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The Geulhemmerberg Cretaceous/Tertiary boundary section (Maastrichtian type area, SE Netherlands); an introduction

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A new Cretaceous/Tertiary boundary site

Sections across the Cretaceous/Tertiary (K/T) boundary in a carbonate platform or clastic setting above wave base are invariably incomplete, with a hiatus of variable magnitude at the boundary. Until recently, such a situation was also envisaged in the type area of the Maastrichtian Stage in the Netherlands province of Limburg. In the area, the boundary was positioned at the Vroenhoven Horizon, separating the Maastricht and Houthem formations (Felder 1975). Moreover, the typical K/T boundary clay layers, known e.g. from nearby Stevns Klint, Denmark, were never reported from this area.

It came therefore as a pleasant surprise that in November 1992 clay layers were discovered near the boundary in man-made caves in the Geulhemmerberg, 7 km ENE of Maastricht (Figure 1). The discovery was made by Jacques Severijns and Rudi Dortangs of the Nederlandse Geologische Vereniging and reported to W.M. Felder (Geological Survey of the Netherlands, RGD, Heerlen). One week later Felder in turn mentioned the finding of clays near the K/T boundary to a party consisting of H. Brinkhuis (Laboratory of Palaeobotany and Palynology, LPP, Utrecht University), A.J.T. Romein (Nederlandse Aardolie Maatschappij, NAM, Assen), P. Schiøler (Danish & Greenland Geological Survey, DGGU, Copenhagen), L. Roncaglia (Modena University) and J.W.M. Jagt (Natural History Museum Maastricht) during a fieldtrip to the ENCI and Curfs quarries (Figure 1). The party was sampling these quarries in the course of project 750.610.01 of the Netherlands Geoscience Foundation (GOA) to investigate dinoflagellate and calcareous nannofossil distributions across the K/T boundary and to test the presence of alleged Danian nannofossil index markers in 'Upper Maastrichtian' strata of the Meerssen Member of the Maastricht Formation (Figure 2). Fortunately, Felder managed to obtain permission for the group to enter the caves for sampling of the clays on the same day.

The caves were made in the interior of the Geulhemmerberg in the 18th and 19th centuries as a result of the quarrying for building-stones. The quarry-men followed a specific 3 m-thick layer of the Meerssen Member, unit IVf-6 of Felder (1975), just below a hardground, which is visible in the ceiling of the caves. This hardground was recently formally described as the 'Berg en Terblijt Horizon' by Felder and Bosch (1996; see Figure 2). Just above this hardground, in unit IVf-7, the topmost unit of the Meerssen Member, thin clay layers can be observed throughout the caves. At some places, in particular where relatively thick clay layers are present, the roof has collapsed exposing the clay-layer sequence.

Preliminary analyses of the first samples of the clays revealed basal Paleocene dinoflagellate and nannofossil assemblages. Meanwhile, Felder investigated the caves in more detail and found a spectacular locality (at measuring point 251) with multiple well-developed clay-layers, one of which more than 10 cm thick. This locality is now known as the Geulhemmerberg 'main site' (Figures 3, 4).

The Geulhemmerberg 'Deep Dark Hole' project

Following Felder's discovery of the 'main site', we invited scientists from different disciplines to investigate splits of samples taken at this location, where the section appeared most complete (measuring point

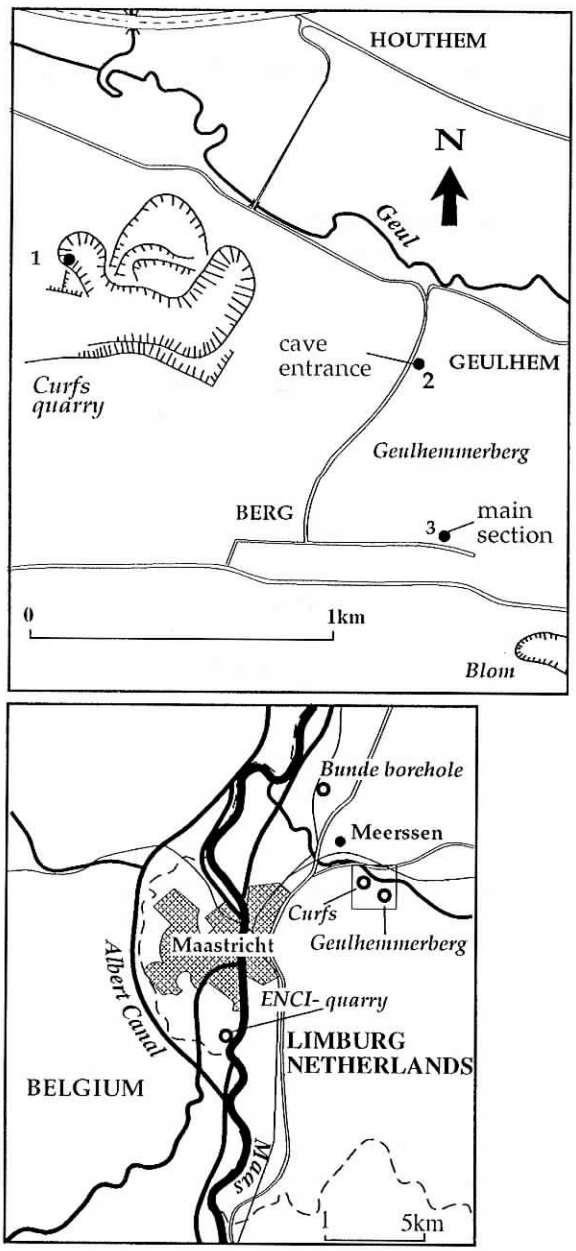


Figure 1. Maps showing localities mentioned in this issue. 1) K/T boundary outcrop in the Curfs quarry. 2) Entrance to the Geulhemmerberg caves. 3) Location of the main sampling site within the caves (measuring point 251).

