

## The Rupelian-Chatthian boundary in the North Sea Basin and its calibration to the international time-scale

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### Abstract

The classical problem of the nature and age of the Rupelian-Chatthian (Early-Late Oligocene) unconformity in its type region is here approached using organic walled dinoflagellate cyst (dinocyst) correlations between the North Sea Basin and well-calibrated central Italian (Tethyan Ocean) sections. Useful Oligocene dinocyst events are the last occurrence of *Enneadocysta pectiniformis* (~29.3 Ma), and the first occurrences of *Saturnodinium pansum* (~29.4 Ma), *Distatodinium biffii* (~27.9 Ma) and *Artemisiocysta cladodichotoma* (~26.7 Ma). The latter event marks the earliest Chatthian. The improved correlations indicate that the Rupelian-Chatthian (R-C) boundary is associated with the so-called 'Oligocene Glacial Maximum'. This phase of important global cooling and glacio-eustatic sea level fall is genetically related to the unconformity between the classic Oligocene stages. Subsequent global warming (so-called 'Late Oligocene Warming Event'), induced a major sea level rise, leading e.g. to the time-transgressive deposition of the typical basal Chatthian glauconitic sands. The oldest of the Chatthian units have a GPTS age of ~26.7 Ma. It further appears that a hiatus of ~500 kyrs spans the classic Rupelian-Chatthian unconformity.

*Keywords:* biochronostratigraphy, dinoflagellate cysts, North Sea Basin, Rupelian-Chatthian boundary, Tethyan Ocean

### Introduction

The Oligocene successions of the southern North Sea Basin (Fig. 1) are internationally important in that they constitute the classic Rupelian (Lower Oligocene) and Chatthian (Upper Oligocene) stratotype sections. Currently, efforts are underway to establish a Global Boundary Stratotype Section and Point (GSSP) for the R-C boundary on the basis of continuous central Italian sections (Coccioni et al., submitted). According to the concepts of the International Stratigraphic Guide (Salvador, 1994), definition of a chronostratigraphic unit should place emphasis on the selection of the boundary stratotype of its lower boundary; its upper boundary is then defined as the lower boundary of the overlying unit. This concept implies that any

R-C GSSP ideally should coincide with the base of the classic Chatthian Stage, stressing the importance of its characterisation.

The lowermost layers of the Chatthian unit-stratotype, i.e. the Doberg section in NW Germany, are long since known as the 'Asterigerina Horizon', named after the bloom of the benthic foraminifer *Asterigerinoides guerichi*. This distinct and widespread bloom can be recognised throughout the North Sea Basin (e.g. Ellermann, 1958; Indans, 1958, 1965; Doppert & Neele, 1983; Ulleberg, 1987; King, 1983, 1989; see overview in Van Simaey et al., 2004) and thus allows clear recognition of the R-C boundary in its type region (Van Simaey et al., 2004). However, accurate calibration of this bioevent to the international polarity time-scale (GPTS) has been notoriously hampered



Fig. 1. Paleogeographic reconstruction of the European continent during mid Oligocene times, with the locations of the 1. southern and 2. central North Sea Basin successions and 3. central Italian sections (modified from Ziegler, 1990; Scotese & Golanka, 1992 and Sissingh, 2003).

by 1. the endemic nature of the North Sea Oligocene benthic foraminifera, 2. the sparsity of chronostratigraphic important calcareous plankton in the Rupelian and Chattian marginal-marine type and reference sections and 3. limited availability of reliable paleomagnetic signals and/or absence of radiometric datable layers in both stratotype sections and regions.

The current biochronological concept of the R-C boundary is based on the last occurrence datum (LOD) of (common) chiloguembelinids (planktonic foraminifera), formalised as the P21 a/b subzonal boundary, calibrated against (mid) magnetopolarity subchron C10n, with an estimated GPTS age of ~28.5 Ma (e.g., Berggren et al., 1995). However, application of this concept – the LOD of the chiloguembelinids – is problematic (Van Simaey et al., 2004). It has become clear that the extinction of chiloguembelinids is not isochronous on a global scale, but is most likely controlled by paleolatitude and paleobiogeography (Van Simaey et al., 2004). The time-transgressive extinction of chiloguembelinids, first at high latitudes and later at low latitudes, reflects regional extinction due to gradual, pervasive cooling of the surface waters during this time. Moreover, in the southern North Sea Basin, including the classic stratotypes, chiloguembelinids are only recorded as isolated occurrences in the lower Rupelian sections (see for further discussion Van Simaey et al., 2004; De Man et al., 2004).

