montenegro. The majority of western European species are also recorded from these areas, some of them with a distinctive chronological meaning while endemic species are also found (especially *Hensonella dinarica*) or even some genera (e.g. *Humiella*). The Berriasian-early Aptian assemblages are less well defined than their western European analogs, there is no clear evidence of a mid-Valanginian break whereas the mid-Aptian break is well marked. The percentage of endemic taxa increases with increasing diversity which shows its maximum during the early Aptian.

As a whole for the two regions, a remarkable turnover in the species of *Salpingoporella* is observed which gives this genus a high biostratigraphic potential. Similarly the Berriasian-Valanginian assemblage and the Hauterivian-early Aptian assemblage are different in composition.

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JURASSIC PERIOD

GEOMAGNETIC POLARITY TIME-SCALE

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The magnetostratigraphy scale in the chronostratigraphy charts is mainly from the compilation by Ogg (1995). Later studies in the Callovian-Oxfordian-Kimmeridgian indicate that this portion of the scale requires modification.

The Oxfordian/Kimmeridgian boundary in the Tethyan realm (base of the Sutneria platynota ammonite zone) was provisionally assigned to the top of polarity chron M25n in the time scale of Gradstein et al. (1994), but later studies suggest an assignment within the older polarity chron M25r (Ogg and Gutowski, 1994; Ogg and Atrops, in prep.). A synchronous Oxfordian–Kimmeridgian boundary between the tethyan and boreal realms, at the base of the Pictonia baylei ammonite zone, is consistent with sequence stratigraphic and magnetic polarity patterns (Gygi et al., this volume; Ogg and Coe, 1997). However, Matyja and Wierzbowski (1997) present biostratigraphic arguments that the Oxfordian-Kimmeridgian stage boundary defined in the boreal realm is equivalent to the middle of the "upper Oxfordian" as defined in the tethyan realm. Further work is required to resolve this discrepancy. Deep-tow magnetic surveys by Sager et al. (1998) have acquired a complex signature of magnetic anomalies M26 through M41 in Pacific crust of early Callovian-Oxfordian age. Portions of this magnetic anomaly sequence have been correlated to Oxfordian ammonite zones (e.g., Ogg and Gutowski, 1996, Juárez et al., 1994, 1995; Ogg and Coe, 1997, and in prep.), and the base of the Callovian appears to correspond to polarity subchron "M36A" of the deep-tow pattern. Magnetostratigraphic polarity successions for the late Bathonian through Callovian stages have not yet been verified, and this interval represents one of the longest gaps in our knowledge of the Mesozoic magnetic polarity time scale.

The Hettangian and Sinemurian stages have not yet yielded a verified magnetostratigraphy. The Sinemurian appears to be dominated by reversed polarity (Steiner and Ogg, 1988 is shown in the chart; generally consistent with Yang et al., 1996), whereas the Hettangian may be dominated by normal polarity (Yang et al., 1996; Kent et al., 1995).

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AMMONITE ZONATIONS

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Introduction

Ammonite biostratigraphy plays a central role in the definition of Jurassic stratigraphy. Stages and their boundaries are primarily expressed in ammonite zones, subzones and horizons. Jurassic ammonite zonations have been under constant revision during the last two decades. Subdivisions used here refer to the most recently published syntheses with data from Callomon, Cope, Duff, Getty, Howarth, Ivimey-Cook, Parsons, Sykes, Torrens, Wimbledon, Wright (*in* Cope et al., 1980a,b), Atrops, Cariou, Contini, Corna, Dommergues, Elmi, Enay, Gabilly, Geyssant, Hantzpergue, Mangold, Marchand, Meister, Mouterde, Rioult, Rulleau, and Thierry (*in* Cariou and Hantzpergue, 1997). The zonal scheme adopted here is somewhat schematic because ammonite zones and subzones on the charts are selected in order to maximize the relative time resolution of the biostratigraphic reference framework while preserving the correlations between faunal realms. However, where possible, the selected zones and subzones follow the most current species index, but retain, where possible, the outdated zones no longer in use to avoid confusing non-ammonite specialists.

Ammonite Resolution and Calibration of the Jurassic System

Recent advances in Jurassic ammonite biostratigraphy concern the increased precision in ammonite subdivisions and the improved correlation of these subdivisions between the different faunal realms in Europe. The Jurassic System, depending on the faunal realm, is subdivided into about 70 or 80 zones and 160 or 170 subzones (an additional 350 horizons are not listed on the charts). Considering the entire Mesozoic, the number of ammonite subdivisions within the 61.5 my Jurassic, represents the highest resolution currently attainable by combining the most detailed records. Correlation of zones and subzones has greatly improved between faunal realms such as boreal (arctic areas and northern Europe), sub-boreal (northwestern and northeastern Europe), sub-Mediterranean (southwestern and southeastern Europe) and tethyan (southern Europe and Tethys margins). However, in the

Bajocian-Bathonian and Tithonian of northern Europe major regressive events isolate ammonite faunal realms which results in very different faunas that cannot be correlated directly. Palaeoecological constraints such as water depth differences between the epi-cratonic platforms in northern Europe and the tethyan ocean margins in southern Europe also constrain direct calibration of ammonite faunas.

Because of the scarcity of radiometric data, all ammonite zones or subzones within a stage are arbitrarily assigned equal duration except in the Kimmeridgian and Tithonian where magnetic polarity data are available Gradstein et al. (1994). However, it must be noted that several ammonite zones are well calibrated with radiometric data and these "tie points" are integrated in the Gradstein et al. (1994) timescale

Boundaries of the Jurassic System

World wide consensus exists on the principal divisions of the Jurassic System. Following the decisions of International Symposiums on Jurassic Stratigraphy (Erlangen, 1984, Lisbon, 1987, Poitiers, 1991), the "Coloquios de Estratigrafia de Espana" (Vitoria, 1970, Granada, 1979, Logroño, 1988), the "Arkell Symposium" (London, 1993) and special meetings of "Working groups" on every stage organized under the auspices of the International Subcommission on Jurassic stratigraphy (Callovian, Stuttgart, 1990, Aalenian-Bajocian, Piobbico, 1990, Skye, 1991, Oxfordian, Zaragoza, 1978, Warszawa, 1992, etc. . . .).

The basal ammonite zone in the Jurassic and the Hettangian Stage where the first *Psiloceratacea* ammonites appear is the Planorbis Zone (Planorbis Subzone), Mouterde and Corna (1991). However, the base of the Jurassic System coincides in western Europe with a major flooding event and there is a tendency to include beds with the first marine invertebrate faunas (bivalves, gastropods, echinoids, foraminifers, etc.) in the Hettangian although they lack the ammonite index fossil.

