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Foraminiferal biofacies analysis of the Rupelian–Chattian transition in the Weelde borehole (northern Belgium)

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Quantitative analysis of foraminifera from the Weelde borehole enables for the first time recognition of biotic events, and reconstruction of environmental change in the late Rupelian and early Chattian in the type region of the Rupelian, northern Belgium. This study completes earlier foraminiferal investigations carried out on outcrops and boreholes through the Lower Rupelian of the Rupel area (Hooyberghs, 1983, 1992; Grimm & Steurbaut, 2001).

Twenty-six samples were collected from the Weelde borehole (8E 159; Lambert x = 190700; y = 231900; see Vandenberghe *et al.*, 2001 for a general discussion) and examined for their microfaunal assemblages, essentially benthic foraminifera. Based on changes in associations, 7 biofacies could be distinguished in the 85 m thick Upper Rupelian – Lower Chattian interval. These biofacies were numbered in accordance to Grimm & Steurbaut's (2001) subdivision of the Lower Rupelian, in order to establish a local benthic foraminiferal succession for the Belgian Oligocene. The lower part of the studied section, corresponding to biofacies 10, is dominated by the agglutinating foraminiferid taxon *Spiroplectinella* spp. (*S. carinata* and *S. deperdita* generally reach over 60% of the association). At the base of biofacies 11 *Karreriella siphonella*, *Turrilina alsatica* and *Rotaliatina bulimoides* reoccur. Higher up, two pulses of *Cibicides ungerianus* are recorded. The lowest pulse almost coincides with the last occurrences (LO) of *Rotaliatina bulimoides* and *Karreriella chilostoma*, which define the top of biofacies 11. This biofacies is furthermore characterised by high frequencies of *Lenticulina* spp. (between 18% and 27%) and *Angulogerina gracilis* (between 16% and 37%). Biofacies 13 can be distinguished by its high percentages of reworked siliceous forms, mainly planktonic foraminifera. The first occurrence (FO) of *Asterigerinoides guerichi* defines the base of biofacies 14. It coincides with a substantial increase in diversity and abundance (richest level of the studied section), with a considerable enrichment in planktonic foraminifera (from generally less than 0.5% to 2.5%) and with the LO of *T. alsatica*. The LO of *Cibicides ungerianus* falls within biofacies 14. It coincides with the LO of *Siphotextularia labiata*, *Alabamina tangentialis* and *Dentalina soluta*. Higher up, in the topmost Rupelian levels (top biofacies 14), *Bulimina elongata* peaks with frequencies up to 23%. The last *Sphaeroidina bulloides*, *Nodosaria spinescens*, *Karreriella siphonella*, *Bolivina* spp. and *Lagena* spp. are recorded at the top of the Rupelian. Their last occurrences coincide with the start of the abundance of *Asterigerinoides guerichi* (70 to 90% of the association), known as the start of the *Asterigerinoides* bloom (= *Asterigerina* Horizon) and traditionally used to denote the very base of the Chattian (Indans, 1965). This event, located at the base of the Voort Sand Formation, is used to define the base of biofacies 15. It coincides with the FO of *Elphidium subnodosum* and *Protelphidium roemeri*. These species become more important higher up in the Chattian section. Their increase, which is associated with a substantial decrease in *A. guerichi* (from 70% to 33%), marks the base of biofacies 16.

Comparison with the foraminiferal successions in the Central North Sea (King, 1983, 1989), The Netherlands (Doppert & Neele, 1983), the Rhine area (Indans, 1958), Northern Germany (Spiegler, 1965) and Denmark (Ulleberg, 1987) reveals that the *Asterigerina* bloom at the base of the Chattian is a widespread event all over the North Sea Basin. It also suggests that the boundary between the Lower and Upper Rupelian, traditionally taken at the onset of the common occurrence of *Cibicides ungerianus* (Spiegler, 1965) has to be pinpointed in the Belgian sections at a level coinciding with S80 (Ritzkowski, in von Daniels *et al.*, 1994).