Outside the North Sea Basin only few well-calibrated, accessible, and continuous Oligocene successions have been documented. The most important among these are the relatively undisturbed, well-exposed pelagic sections in Italy (Fig. 1), which have come to play a principal role in the quest for Paleogene GSSPs. The

Massignano section (central Italy) has been ratified as the GSSP for the base of the Oligocene (Odin & Montanari, 1988, 1989), and the Lemme section (NW Italy) for the base of the Miocene (Steininger et al., 1997). Various central Italian sections (e.g., Contessa Quarry, Monte Cagnero and Pieve d'Accinelli section) are now being evaluated as candidates for the basal Chattian GSSP (Coccioni et al., submitted). Much recent effort has been devoted to the establishment of an integrated biostratigraphic frame for these mid Oligocene sections, with detailed organic walled and calcareous plankton zonations and accurate radiometric age-assessments (Coccioni et al., submitted). As explained above, in order to define a R-C GSSP in the pelagic central Italian successions, it is of principal importance to understand their relationship with the classic marginal-marine unit-stratotypes of Rupelian and Chattian stages in the North Sea Basin (e.g. the discussion concerning the positioning of the Eocene-Oligocene boundary in Brinkhuis & Visscher, 1995). For the R-C boundary, this is especially challenging, as most of the biotic events used in standard Oligocene zonation schemes are not recorded in the North Sea Basin because of its generally restricted- to shallow marine setting during this time.

Organic walled dinoflagellate cysts (dinocysts) have been demonstrated to have good potential for establishing correlations between deep and marginal marine successions from widely different depositional environments (e.g., Brinkhuis & Visscher, 1995). Well-calibrated, high-resolution dinocyst zonal schemes covering the entire Oligocene have been established on the basis of central Mediterranean deep and shallow marine successions (e.g., Brinkhuis et al., 1992; Brinkhuis & Biffi, 1993; Brinkhuis 1994; Zeevenboom, 1995; Wilpshaar et al., 1996). Recently, dinocyst associations from the mid Oligocene central Italian sections (Contessa Quarry, Monte Cagnero and Pieve d'Accinelli section) were (re)investigated in higher detail and resolution in the frame of follow-up projects aimed at obtaining more accurate chronostratigraphic and absolute age calibrations (Coccioni et al., submitted; Van Simaey et al., in prep.). In addition, recent dinocyst studies from several boreholes in the southern North Sea Basin revealed that well preserved and diverse dinocyst associations occur throughout most of the upper Rupelian and lower Chattian sections (Van Simaey et al., 2004). The latter resulted in the establishment of a new, high resolution Oligocene dinocyst zonation scheme for the southern North Sea Basin (Van Simaey et al., in press).

The principal objectives of the present study are to 1. attempt correlation of dinocyst events from the upper

Rupelian and lower Chattian unit-stratotypes from the southern North Sea Basin with their well-calibrated counterparts from central Italy, 2. determine the nature and age of the R-C unconformity, and 3. elaborate on the paleoenvironmental changes associated with this transition.

### Mid Oligocene dinocyst events

#### The southern North Sea Basin

In the southern North Sea Basin, the dark green, glauconite-rich, fine Chattian sands, unconformably overlie the upper Rupelian silty clays (e.g., Vandenberghe et al., 1998, 2001). An integrated study on various groups of microfossils showed that the R-C unconformity is associated with a hiatus, marking a major change in paleotemperature and paleobathymetry. Shallow marine to restricted marine subtropical species at the base of the Chattian strongly contrast with the deeper marine and cool-temperate upper Rupelian biota (Van Simaey et al., 2004; De Man & Van Simaey, 2004). These records are indicative of a sea level driven unconformity and hiatus between the top of the Rupelian and the base of the Chattian transgression (Van Simaey et al., 2004).