Opinions strongly diverge for the top of the Jurassic System (Jurassic/Cretaceous boundary). In the tethyan area the final zone of the Tithonian is the Durangites Zone (Mediterranean realm: southern Spain, Italy, Karpathians and Balkans, Enay and Geyssant, 1975) or its traditional equivalent the Transitorius/Microcanthum Zone (sub-mediterranean realm, southeastern France and southern Germany). The Berriasian begins with the Jacobi Zone. In the boreal/sub-boreal scheme (Casey, 1973; Cope 1984) the top of the Lamplughi Zone is correlated with the top of the Jacobi Zone. Below the Lamplughi Zone, no correlation is possible between boreal and tethyan areas because of the total absence of common taxa due to a major regressive event near the Jurassic/Cretaceous boundary. Moreover, opinions diverge on the position of the top of the Portlandian Stage (*sensu anglico*), it is placed either at the top of the Lamplughi Zone (Wimbledon, 1980) or at the top of the Oppressus Zone (Birkelund, Callomon and Fursich, 1984). At the present day, there is no consensus on the Jurassic/Cretaceous boundary (Hoedemaeker, 1987, 1991). Jurassic stages on the chart reflect what we believe to be a majority view (Geyssant and Enay, 1991), although alternative solutions are entered as well.

Subdivisions of the Jurassic Subsystems

The main subdivisions of the Jurassic follow the decisions of the "Colloques du Jurassique" in Luxembourg (1962, 1967) albeit with minor modifications.

The Lias/Dogger and Dogger/Malm boundaries can be correlated between the faunal realms with relative ease due to a homogenization of faunas. The Lias/Dogger boundary (= Toarcian/ Aalenian boundary) is placed between the last Toarcian ammonite zone (Aalensis/ Fluitans Zone) recognizable in both the boreal and tethyan domains (Elmi et al., 1991), and the basal zone of the Dogger (Opalinum Zone, Opalinum Subzone) of the Aalenian Stage (Contini et al., 1991). Such a decision eliminates the traditional boundary established by Haug in the last century and discussed by generations of biostratigraphers but has the advantage of coinciding with the boundary of the "Brauner Jura" in Germany.

The Dogger/Malm boundary (= Callovian/Oxfordian boundary) coincides in the sub-boreal and sub-mediterranean realms with the top of the Lamberti Zone, Lamberti Subzone (Thierry et al., 1991). The Oxfordian begins with the Mariae Zone, Scarburgense Subzone (Cariou et al., 1991), which can be recognized in both areas as well.

Boundaries between stages and stage-subdivisions

Stage boundaries and their subdivisions into zones, subzones and horizons, have been continuously refined over the last twenty years. Subdivisions in the Hettangian (Mouterde and Corna, 1991), Sinemurian (Corna et al., 1991) and Pliensbachian (Dommergues et al., 1991), are essentially based on the subdivision defined in northwestern Europe (sub-boreal realm: England, France, northern Spain, Portugal and Germany). Prominent differences in ammonite faunas appear only southward in the tethyan realm (Italy and southern Spain). Provincialism begins to be noticeable in the Toarcian (Elmi et al., 1991), Aalenian (Contini et al., 1991) and Bajocian (Contini et al., 1991), but the northwestern European areas (sub-boreal realm) remain the basic reference for the zonal scheme. Alternative units have been plotted alongside the standard divisions, as well as for zones or subzones in the two realms.

The basic scheme for the Bathonian is based on Mediterranean areas (Mangold, 1991) where the ammonite faunas are more diverse and better known than in northwestern Europe. However, there is no complete agreement on a standard scheme of stage zonal subdivisions and on correlations between boreal and tethyan realms, therefore some of the alternative zones and subzones currently used are referred to on the chart.

For the Callovian (Thierry et al., 1991) and lower Oxfordian (Cariou et al., 1991) when boreal influences extend southward to Spain and Portugal, the standard reference is based again on the northwestern European sub-boreal realm. Correlation of biostratigraphic units are rather easy during the Callovian.

Problems arise with middle-upper Oxfordian, Kimmeridgian (Cariou et al., 1991; Hantzpergue et al., 1991) and especially during the Tithonian (Geyssant and Enay, 1991) when increasing provincialism complicates correlations. Connections between southern Europe and northern Europe are episodic and endemic faunas settle in northern Aquitaine, the northern Paris Basin and Germany ("Biome franco-germanique", Hantzpergue et al., 1991). The late Jurassic regression influences ammonite diversity and distribution. On the chart, it was impossible to represent all subtleties, therefore the boreal scheme for the Oxfordian through Tithonian Stages was selected as the standard.

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OSTRACODES

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Numerous detailed analysis of European Jurassic ostracode faunas during the past 20 years have provided a good knowledge of the stratigraphical and palaeogeographical distribution of a great number of species. Ostracode bioevents can be generally correlated to ammonite zones, especially in the lower Jurassic.

Most data come from the boreal and sub-boreal realms: Great Britain, Paris Basin, Denmark. Information from the European tethyan realm (southern France, Spain, Portugal, Italy) is still scarce.

Late Jurassic

For northern Europe, most late Jurassic ostracode events were identified in Great-Britain by Christensen and Kilenyi (1970). Subsequent work by Kilenyi (1978), Wilkinson (1983), Wignall (1990) in Great-Britain, and by Schudack (1994) brought additional information.

As noticed by Kilenyi (1978) "The correlation of British upper Jurassic marine ostracode faunas with those described from Germany, France, Poland and Denmark present no problems. Very often the ranges of individual species agree over long distances within one or two ammonite zones"

Middle Jurassic

Aalenian ostracodes are only well known from Germany (Plumhoff, 1963). Because of the strong condensation of the Bajocian sections, especially in southern England and northern France, relatively little is known on Bajocian ostracodes although Bate (1975) proposed a zonation for the early Bajocian (Discites to Humphresianum ammonite Zone). To the contrary, Bathonian ostracodes are well known, especially from southern England and northern France, and several workers have proposed zonations: Bate (1978), Sheppard (1981a,b and Depêche 1984). However, as stated by Bate (1978), the rare occurrence of ammonites in the Bathonian makes correlations of the varied lithologies very tenuous.

Early Jurassic

The most comprehensive study of early Jurassic ostracodes can be found in Michelsen (1975) who studied a large number of wells in the Danish Embayment. Additional useful data on the lower Lias of northern Europe can also be found in Lord (1978), Sivhed (1980), Donze (1985) and Boomer (1991).

For the upper Lias Toarcian, references are made essentially to the works of Bate and Coleman (1975) in Great Britain and of Knitter (1984) in southern Germany.