The changes in biofacies throughout the Rupelian and Chattian of Belgium indicate substantial changes in the physical and chemical conditions of the seafloor. However, it must be kept in mind that the associations underwent strong diagenesis (pyritization, dissolution, etc.) and that they probably only reflect a fraction of the biocoenoses. Biofacies 10, 11 and 12, corresponding to the lower part of the Upper Rupelian, are relatively rich in coldwater forms (*Angulogerina gracilis*, *Lenticulina* spp., *Pullenia bulloides*) and are almost completely devoid of planktonic foraminifera (only 5 specimens in samples W26 to W13). Their overall characteristics indicate rather deep outer shelf environments, marked by cold (mean temperature probably less than 10°C), well-oxygenated bottom waters, normal salinities, and with almost no connection with the oceanic realm. The microfauna of biofacies 13 consists of only few calcareous *in situ* benthic foraminifera. It is dominated by siliceous forms (essentially foraminifera, a few radiolaria), considered to be reworked from older deposits, probably Upper Cretaceous in age. This reworking suggests changes in sediment supply and in circulation patterns, probably due to major tectonically controlled sea-level changes. The income of *A. guerichi*, the decrease in *Lenticulina* spp., the substantial increases in foraminiferal species diversity (from around 10 to 34 taxa) and in specimens in biofacies 14 suggest somewhat warmer, less deep bottom waters, with open connection to the oceanic realm. Later on, at the base of the Chattian, as shown by biofacies 15, palaeoenvironments changed again, passing into a confined, shallow, warm water depositional system. The association of biofacies 16 indicates a somewhat less confined depocentre, although with quite similar sea-bottom conditions.

In terms of basin evolution, the micropalaeontological data from the Weelde borehole reveal that palaeoenvironments in the southern bight of the North Sea Basin evolved from outer shelf (~100m) during the early Late Rupelian to inner shelf (~50m) during the Terminal Rupelian. This bathymetric change coincided with a slight change in climatic conditions, from cold during the majority of the Late Rupelian to warm temperate at the end of the Rupelian. These palaeoenvironmental changes at the base of the Eigenbilzen Sand Formation coincide with an influx of reworked material and the onset of a predominantly sandy depositional regime. These phenomena may point to the presence of an up to now undiscovered third Rupelian 3rd order depositional sequence in the Rupelian type-area. This seems to confirm the recently defined three-fold Rupelian sequence stratigraphic model of Hardenbol *et al.* (1998), which was based on data from the Pannonian Basin. Whether or not the observed sequence is indeed a 3rd order depositional sequence shall have to be confirmed by further investigations. The base of the Chattian Voort Sand Formation represents a break in sedimentation, introducing major palaeoenvironmental changes, essentially marked by shallowing and drastic warming of the seawater.

The sudden warming at the base of the Chattian might correlate with the Late Oligocene warming of Zachos *et al.* (2001), which is dated at 26.5 Ma. This of course would have serious implications for the future Rupelian/Chattian boundary criterion and its GSSP, seen that, according to Berggren *et al.* (1995), the Rupelian/Chattian boundary is now considered to have an age of 28.5 Ma.

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Tephrostratigraphical study of Holocene deposits from two Chilean lakes' watersheds – Example from lakes Icalma and Galletue (Southern Chile, S 38° –W 71°)

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This study is part of the S.S.T.C. project EV/10/12B entitled '*A continuous Holocene record of E.N.S.O. ("El Niño Southern Oscillation") variability in Southern Chile*'. The purpose of this project is to characterise the influences of "El Niño" type of phenomenon on the Southern Hemisphere's Holocene climate. This was achieved by studying lakes cores in a multidisciplinary way. In the framework of this project, a field campaign was conducted during the austral summer of 2002 to sample several locations.