The recently established Oligocene dinocyst zonation for the southern North Sea Basin (Van Simaey et al., in press) is applicable to both the marginal-marine Oligocene sections from onshore NW Europe and the sparse Oligocene dinocyst data from the central North Sea Basin (Fig. 1). Several dinocyst events occur near the R-C transition and are calibrated against other microfossil zones for the southern North Sea Basin and to the paleotemperature curve based on benthic foraminiferal assemblages (De Man & Van Simaey, 2004; see Fig. 2). Useful dinocyst events in the upper Rupelian and lower Chattian are the last occurrence (LO) of *Enneadocysta pectiniformis*, which virtually coincides with the first occurrence (FO) of *Saturnodinium pansum*; these dinocyst events define the base of the NSO-4b zone (Van Simaey et al., in press). The FO of *Distatodinium biffii* defines the base of NSO-5a; this event occurs in the upper part of the Rupelian, well below the base of the Chattian, the latter as recognised by the bloom of benthic foraminifer *Asterigerinoides guerichi*. The FO of *Artemisiocysta cladodichotoma* is at the base of NSO-5b, and coincides with the onset of the 'Asterigerina Horizon'. The LO of *Rhombodinium draco* is a little younger than the base of the Chattian. Higher up the Late Oligocene, the last occurrence of *Areoligera*

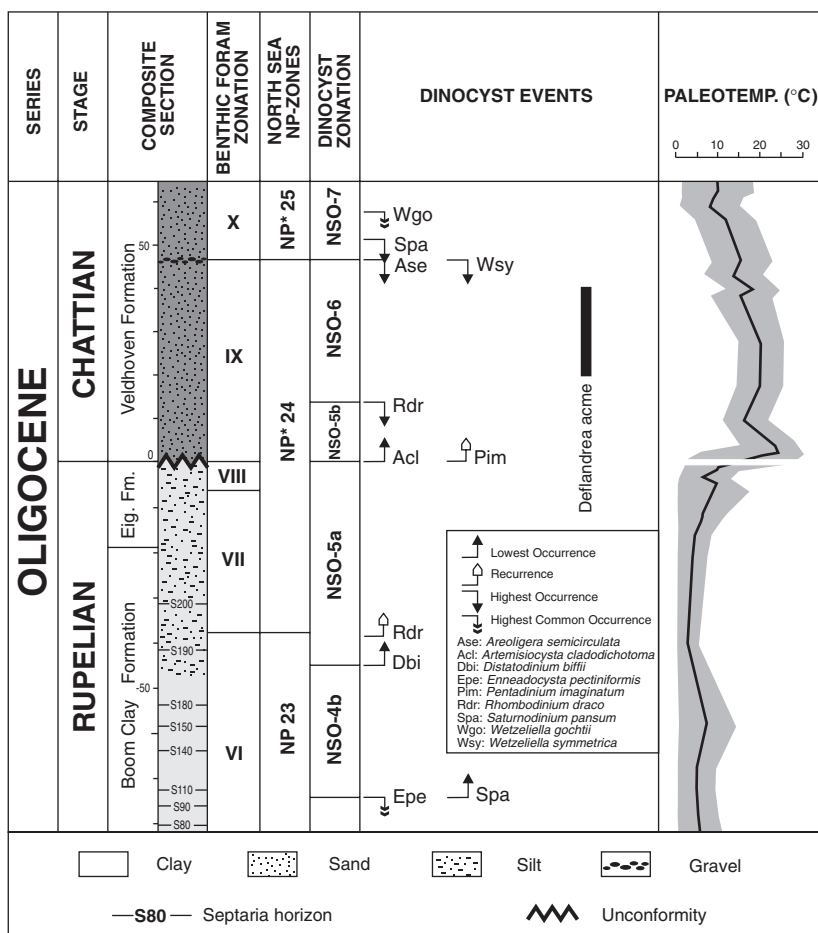


Fig. 2. Composite diagram of the mid Oligocene dinoflagellate cyst events in the southern North Sea Basin (after Van Simaey et al., in press), correlated against the southern North Sea Basin benthic foraminiferal zonation scheme (after De Man et al., 2004), the North Sea nannoplankton zones (after Van Simaey et al., 2004) and the paleotemperature curve as constructed by De Man & Van Simaey (2004). (Eig. Fm. = Eigenbilzen Formation).

*semicirculata* and *Saturnodinium pansum* define the top of the NSO-6 zone (Van Simaey et al., in press; see Fig. 2).