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RADIOLARIANS

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Numerous Italian and German authors (Parona, 1890, 1892; Pantanelli, 1880; Rust, 1885, 1898) were among the pioneers in publishing papers dealing with Jurassic radiolarians. Since then successive workers published new information on the Jurassic fauna of Europe (Cayeux, 1891, 1896; Deflandre, 1953; Dumitrica, 1970; Baumgartner, 1980 ; De Wever, 1982, 1986). However, in the last two decades the number of papers published increased dramatically and the first biozonation for Europe was published by Baumgartner, De Wever and Kocher in 1980. Unfortunately, most papers dealt with the tethyan area and very little work was done on the boreal area.

Information on Jurassic radiolarians is abundant for the folded tethyan terranes and radiolarians are rock forming (radiolarite) in numerous localities. The present set of tethyan marker species is based on recent publications by Gorican (1987, 1994) and on the synthesis published by the InterRad working group.

There is essentially no literature describing well preserved boreal or sub-boreal faunas. Only occasional species are mentioned from scattered localities in Scotland, (Dyer and Copestake 1989) and Russia (Khabakov 1973; Bragin in press). Illustrations are, however, marginal and of limited use. Therefore, since no reliable datums exist for the boreal province none were entered on the Jurassic chart.

In western Europe faunal differences between warm and cold depositional environments has not yet been demonstrated with certainty. This is mainly do to the fact that most information comes from radiolarite-type rocks which were deposited under the most active parts of upwelling (De Wever et al., 1994). In settings of upwelling mixtures of species representing warm, cold, shallow and deep water faunas often co-occur. Before a distinction between provinces can be attempted, it will be necessary to identify from the appropriate data which markers are indicators of boreal or tropical environments.

Most of the Jurassic datums are calibrated with other biozonations such as ammonites, calcareous nannofossils or foraminifers. First order calibration is to biozones of other fossil groups or in absence of such data directly to the stage. There is no first order calibration with the numerical scale in Ma.

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TRIASSIC PERIOD

GEOMAGNETIC POLARITY TIME-SCALE

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The magnetostratigraphy scale in the chronostratigraphy charts is mainly from the compilation by Ogg (1995). Later studies in the Anisian through Rhaetian indicate that this portion of the scale requires modification.

Two independent magnetic polarity scales are shown for the Upper Triassic. The first column is derived from continental sediments in North America and is scaled according to the placement of stage boundaries in published stratigraphic studies, whereas the second column is derived from marine sediments in southwestern Turkey and has been rescaled to correspond to individual ammonite zones within each stage (reviewed in Ogg, 1995; see also Gallet et al., 1996). Drilling of lacustrine deposits in the Newark Basin of eastern U.S. has yielded a complete upper Triassic magnetic polarity pattern scaled to Milankovitch cycles of eccentricity (Kent et al., 1995), but the correlation to standard geological stages and associated magnetostratigraphy scales derived from macrofossil- and conodont-bearing sediments remains uncertain.

The boundaries of the Anisian have now been calibrated with magnetostratigraphy (Muttoni et al., 1995, 1997). The polarity pattern from ammonite-zoned Griesbachian through Spathian substages in the Canadian Arctic can be correlated to the magnetostratigraphy of the Werfen Formation of marginal-marine deposits in the Dolomites of Italy using constraints from biostratigraphy and sequence-stratigraphy (Graziano and Ogg, 1994).

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CALCAREOUS NANNOFOSSILS

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Since we know little about the modes of life of the few Triassic nannofossils-be they planktic, nektic or benthic- and since, in the present context, the emphasis is on the stratigraphic distribution of fossils and not on their systematic position, calcispheres and other calcareous forms of unknown affiliation are included. Note that calcareous nannofossils from the Triassic have so far only been found in a few areas. Di Nocera and Scandone (1977) and Wiedmann et al. (1979) first illustrated late Triassic calcareous nannofossils from the Triassic of Greece, the southern Alps and southern Germany, Jafar (1983) , Janofske (1987, 1992) and a few other authors (see Janofske, 1992) augmented our knowledge with reports of calcareous nannofossils from the alpine upper Triassic. The Triassic calcareous nannofossils from other regions were treated by Bown (1992; British Columbia, Canada and Timor) and Bralower et al. (1991; ODP Leg 122 NW Australia).

Direct correlation of calcareous nannofossil findings with ammonite zonations are very rare. The positions of most events on the chart are thus chosen more as educated guesses than after any criterion.

Carnian

In the lower Carnian (Cordevolian; aon ammonite zone), the assemblage is dominated by "calcispheres", namely *Orthopithonella misurinae* and *O. prasina*. Also found are *Carnicalyxia tabellata* and *Cassianospica curvata* (Janofske, 1992).

Norian

The Norian of the Queen Charlotte Islands, B.C., Canada furnished: *Prinsiospheara triassica*, *Thoracosphaera* sp. indet., *Orthopithonella geometrica* and the first two "real coccoliths" *Crucirhabdus minutus* and, questionably, *C. primulus* (Bown, 1992). Bralower et al. (1991, 1992) reported *O. geometrica, T. wombatensis, P. triassica* and *C. primulus* to appear together on the Wombat Plateau off northwestern Australia followed by *Thoracosphaera* sp.

Rhaetian

Richer assemblages are reported from the Rhaetian of the Northern Calcareous Alps (stuerzenbaum to marshi ammonite zones) by Janofske (1992); *P. triassica, Or. geometrica, Obliquipithonella rhombica, Eoconusphaera zlambachensis, C. minutus* and *Archeozygodiscus koessenensis*. The upper Triassic of west Timor yielded *P. triassica, E. zlambachensis* and *C. minutus* according to Kristan-Tollman et al. (1987) and Bown (1992). From the Wombat Plateau, Bralower et al. (1992) reported the FO of *E. zlambachensis* together with the FO's of *C. minutus* and *A. koessenensis* while all species found in the Norian continued into the Rhaetian.

Rhaetian/Hettangian boundary (= Triassic/Jurassic boundary)

According to Bown (personal communication 1994), the last occurrence (LO) of *P. triassica* best approximates the Triassic/Jurassic boundary, Bown (1992) found no calcareous nannofossils in the section in the New York Canyon, Nevada, a section which had been proposed for the Triassic-Jurassic System boundary.

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OSTRACODES

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Relatively detailed zonations based on ostracodes have been provided only for the Germanic realm although ostracode records and diversity are much greater in the Alpine realm. Zonations based on ostracodes have been established in the Germanic and pre-Caspian Basins by Will (1969), Kozur and Mostler (1972), Kozur (1975), and in Great Britain by Anderson (1964) and Bate (1978). Since these zonations have been established in lagoonal and marginal marine environments, correlations with conodonts and/or ammonites zones are very tentative.