The object of this study is to outline the tephrostratigraphy of six outcrops and two peat bogs in lakes Icalma and Galletue's watersheds.

Lakes Icalma and Galletue (S 38° – W 71°) are two small glacial lakes located in the Araucania Region (Region IX, Chile) and surrounded by several Quaternary volcanoes, most of them still in latent activity. This region is situated in the central part of the Southern Volcanic Zone defined by several authors (López–Escóbar, 1984; López–Escóbar *et al.*, 1977; Thorpe & Francis, 1979) and characterised by a dominance of basalts, basaltic andesites and dacites, rich in orthopyroxene, clinopyroxene and Fe-rich olivine (Futa & Stern, 1988; López–Escóbar, 1984). Important Holocene sandy to silty deposits, intercalating two major pumice layers, cover the lakes' watersheds. This study focuses on these two pumice layers that are undeniably the most important volcanic markers of this region.

A more complete study of these two pumice deposits shows their mineralogical differences. Part of the mineralogy is common to the two pumice layers: plagioclase (andesine), orthopyroxene (hypersthene), clinopyroxenes (diopside and Ca–rich augite), titano–magnetite and fluorapatite. The lower pumice has two distinct olivine populations, one of which (Fo_{82-85}) did not crystallise in equilibrium with the magmatic liquid. The titano–magnetite from this deposit is also richer in Fe than the one found in the upper pumice. Glass shards from the upper pumice have a K–rhyolitic composition while the lower pumice glass shards are rhyodacitic. The whole rock X–ray fluorescence analysis completes these results and allows us to show that the basalt forming *Caldeira Meseta del Arco*, from which the upper pumice erupted, does not correspond to the classic high-alumina basalts of the Lake District and can be more likely assimilated to an olivine phenocryst high-alumina basalt.

The peat bogs study reveals a much thinner tephra succession and allows us to realise a mineralogical zonation reflecting the regional volcanism evolution. The upper pumice is found in both peat bogs while the lower pumice is lacking because these points are beyond its most advanced dispersion lobe.

An isopach map and a three–dimensional model coupled with the presence of olivine in the lower pumice allow us to propose two different origins of the pumice layers and to reject the hypothesis of a two–times draining model of a common and partially layered magmatic chamber. The lower pumice erupted in two pulses of a single eruption, that probably took place at *Volcán Llaima* in the first half of the Holocene (9030 ± 45 a BP, this work; 4580 ± 70 a BP, Mardones et al. 1993). This eruption was caused by a magma mixing as suggested by two clearly distinct olivine populations. The upper pumice erupted from *Caldeira de Sollippulli* at about 2900 ± 45 a B.P. (Naranjo et al., 1993)

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A very-high resolution paleomagnetic study of Calypso cores in the Porcupine Seabight, SW Ireland

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The Porcupine Seabight (PSB), which forms a deep embayment in the Atlantic shelf, off the south-western coast of Ireland, is a Mesozoic basin, enclosed by four shallow platforms: Porcupine Bank in the west, Slyne Ridge in the north, Irish Mainland Shelf in the east and Goban Spur in the south. Only a relatively small opening towards the deeper North-Atlantic basin is present in the southern part. The PSB gained fame already at the end of the 19th century for its special deep-water habitats. Very-high resolution seismic profiling has revealed the presence of large seabed (carbonate) mounds (Henriet *et al.*, 1998; De Mol *et al.*, 2002; Huvenne *et al.*, 2002). They occur in 3 well-delineated provinces, each featuring distinct morphologies: the Belgica mound province on the eastern flank is characterized by conical mounds asymmetrically buried along the eastern slope of the PSB. In the northern part of the Seabight, the Magellan mound province features large numbers of small, buried mounds. South of them, complex mound structures at the seafloor are found in the ÔHovland' mound province. Modelling and some current measurements suggest the presence of locally strong internal waves and tides (Rice *et al.*, 1991), within the depth range of outcropping mounds and a residual northward flowing current (New *et al.*, 2001).