#### The central Mediterranean region

To establish a detailed Oligocene dinocyst zonation for the Mediterranean area, a number of otherwise well documented central Italian sections have been investigated. High-resolution dinocyst zonations have been established for the lower (Brinkhuis & Biffi, 1993), mid (Wilpshaar et al., 1996) and upper (Zevenboom et al., 1995) Oligocene pelagic sections and are calibrated against the planktonic foraminifera and calcareous nannoplankton zonations as well as to the global polarity time scale (GPTS). In the light of new and more accurate age assessments (Coccioni et al., submitted), the dinocysts from three pelagic central Italian sections, respectively the Monte Cagnero, Pieve d'Accinelli and Contessa section were reinvestigated (Coccioni et al., submitted; Van Simaey et al., in prep.). These studies led to a re-evaluation of the former proposed mid Oligocene dinocyst zones, calibrated against updated magnetobiostratigraphic information. The FO of *Distatodinium biffii*, defining the base of the *Distatodinium biffii* (Dbi) Interval Zone (Wilpshaar et al., 1996), is now correlated to the uppermost part of magnetochron C9r and, assuming constant sediment accumulation rates, has an estimated age of 27.9 Ma (Van Simaey et al., in prep.).

Isolated records of *Artemisiocysta cladodichotoma* are recorded from the uppermost part of magnetochron C9n and the lower part of C8r, at a level near two volcanic ash layers, dated respectively at 27.1 Ma for the lower and 26.7 Ma for the upper (Coccioni et al., submitted; see Fig. 3). A remarkable dinocyst event from the central Mediterranean successions is recorded in the interval between the FO of *Distatodinium biffii* and the FO of *Artemisiocysta cladodichotoma*: representatives of the Arctic genus *Svalbardella* are conspicuously present (up to 10%) in a distinct interval correlative to the upper part of subchron C9n. The *Svalbardella* interval terminates before the onset of subchron C8r. The estimated duration for the *Svalbardella* interval, based on radiometric and magnetostratigraphic age assessments, and assuming constant sedimentation rates, is ~500 kyrs (Van Simaey et al., submitted; see Fig. 3 and discussion below).

#### Calibration of the mid Oligocene dinocyst events in the southern North Sea Basin

Despite the increasing amount of first-order correlations between dinocyst events and the GPTS (Brinkhuis et al., 2003; Williams et al., 2004; Eldrett et al., 2004), still only few well calibrated mid Oligocene dinocyst studies are available. Despite these restrictions, some North Sea events show good potential for interregional correlation and calibration. According to Williams et al. (2004), the FO of *Saturnodinium*