Detailed information on Triassic ostracodes from the Germanic realm are available from two main stratigraphic intervals: the Ilyrian (late Anisian) to Julian (early Carnian) and the Sevatian (late Norian) to Rhaetian.

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RADIOLARIANS

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Records of radiolarians are still relatively rare from Triassic sedimentary rocks and most of the information available is concerning Alpine faunas.

Triassic radiolarian are known since a long time but comprehensive studies are rather recent. A preliminary note by Rust (1887) was followed by a more comprehensive study, Rust (1892) which recorded 29 species from 28 Triassic samples of central European hornsteins and calcareous limestones. Parona (1892) figured a dozen poorly preserved forms. More recent studies on the same levels are from De Wever et al. (1979); De Wever (1982); Kozur and Mostler (1972, 1978, 1979); Dumitrica (1978a,b); Gorican and Buser, (1990) and Lahm, 1984).

Samples yielding radiolarians are rare from scattered localities in Europe, mainly concentrated in the tethyan area (Austria, Italy, Slovenia, Serbia, Montenegro, Albania, Greece and Turkey). Most of the Triassic FADs and LADs were calibrated with conodonts, ammonites or pelecypods.

Few well preserved boreal and sub-boreal faunas have been described to date and therefore no FADs or LADs of boreal markers are entered on the chart. Only recently some faunas were recorded from Russia (northern Siberia, Egorov, 1995).

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DINOFLAGELLATES

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Records of dinoflagellates are relatively rare in the Triassic and are essentially restricted to its upper part. The oldest unequivocal representative of this group was described by Stover and Helby (1987) from the middle Triassic of Australia. Although palynomorphs of marine origin are abundant in the lower and middle Triassic of the Arctic as well as in the Muschelkalk of the Alpine/Germanic realm, no dinoflagellate cysts were identified.

Southern hemisphere

The most complete succession of dinoflagellates is known from Australia where Helby et al. (1987) subdivided the upper Triassic into five zones. Most of the FADs and LADs on the chart are based on this publication. However, the calibration of these assemblages is relatively poor because of the absence of independent control. The assemblages described by Brenner et al. (1992) from the Wombat Plateau, offshore northwestern Australia which are calibrated with ostracodes and magnetostratigraphy confirm the stratigraphic interpretation given by Helby et al. (1987).

Arctic

In the Arctic, Norian and Rhaetian sections are characterized by regular occurrences of dinoflagellates. Assemblages calibrated with ammonites are known from the middle Norian (N. columbianus zone) of the Canadian Arctic Islands (Bujak and Fisher, 1976). Based on sporepollen evidence, lower Norian and upper Carnian ages are suggested for the oldest occurrences of the *Sverdruppiella/Noricysta* assemblages.

Alpine/Germanic

In the Alpine/Germanic realm, distribution of dinoflagellates is restricted to the uppermost Triassic. Diverse assemblages were described from the Rheatian in the Alpine Kendelbach Graben section in Austria (Morbey, 1975). Most of the assemblages from the Rheatian Germanic facies are not diverse. No dinoflagellates older than Rheatian are known from the Alpine/Germanic realm.

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SPORE-POLLEN

Peter A. Hochuli

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In Europe two distinct provinces—Germanic/Alpine and Arctic—can be distinguished based on the distribution of spore pollen. The events from the Alpine/Germanic realm are plotted in the same column despite the fact that not all of the recorded species are known from both areas. In this province three, probably climatically induced, cycles are reflected in the flora which essentially correspond to the classical threefold lithological subdivision of the Triassic (Bunstandstein, Muschelkalk and Keuper).

Based on available data, some of the widely used markers of the Alpine/Germanic realm seem to have different ranges in the Arctic, although the most distinctive differences between the two provinces are in the quantitative distribution of taxa. Compared to southern localities, palynological successions are more complete in the Arctic.

Germanic/Alpine

In the Germanic realm, calibration with the stratigraphic standard is poor because the Germanic sediments are marginal marine or nonmarine whereas the standard is marine. Consequently the ranges of many species are constrained only by the inferred age of the formation they occur in, whereas others are tied to major stratigraphic events. First-order correlations can be worked out for the upper part of the lower Muschelkalk (upper Wellenkalk) and for the uppermost part of the Muschelkalk. So far the most complete palynological records were published by Orlowska-Zwolinska (1977, 1983) from Poland. Van der Zwan and Spaak (1992) proposed a zonal scheme for the lower and middle Triassic.

In some parts of the alpine Triassic, the ranges of palynomorphs are constrained by the occurrence of ammonites. Well-dated assemblages are known from the interval between the Anisian and the lower Carnian and from the upper part of the upper Triassic.

The most complete palynological records in the Alpine realm have been published by Brugman (1986). This author proposes a series of phases in the evolution of the palynological assemblages between the Spathian and the lower part of the Carnian based on both first and last occurrences and the abundance of specific taxa. However, these successions are based on isolated outcrop samples or relatively short stratigraphic intervals. The palynological records from the upper part of the Carnian and the Norian are incomplete as a result of poor preservation of palynomorphs.

Arctic

A first overview Triassic palynostratigraphy has been published by Hochuli et al. (1989) based on some dated core and outcrop samples from exploration wells of the Barents Sea area. Although not complete, reliable independent stratigraphic control from ammonites exists for the interval between the upper part of the lower Triassic (Smithian) and the base of the Carnian. A few well controlled records are also known from the Griesbachian and the Norian. New evidence from a well-calibrated Smithian interval of the mid-Norwegian shelf was recently published by Vigran and Mangerud (1991). The ranges of several species on the chart are taken from a more complete account of the palynological records from dated cores of Smithian to Ladinian age of the Barents Sea (Vigran et al., in prep.) Some events on the chart are based on unpublished data of P. van Veen.