This study is focussed on the integration of different paleomagnetic parameters for the study of Quaternary sediments in the PSB. It is based on a high-resolution research of three deep-sea cores. First, the most important magnetic parameter in this research, the magnetic susceptibility (MS), is coupled to other geophysical parameters i.e. gamma density, P-wave velocity and reflectance. This multi-proxy approach made it possible to postulate a paleoclimatological framework for each core. Secondly, a relationship was found between the anisotropy of magnetic susceptibility and the postulated paleoclimatological frameworks. Finally relative paleo-intensity data are used to suggest a rudimental relative dating framework.

The 3 cores (MD01-2449, MD01-2450 and MD01-2452) available for this study were obtained with the Calypso piston corer on board of the R/V Marion Dufresne during the MD123-Geosciences campaign (September 2001), within the framework of the EC FP5 Geomound project. A site survey was performed with 3.5 kHz and 12 kHz echosounder prior to all coring operations. The first coring site (MD01-2449) lies outside the influence of the mounds (south of the Belgica mound province), in a water depth of 435 m. The core has a length of 25 m. The second core (MD01-2450) is situated in the Belgica mound province on the SW flank of a mound and this in a water depth of 944 m. The core has a length of 12 m. The third core is situated in the sediments over the buried Magellan mounds in a water depth of 617 m. The core length is 19 m.

All cores were analysed with the Geotek Multi Sensor Core Logger, measuring magnetic susceptibility (Bartington loop sensor), gamma density and P-wave velocity. These measurements were followed by photographic analyses, photospectrometric (reflectance) analyses and lithological descriptions. Individual samples of the cores, for detailed paleomagnetic research, were collected in 8 cm^3 PVC cubes every 5 cm and taken on the central axis of the core in order to minimize the effect of sediment disturbance. All the paleomagnetic measurements were carried out in the paleomagnetic laboratories of the Geophysical Centre of the Royal Meteorological Institute (Dourbes, Belgium). The initial bulk magnetic susceptibilities and anisotropies of magnetic susceptibilities were measured on a KLY-3S Kappabridge. Anhysteretic remanent magnetisations (ARM) were imparted in an alternating field of 100 mT and a steady field of 0.05 mT. Isothermal remanent magnetisations (IRM) were imparted at field steps of 0.3 and 1.5 T. All remanences (natural remanent magnetisations (NRM), anhysteretic remanent magnetisations (ARM) and isothermal remanent magnetisations (IRM)), only measured on the samples of core MD01-2450, were registered by a 2G Enterprises Superconducting Rock magnetometer model 760 with RF-SQUIDS.

An integration of data sets, mainly carried out on the core at the SE-flank of a Belgica mound (MD01-2450), made it possible to get an idea of the magnetic minerals responsible for the most important magnetic signals. Some coercivity spectrum analyses showed that magnetite is the most important magnetic mineral. Higher susceptibilities correspond to higher magnetite concentrations. Moreover, peaks in MS correspond with lower ARM/MS-ratios and thus coarser fractions of (titano)magnetite. However, the lab-imparted IRM of core MD01-2450 indicate the presence of another magnetic mineral between 630 and 1080 cm. A higher IRM/MS-ratio for this part of the core could be caused by the presence of ferromagnetic iron sulphides (Roberts, 1995). These iron sulphides can be the result of an authigenic anaerobic process with sulphate reduction.

The descriptions of the MS-signals and the other geophysical parameters (gamma-density, P-wave velocity and reflectance) suggested a subdivision in different zones and peaks, which made it possible to create a paleoclimatological framework for each core. Glacial-interglacial variations had an important impact on the sedimentation in the Porcupine Basin. Glacial periods are characterized by the deposition of clayey, magnetic-rich material; interglacials by the deposition of more sandy magnetic-poor material. This sandy material can bear witness of higher bottom circulations during interglacials. The input of Mediterranean Outflow Water (MOW) could play a very important role.