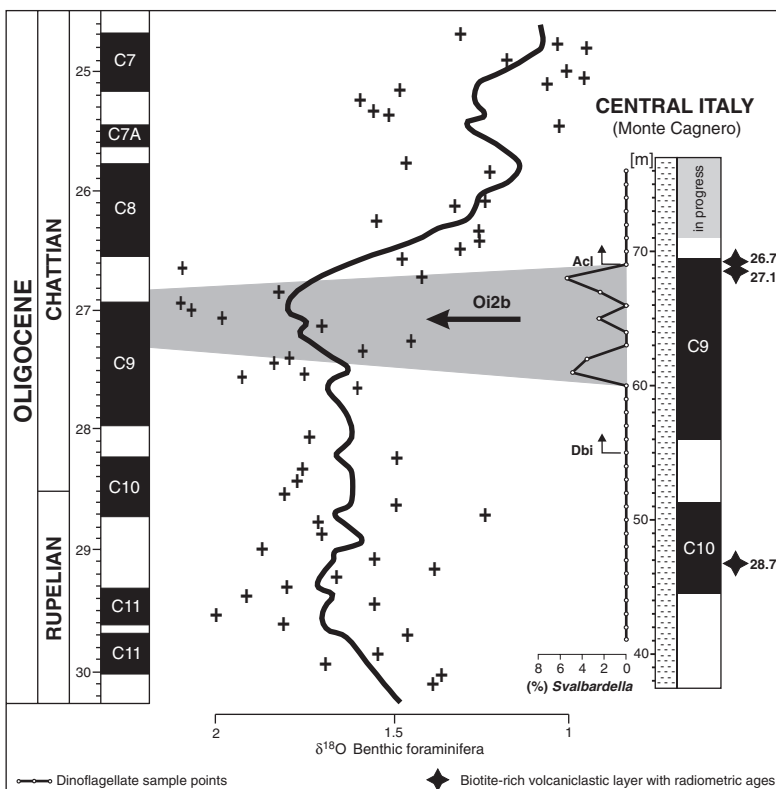


Fig. 3. Oligocene deep-sea benthic foraminiferal  $\delta^{18}O$  curve (after Miller et al., 1998), calibrated against the Monte Cagnero section in central Italy (magnetostratigraphy and radiometric age assessment after Coccioni et al., submitted; dinoflagellate cyst events after Van Simaey et al., in prep.). The grey zone indicates the *Svalbardella* abundance in the upper part of magnetochron C9n and is termed as the Oligocene Glacial Maximum (OGM). (Same abbreviations as in Fig. 2). Rupelian-Chattian boundary according to the concepts of the magneto-biochronologic time-scale (Berggren et al., 1995).

*pansum* and the LO of *Enneadocysta pectiniformis* in Northern Hemisphere mid latitudes occur respectively at 29.4 and 29.3 Ma. Hence, we here attribute an age of ~29.4 Ma for the base of NSO-4b (Fig. 4). Assuming an isochronous first occurrence for *Distatodinium biffii* and *Artemisiocysta cladodichotoma* in both the North Sea Basin and Tethyan Ocean, and considering the first occurrence of these species in the well-calibrated central Italian sections, the age-calibration for the base of NSO-5a and NSO-5b is respectively ~27.9 and ~26.7 Ma (Fig. 4).

### **The Oligocene Glacial Maximum, the Late Oligocene Warming Event and the Rupelian-Chattian unconformity**

A globally synchronous *Svalbardella* abundance has been recorded in the middle to upper part of magnetochron C9n (Van Simaey et al., submitted; see Fig. 3 and Fig. 4). The abundance of this Arctic, cold water taxon, in both high and low latitudes, pointing to a lowering of the sea surface temperature (SST), is consistent with the reported timing of one of the major Oligocene deep-sea benthic foraminiferal  $\delta^{18}\text{O}$  events, known as the Oi2b-event (Miller et al., 1991, 1998; see Fig. 3), and hence favours a scenario of global cooling and concomitant Antarctic ice-sheet expansion (Van Simaey et al., submitted). This episode, representing ~500 kyrs of profound global cooling, is termed 'Oligocene Glacial Maximum' (OGM), and has a calculated age of ~27.3 to ~26.8 Ma (see Fig. 3). These ages are based on accurate  $^{40}\text{Ar}/^{39}\text{Ar}$  datings of biotite-rich volcanoclastic layers at the very top of chron C9n in central Italy (Coccioni et al., submitted). In Van Simaey et al., submitted, the OGM has a GPTS age of 27.5 to 27.0 Ma after Berggren et al., 1995.

So far, no distinct *Svalbardella* abundance has been recorded in the upper Rupelian and lower Chattian successions from the southern North Sea Basin (see Fig. 2 and Fig. 4). This Arctic, cold water taxon, if found at all, has only been picked up as isolated, reworked specimens in basal Chattian successions (Van Simaey et al., 2004). Recently, however, sidewall samples from a thick (>1000m) Oligocene section in the central North Sea Basin, i.e. the Mona-1 borehole, revealed a distinct *Svalbardella* abundance (up to 6%) in a sample above the FO of *Distatodinium biffii* and below the FO of *Artemisiocysta cladodichotoma* (Van Simaey, personal observations; Heilmann-Clausen, pers. com.; see Fig. 4). This record demonstrates that the *Svalbardella* event also occurred in the North Sea Basin, at the same chronostratigraphic position as compared to the central Mediterranean records (Fig. 4). As mentioned above, a distinct sea

level driven unconformity is universally present in southern North Sea Basin successions in the interval between the FO of *Distatodinium biffii* and the FO of *Artemisiocysta cladodichotoma*, marking the R-C boundary. Only in more offshore settings (i.e. central North Sea) the correlative conformity, representing the lowstand and early transgressive phase, has been preserved; these units being marked by the *Svalbardella* abundance.