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MESOZOIC AND CENOZOIC SEQUENCE CHRONOSTRATIGRAPHIC CHART

Jan HARDENBOL, Jacques THIERRY, Martin B. FARLEY, Thierry JACQUIN, Pierre- Charles de GRACIANSKY, and Peter R. VAIL, 1998,
Mesozoic and Cenozoic Sequence Chronostratigraphic Framework of European Basins,
in, de Graciansky, P.-C., Hardenbol, J., Jacquin, T., and Vail, P. R., eds.,
Mesozoic and Cenozoic Sequence Stratigraphy of European Basins, SEPM Special Publication 60

Chart 1

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Saga Petroleum (Norway)
Total (France)

Schematic Condensed Section
Top Low Stand (where indicated)
Maximum Flooding Surfaces: Minor, Medium, Major
Sequence Boundaries: Minor, Medium, Major

CENOZOIC SEQUENCE CHRONOSTRATIGRAPHY

JAN HARDENBOL, JACQUES THIERRY, MARTIN B. FARLEY, THIERRY JACQUIN, PIERRE-CHARLES DE GRACIANSKY, AND PETER R. VAIL

1998
Mesozoic and Cenozoic Sequence Chronostratigraphic Framework of European Basins
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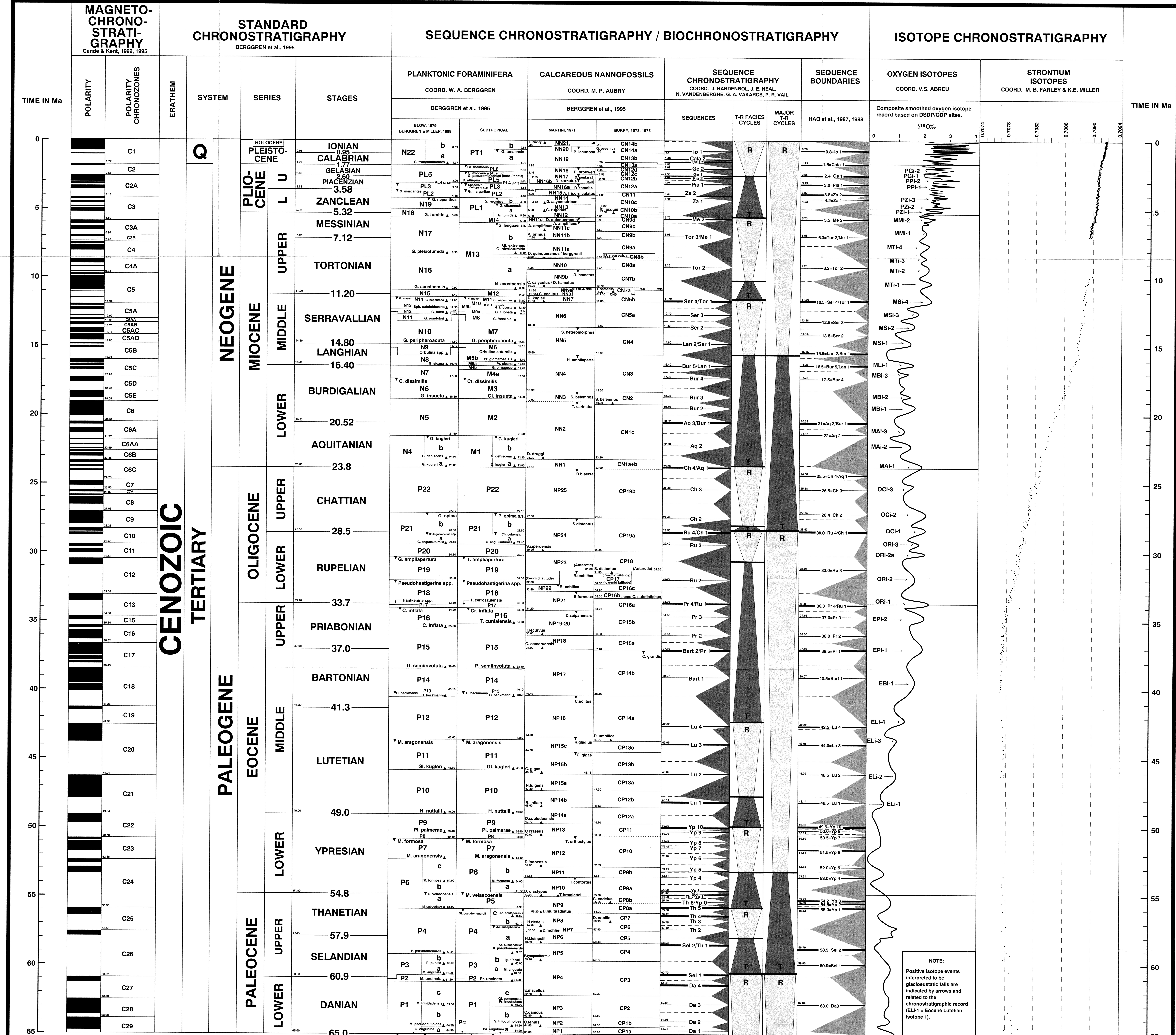
Mesozoic and Cenozoic Sequence Stratigraphy of European Basins, SEPM Special Publication 60.

Chart 2



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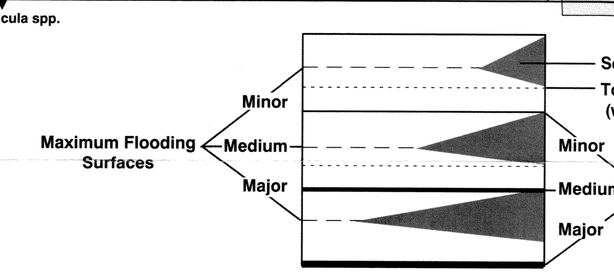

Sequence nomenclature

Sequence boundary nomenclature for the new sequences is based on the stage in which a sequence boundary occurs and its ordinal position counting up from the stage base. For example, the sequence boundaries in the Ypresian are Yp1 through Yp10 with Yp1 the oldest. Note that it is the position of the sequence boundary that determines the name, even if most of the sequence is in the next younger stage. In the new sequences lowstands are not distinguished. The systems tract boundary between lowstand and transgressive systems tracts is not of chronostratigraphic significance and thus is not shown on this chart.