Six Heinrich Events (HE) can be recognized in the 3 cores during the latest glacial, especially by peaks of MS. In the two cores, located on the eastern flank of the basin, these peaks are not as clear as in the core on the northern flank. Possibly, the eastern flank is more influenced by processes on the Irish shelf and by the Irish-British ice sheets than the northern flank. Glacial-interglacial variations are also more visible in this northernmost core.

The patterns of the relative sedimentation rates between HE are nearly the same for the three cores. Sedimentation rates increase at the end of the latest glacial and are relatively slow in the middle of this glacial. The relative high mean sedimentation rate (19 cm/ka) in the basin shows that this basin acts as a sort of trap. The sediment can be easily caught into the basin, but cannot easily get out of it again.

It is already mentioned that magnetite seems to be the most important magnetic mineral. Ellwood *et al.* (1980) showed that the anisotropy of magnetic susceptibility, with magnetite as most important magnetic mineral, should be caused by the shape of the magnetite grains. There seems to be a relation between the degree of anisotropy P (= a measure of the degree of organization of the particles) and paleoclimatological zones. During the latest glacial the background signal of the degree of anisotropy increased to a maximum and then decreased. The lowest degrees are observed in the beginning and at the end of the glacial. During the interglacial an opposite trend can be observed. There is a lot of discussion about the increase or decrease of the degree of anisotropy during glacials and interglacials (Kissel *et al.*, 1998). Probably the degree of organization of the magnetic particles is due to the texture of the surrounding sediment particles. The lower amount of anisotropy during the interglacial would then be due to the surrounding more sandy texture. Indeed, interglacials and warmer periods in the Porcupine Basin are characterized by the deposition of more sandy material and thus probably by heavier bottom current circulations (Van Rooij *et al.*, in prep.). Sandy sediment particles do not really have the property to organize themselves. Consequently, the magnetic particles, embedded in this sandy matrix, will show a decreased degree of organisation. During glacials more clayey material is deposited. Clay particles are very sensitive for compaction and are strictly ordered in sheets. It is thus a logic consequence that fine magnetite particles will be taking up in this clay structure and show an increased degree of organization.

Natural remanent magnetisations (NRM) were only carried out on core MD01-2450. The normalized relative intensity curve can be compared with a standard paleo-intensity curve of Tric

et al. (1992). An increasing trend of the paleo-intensity can be seen during the latest 40 ka. The same trend can be recognized in the normalized relative paleo-intensity curve of core MD01-2450. Thus, the upper 630 cm of this core must be younger than 40 ka. Moreover, there seems to be a correlation between the superimposed HE in the normalized paleo-intensity curve of core MD01-2450 and the superimposed ages of those events on the intensity curve of Tric et al (1992).

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Geochemical study of soils in the Grand Duchy of Luxembourg

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The increasing concern for the effect of soil contamination with heavy metals on human health has resulted in soil remediation legislation, such as the Soil Remediation Decree (valid in Flanders since 1995), that is mainly based on remediation and reference values. However, for these legislations to be sound, they should be based on true background concentrations of the elements (Salminen & Tarvainen, 1997). On the one hand, these natural background levels provide a reference point for the estimation of pollution. On the other hand, heavy metal concentrations in soils are mainly dependent on the parent material on which the soils have developed, and as such can differ widely (Fergusson, 1989; Tack et al., 1997, Salminen & Tarvainen, 1997). Therefore it is not appropriate to use general reference values, since the geogene concentrations of metals in a specific soil type may well exceed them (McLean & Bledsoe, 1992). Background concentrations should be determined locally by direct analysis of uncontaminated soils. The study presented here has attempted to do so for an area in the South of the Grand Duchy of Luxembourg.