Combined evidence thus strongly suggests that all these phenomena are tied to the OGM. It suggests a scenario of global cooling, concomitant Antarctic ice-sheet growth and significant glacio-eustatic sea level fall. The global sea level low caused sub-aerial exposure and erosion of the marginal to restricted marine settings. This lowstand phase resulted in a major break in sedimentation. The subsequent transgression is here related to the warming during magnetochron C8, known as the 'Late Oligocene Warming Event' (LOWE, Zachos et al., 2001). This phase induced the basal Chattian major sea level rise, depositing tropical to subtropical time-transgressive sediments (see De Man & Van Simaey, 2004), unconformably overlying older strata. The preceding colder (OGM) phase is witnessed by isolated, reworked specimens of *Svalbardella* spp. at the base of the Chattian in the southern North Sea Basin (Van Simaey et al., 2004).

Attributing the OGM, and the corresponding glacio-eustatic sea level fall, to the R-C unconformity in the southern North Sea Basin, has considerable implications for the age assessment of the R-C boundary: Since the OGM correlates to the upper part of magnetochron C9n, with a derived radiometric and GPTS age of ~27.3 to ~26.8 Ma, the base of the Chattian unit-stratotype is not older than ~26.8 Ma. The subsequent Late Oligocene Warming Event, calibrated against magnetochron C8, reaches the lowest deep-sea benthic foraminiferal  $\delta^{18}\text{O}$  values around ~26 Ma (Miller et al., 1998; Zachos et al., 2001). If one assumes that age for the LOWE sea level maximum, the third order sea level fluctuation spanned some ~0.8 Ma. This also indicates that the oldest of the time-transgressive glauconitic fine Chattian sands in the southern North Sea Basin, were deposited close to 26.7 my ago. The R-C hiatus (unconformity) thus spans some 500 kyrs (i.e. from ~27.3 to ~26.8 Ma). This assessment matches the dinocyst-based (GPTS) ages for the top of the Rupelian and the base of the Chattian.

### **Concluding remarks**

Dinocyst biostratigraphy enables correlation between the mid Oligocene North Sea Basin successions and

the well-calibrated pelagic sections from central Italy. Based on the established correlations, and assuming isochronous first occurrences, the lower boundaries of the North Sea Oligocene dinocyst zones NSO-5a (top Rupelian) and NSO-5b (base Chattian) are respectively dated as 27.9 and 26.7 Ma. In all

probability, the recorded *Svalbardella* abundance in the central North Sea Basin occurred at the same chronostratigraphic position as compared to the central Mediterranean records, and is attributed to the Oligocene Glacial Maximum (OGM).