Chart 3

CENOZOIC BIOCHRONOSTRATIGRAPHY

JAN HARDENBOL, JACQUES THIERRY, MARTIN B. FARLEY, THIERRY JACQUIN, PIERRE-CHARLES DE GRACIANSKY, AND PETER R. VAIL

1998
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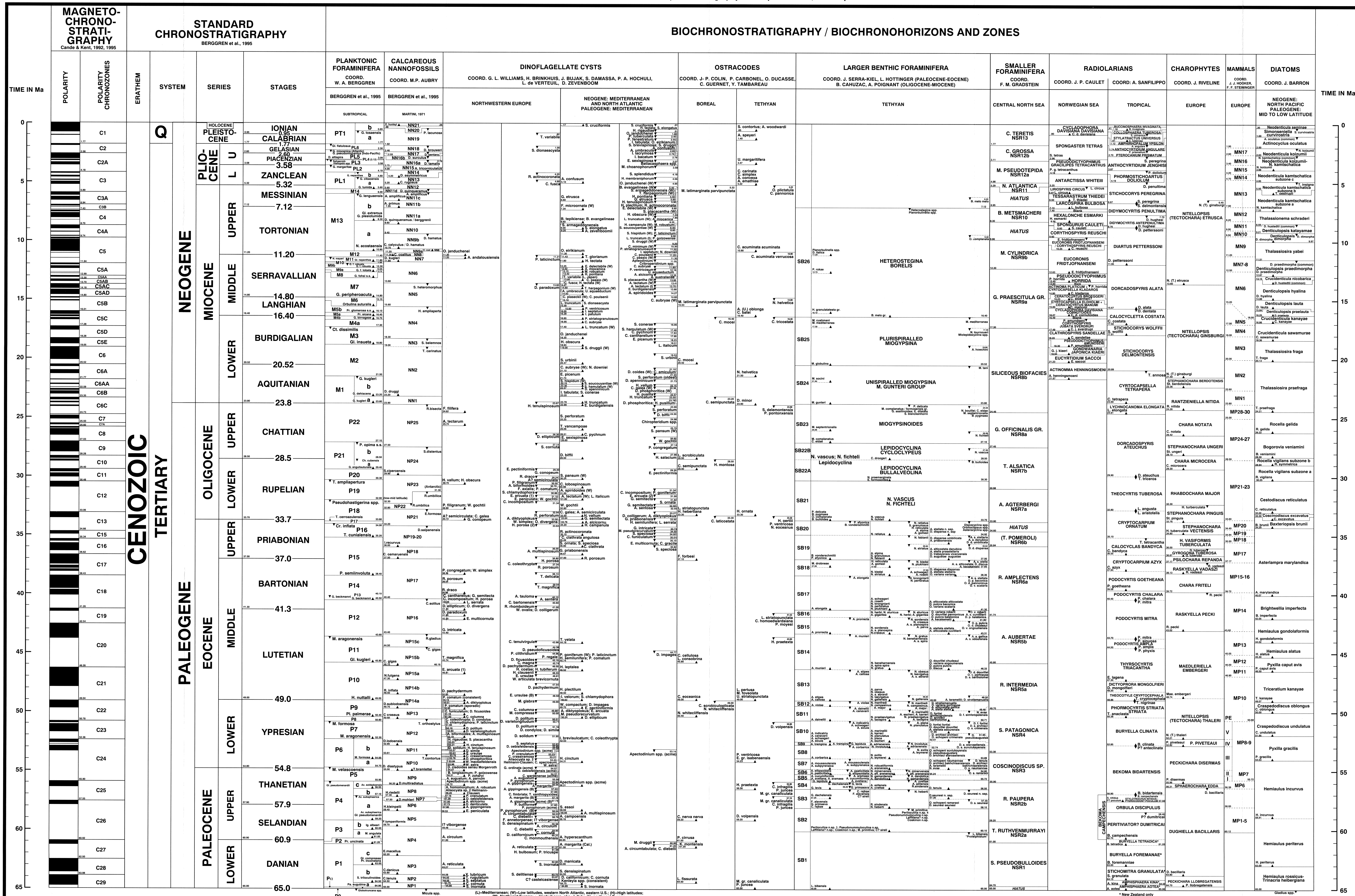

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1. Ages for the stage boundaries are directly inferred from radiometric data and are shown to the nearest 0.1 m.y. or 0.01 in the Neogene (Berggren, et al., 1995). All other ages shown to the nearest 0.01 m.y. are intended only as a place holder to help determine the relative position of events in different columns. Roundoff error in plotting required two decimal point precision for each entry to avoid apparent misalignments.

2. First Appearance Datums (FADs; originations; ▲) and Last Appearance Datums (LADs; extinctions; ▼) closely spaced in time may have bent flags. In this case, the time position of the event is the flag stem at the edge of the column.

3. The standard format for names other than ammonites is:
Zones--full generic and specific name
Appearance Datums--Abbreviated generic name and full specific name except for "sp(p)." for which full generic names are given.

4. Uncertain stratigraphic positions for zonal boundaries, FADs, and LADs are shown with dashed lines.

5. B. clinata / P? anteclinata Evolutionary transition.

CRETACEOUS SEQUENCE CHRONOSTRATIGRAPHY

JAN HARDENBOL, JACQUES THIERRY, MARTIN B. FARLEY, THIERRY JACQUIN, PIERRE-CHARLES DE GRACIANSKY, AND PETER R. VAIL

1998
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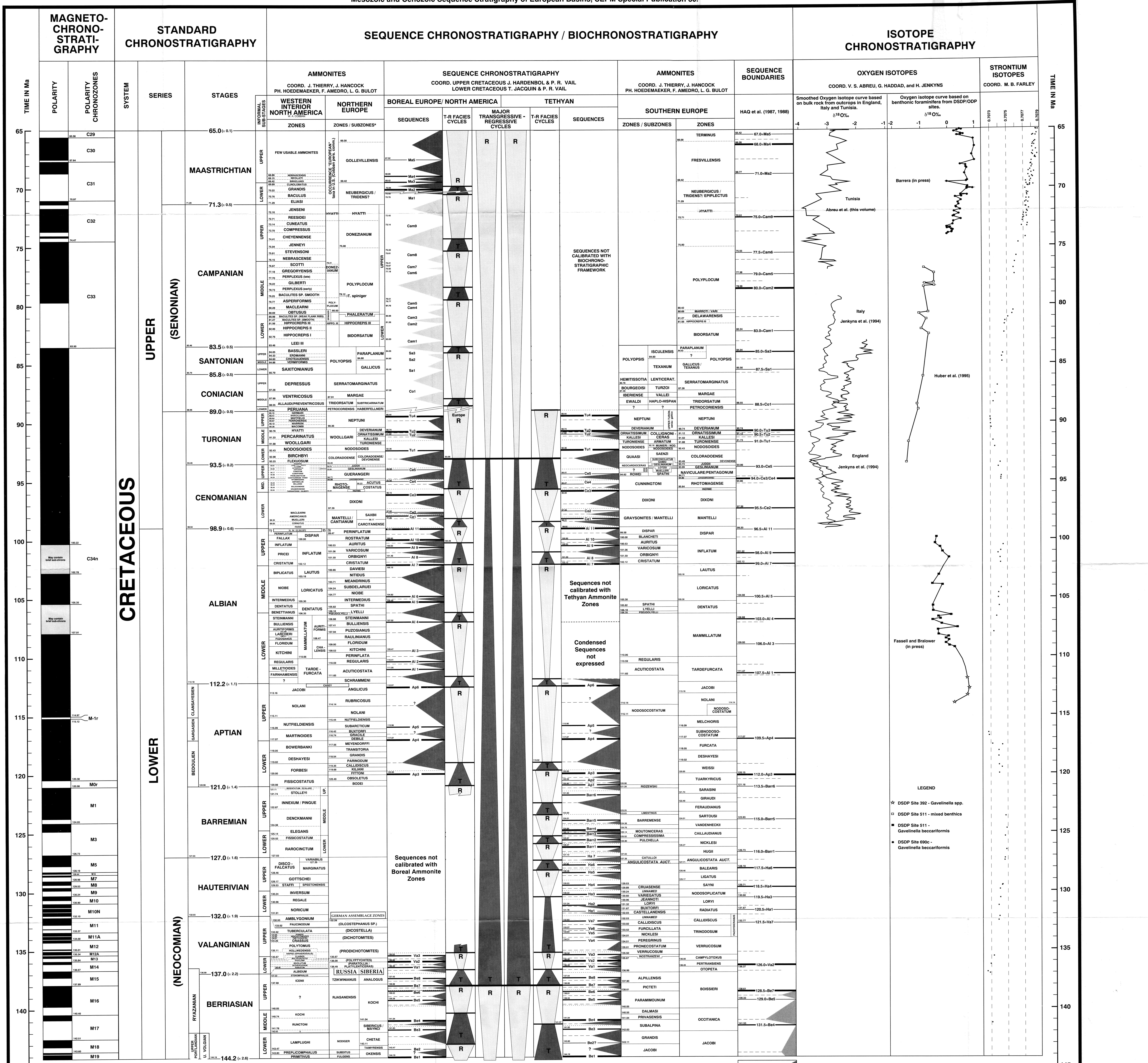
Chart 4