The study area is characterized by a sequence of different lithologies, and was therefore ideal for assessing the influence of geological substrate on the heavy metal content of soils. The parent materials studied here, all of Jurassic origin, are the iron rich Minette, the bituminous slates and the Bifrons slates. On each of these, two sites were selected. For this selection, special care was taken to ensure that the sampling sites were not, or at least minimally, influenced by man (Horckmans *et al.*, 2002). The soils on the Minette were shallow and stony Cambisols, while the profiles on the slate soils were much deeper, very rich in clay and could be characterized as Stagni-vertic Luvisols or Stagni-vertic Cambisols.

Samples were taken of the diagnostic horizons of the six soil profiles (for a total of 26 soil samples), dried at 40°C and disaggregated. Elemental composition was determined after dissolving the soil samples in a mixture of hydrochloric acid, nitric acid and hydrofluoric acid. The main elements (Al, Fe, Ca, Mg, K, Na) were measured with AAS (Varian Techtron), while the trace elements (As, Ba, Cd, Co, Cr, Cu, Ni, Pb, Rb, Se, Sr, V and Zn) were analysed with a HP 4500 ICP-MS. Additionally, soil characteristics such as organic carbon, pH and lime content were determined, as well as cation exchange capacity and base saturation. Grain size distribution was analysed using a Malvern Mastersizer S longbed diffractometer.

Due to the limited number of samples analysed, the results of the study are only indicative. However, some general trends could be seen. Firstly, based on differences in elemental composition, the soils could be divided in two groups: the Minette soils and the Slate soils (with little variation between the soils developed on the bituminous and the Bifrons slates). Iron contents in the Minette soils ranged up to 30%, while those in the other soils remained under 5%. The soils on the slates were richer in Al and Ca (with increasing values of the latter towards the deeper horizons). As for the trace elements, As, Co and Cr were more abundant in the Minette soils, while Cu and V predominated in the Slate soils. Other elements occurred in similar concentrations in both types. Secondly, the need for adapting background levels of heavy metals in soils to the lithology on which the soils develop, was demonstrated by comparing the obtained heavy metal contents to values found in a study of overbank sediments in the Grand Duchy of Luxembourg (Swennen *et al.*, 1998), a study of soils on Paleozoic-Mesozoic parent materials (De Temmerman *et al.*, 1984) and to the remediation values of the Soil Remediation Decree. Of course the latter are only valid for soils in Flanders, but they were included to demonstrate the possible consequences of using badly adjusted background and remediation values. Indeed, it was shown that several elements (such as As, Cr and Ni) occurred in much higher concentrations than given in the mentioned studies, and some even exceeded the remediation values, meaning that in Flanders they would, wrongly, be considered contaminated. This was mostly the case for the Minette soils, since the substrate here is very different from that of the studies. For example, As values ranged from 98-278 mg/kg in the Minette soils, while the highest concentration found in the studies was about 30 mg/kg, and the remediation value for natural areas given in the VLAREBO is 69 mg/kg.

In an attempt to link these heavy metal contents to other soil characteristics, a limited statistical analysis was performed, including correlation coefficients, scatter-plots and principal component analysis. Given the limited number of samples, this approach was only explorative. However, the heavy metal content of the Minette soils seemed to be linked to the iron content. No relationship with clay content (a parameter commonly linked to heavy metal content due to its sorption cacapacity) was apparent, but this could be due to the limited variation of this factor among the samples. All samples of the Slate soils displayed high clay contents of 60 - 70 % clay, while the Minette soils still had some 30% clay. Further research, on a more elaborate and diverse number of samples might clarify the relationship.

Although the study presented here was only a first step in determining the heavy metal distribution in the Grand Duchy of Luxembourg, it did show the importance of measuring background concentrations locally. Values found here differed widely among different soil types, as well as from literature values. The influence of the geological substrate on the heavy metal content of soils is very important, and must be taken into account.

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