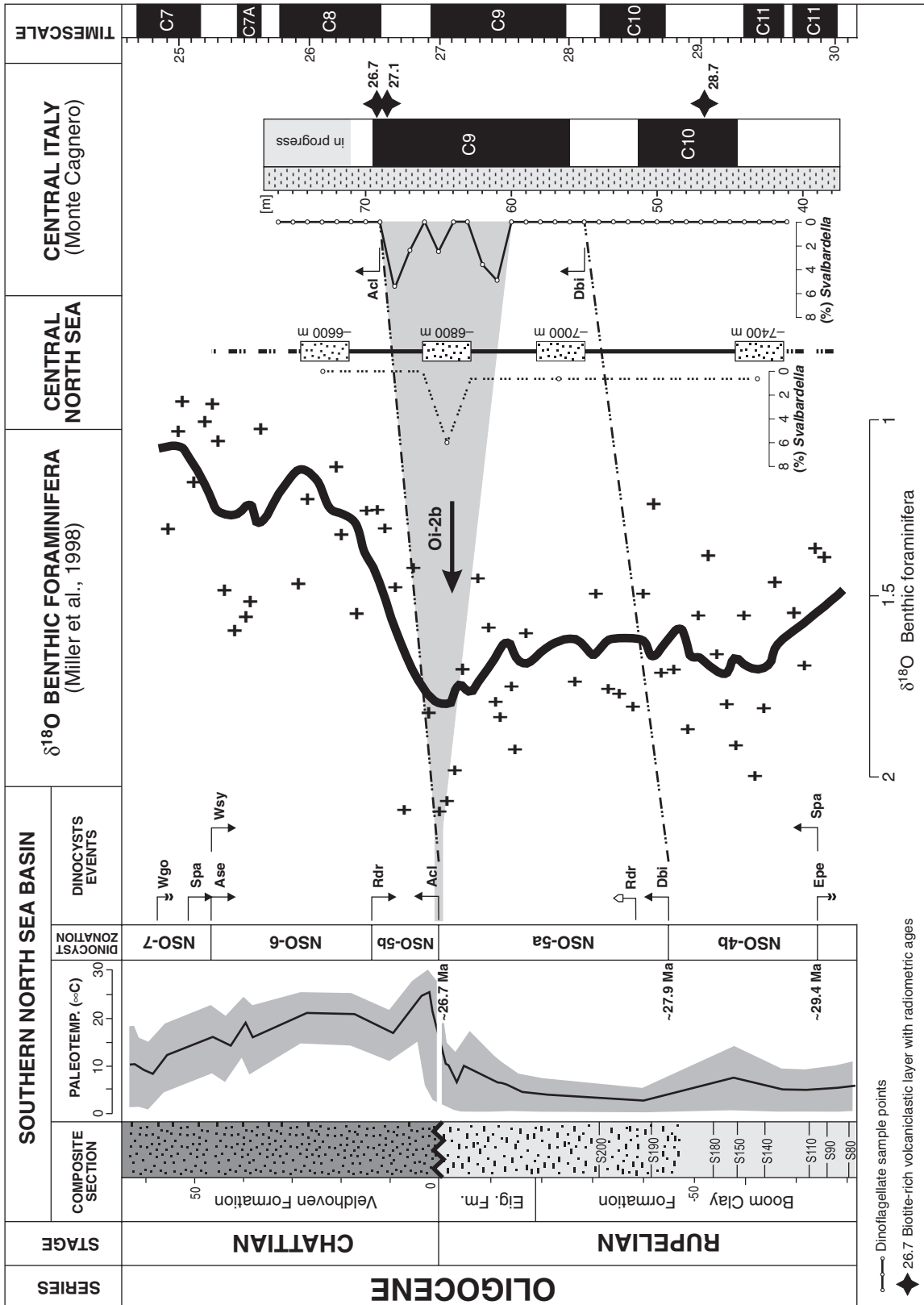


Fig. 4. Calibration of the mid Oligocene dinocyst events in the southern North Sea Basin, based on the correlation with the well-calibrated central Italian sections. The *Svalbardella* abundance in the central North Sea Basin is at the same chronostratigraphic position as compared to the central Mediterranean records, and hence can be attributed to the Oligocene Glacial Maximum (OGM). The dinocyst correlation further suggests that the OGM, and the corresponding glacio-eustatic sea-level fall are genetically related to the unconformity between the Rupelian and Chattian stages in the southern North Sea Basin. The base of the Chattian as defined in the unit-stratotype. Legend as in Fig. 2.

The dinocyst correlation thus suggests that the OGM, and the corresponding glacio-eustatic sea level fall are genetically related to the unconformity between the Rupelian and Chattian Stages in the southern North Sea Basin. The global sea level low during the latest Rupelian (magnetosubchron C9n) caused temporal sub-aerial exposure of the marginal marine southern North Sea Basin, triggering an erosional phase. The subsequent Late Oligocene Warming Event, calibrated against magnetochron C8, induced a major sea level rise, which transgressed over the marginal marine southern North Sea Basin. The erosive nature of the Chattian transgression is witnessed by the isolated, reworked specimens of *Svalbardella* spp. at the base of the Chattian in the southern North Sea Basin.

The duration of the gradual, pervasive sea level rise between the OGM sea level low (~26.8 Ma) and the LOWE maximum sea level high (~26 Ma) lasted approximately ~0.8 Ma. The oldest of the time-transgressive glauconitic fine Chattian sands in the southern North Sea Basin were deposited around 26.7 Ma.

An important consequence of these results is that any R-C GSSP should be positioned to match at least the age of the basal Chattian deposits, here correlated to magnetosubchron C8r. In addition, it should be positioned above the middle part of magnetosubchron C9n, i.e. above the Rupelian s.s. It has become clear that this phase in Earth history is intrinsically related to a global cold transient event, the OGM. It may be argued that the positioning of the R-C GSSP should involve multiple criteria, including peak Arctic dinoflagellate migration, heavy planktonic and benthic  $\delta^{18}\text{O}$  values, and peak sea level fall.

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