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AMMONITE ZONATIONS:
....Albian - 1) Amedro Zones
2) Amedro / Owen Zones
3) Owen Subzones
....Aptian - Casey Zones / Subzones
....Barremian - Kemper/Koenen
....Hauterivian - Kemper
....Valanginian - Kemper
....U-M Berriasian - Casey/Bogoslovsky
....L Berriasian - Swinnerton
xxxxxxxxxxxxxxxx DENOTES BOUNDARY DIFFERENT FROM STANDARD CHRONSTRATIGRAPHY

Sequence nomenclature

Sequence boundary nomenclature for the new sequences is based on the stage in which a sequence boundary occurs and its ordinal position counting up from the stage base. For example, the sequence boundaries in the Cenomanian are Ce 1 thru Ce 5 with Ce 1 the oldest. Note that it is the position of the sequence boundary that determines the name, even if most of the sequence is in the next younger stage. In the new sequences lowstands are not distinguished. The systems tract boundary between lowstand and transgressive systems tracts is not of chronostratigraphic significance and thus is not shown on this chart.

Maximum Flooding Surfaces: Minor, Medium, Major
Schematic Condensed Section
Top Lowstand (where indicated)
Sequence Boundaries: Minor, Medium, Major

CRETACEOUS BIOCHRONOSTRATIGRAPHY

JAN HARDENBOL, JACQUES THIERRY, MARTIN B. FARLEY, THIERRY JACQUIN, PIERRE-CHARLES DE GRACIANSKY, AND PETER R. VAIL

1998
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Chart 5

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Shell (UK & The Netherlands)
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Total (France)

1. Ages for the stage boundaries are directly inferred from radiometric data and are shown to the nearest 0.1 m.y. with statistical uncertainty in parentheses (Gradstein, *et al*., 1995). All other ages shown to the nearest 0.01 m.y. are intended only as a place holder to help determine the relative position of events in different columns. Roundoff error in plotting required two decimal point precision for each entry to avoid apparent misalignments.

2. First Appearance Datums (FADs; originations; ——▲) and Last Appearance Datums (LADs; extinctions; ▼——) closely spaced in time may have bent flags. In this case, the time position of the event is the flag stem at the edge of the column.

3. The standard format for names other than ammonites is:
Zones--full generic and specific name
Appearance Datums--Abbreviated generic name and full specific name except for "sp(p)." for which full generic names are given.

4. Uncertain stratigraphic positions for zonal boundaries, FADs, and LADs are shown with dashed lines.

JURASSIC SEQUENCE CHRONOSTRATIGRAPHY

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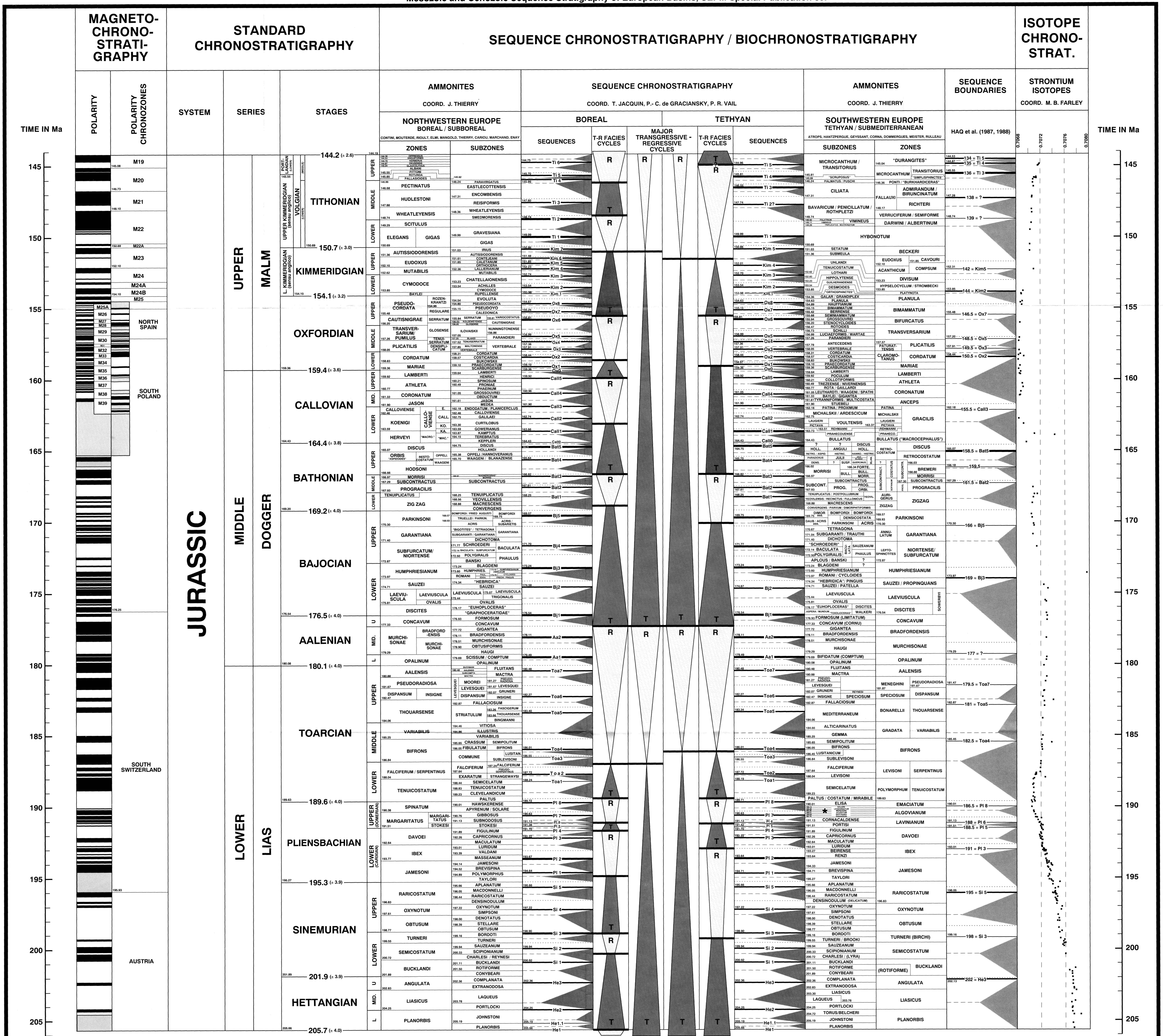
Chart 6



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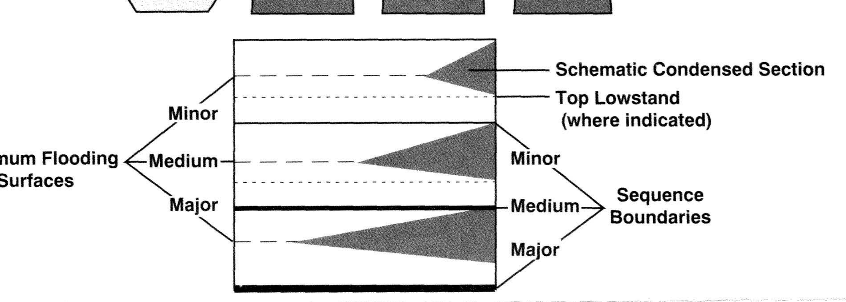

*

190.13	SOLARE
190.26	LEVIDORSATUM
190.38	MENEGHINI
190.51	ACURATUM
190.63	BERTRANDI
190.76	RAGAZZONI

Sequence nomenclature

Sequence boundary nomenclature for the new sequences is based on the stage in which a sequence boundary occurs and its ordinal position counting up from the stage base. For example, the sequence boundaries in the Toarcian are Toa1 thru Toa7 with Toa1 the oldest. Note that it is the position of the sequence boundary that determines the name, even if most of the sequence is in the next younger stage. In the new sequences lowstands are not distinguished. The systems tract boundary between lowstand and transgressive systems tracts is not of chronostratigraphic significance and thus is not shown on this chart.

JURASSIC BIOCHRONOSTRATIGRAPHY

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Chart 7

Sequence Stratigraphy of European Basins Project

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Maxus (USA)
Mobil North Sea (Norway)
Shell (UK & The Netherlands)
Saga Petroleum (Norway)
Total (France)

*

190.13	SOLARE
190.26	LEVIDORSATUM
190.38	MENEGHINI
190.51	ACURATUM
190.63	BERTRANDI
190.76	RAGAZZONI

1. Ages for the stage boundaries are directly inferred from radiometric data and are shown to the nearest 0.1 m.y. with statistical uncertainty in parentheses (Gradstien, et al., 1995). All other ages shown to the nearest 0.01 m.y. are intended only as a place holder to help determine the relative position of events in different columns. Roundoff error in plotting required two decimal point precision for each entry to avoid apparent misalignments.

2. First Appearance Datums (FADs; originations; ▲) and Last Appearance Datums (LADs; extinctions; ▼) closely spaced in time may have bent flags. In this case, the time position of the event is the flag stem at the edge of the column.

3. The standard format for names other than ammonites is:
Zones--full generic and specific name
Appearance Datums--Abbreviated generic name and full specific name except for "sp(p)." for which full generic names are given.

4. Uncertain stratigraphic positions for zonal boundaries, FADs, and LADs are shown with dashed lines.

TRIASSIC SEQUENCE CHRONOSTRATIGRAPHY / BIOCHRONOSTRATIGRAPHY

JAN HARDENBOL, JACQUES THIERRY, MARTIN B. FARLEY, THIERRY JACQUIN, PIERRE-CHARLES DE GRACIANSKY, AND PETER R. VAIL

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Chart 8

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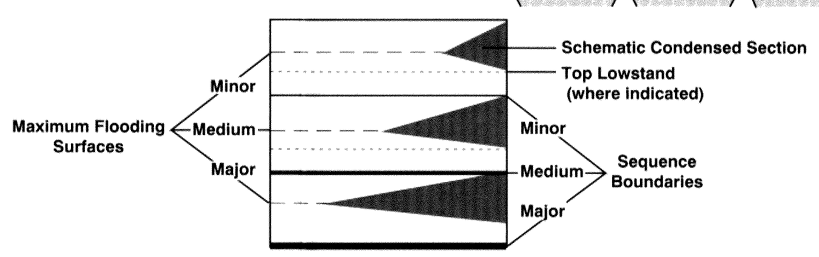
Elf Aquitaine Petroleum (France)
Exxon Production Research (USA)
Institut Français du Pétrole (France)
Maxus (USA)
Mobil North Sea (Norway)
Shell (UK & The Netherlands)
Saga Petroleum (Norway)
Total (France)



Sequence nomenclature

Sequence boundary nomenclature for the new sequences is based on the stage in which a sequence boundary occurs and its ordinal position counting up from the stage base. For example, the sequence boundaries in the Anisian are An1 thru An4 with An1 the oldest. Note that it is the position of the sequence boundary that determines the name, even if most of the sequence is in the next younger stage. In the new sequences lowstands are not distinguished. The systems tract boundary between lowstand and transgressive systems tracts is not of chronostratigraphic significance and thus is not shown on this chart.

1. Ages for the stage boundaries are directly inferred from radiometric data and are shown to the nearest 0.1 m.y. with statistical uncertainty in parentheses (Gradstein, et al., 1995). All other ages shown to the nearest 0.01 m.y. are intended only as a place holder to help determine the relative position of events in different columns. Roundoff error in plotting required two decimal point precision for each entry to avoid apparent misalignments.

2. First Appearance Datums (FADs; originations; ▼———) and Last Appearance Datums (LADs; extinctions; ———▲) closely spaced in time may have bent flags. In this case, the time position of the event is the flag stem at the edge of the column.

3. The standard format for names other than ammonites is:
Zones--full generic and specific name
Appearance Datums--Abbreviated generic name and full specific name except for "sp(p)." for which full generic names are given.

4. Uncertain stratigraphic positions for zonal boundaries, FADs, and LADs are shown with dashed lines.