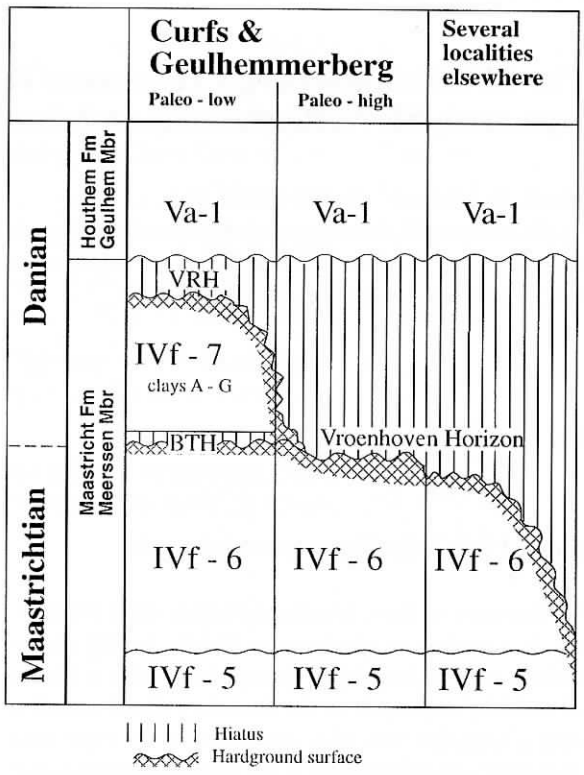


Figure 2. Generalized overview of the stratigraphy around the K/T boundary in south Limburg. Main rock-type is calcarenitic limestone. BTH = Berg en Terblijt Horizon; VRH = Vroenhoven Horizon. Lithological subdivisions after Felder (1975).

251; Figures 3, 4). Some 25 colleagues responded with enthusiasm and the Geulhemmerberg 'Deep Dark Hole' project was initiated. Its main results are presented in this issue. At measuring point 251 the exposed succession of calcarenites and clays measures some 125 to 150 cm (Figure 4). Above the Berg en Terblijt Horizon, in unit IVf-7, up to seven clay-layer complexes have been identified, labelled A to G. Where necessary, individual clay layers within these complexes are indicated with A1, A2, or D1, D2, etc. Two sets of vertically continuous samples have been taken in December 1992, one labelled IG 1 to 22, and one G1 to 7 (A, B, C etc.). These are known as the Amsterdam and Utrecht sets, respectively. Positions of the various samples are indicated in Figure 4. Most authors in this issue refer to either one of these sets in their papers.

A little history of the K/T boundary

As member of the former Working group on the Cretaceous/Paleogene boundary of the International Commission on Stratigraphy (ICS) of the International Union of Geosciences (IUGS), one of us (J.S.) has been involved in the selection of the K/T boundary type locality, or 'Global Stratotype Section and Point'

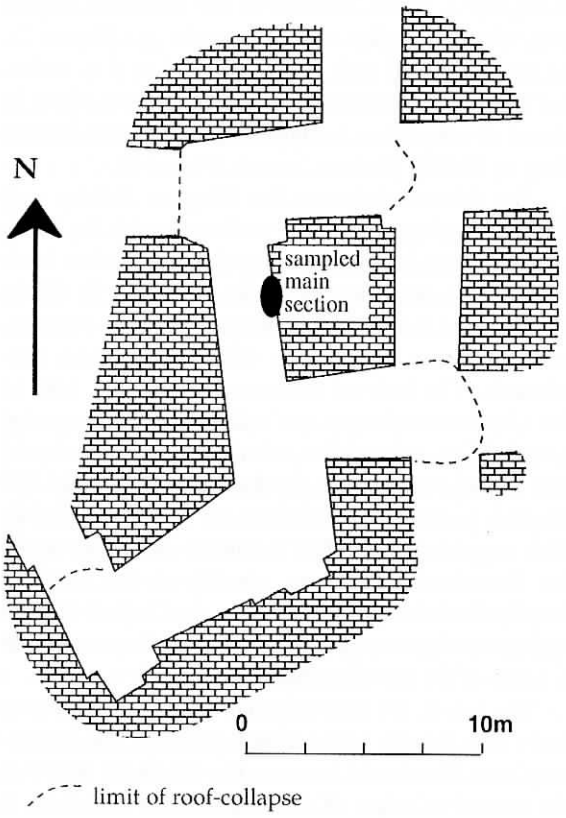


Figure 3. Map of the sector of the Geulhemmerberg caves where the main section at measuring point 251 has been sampled (sample series IG1–22, G1–7, Figure 4).

(GSSP). The definition of the GSSP of the K/T boundary (formally K/Pg boundary, but leading journals continue to use K/T) is '. . . in the El Haria section near El Kef, Tunisia, at the base of the boundary clay . . .' (Cowie et al. 1989), as decided by a majority of the members of the working group. The El Kef K/T GSSP serves as the reference for any other K/T boundary in the world, in marine or continental facies.

The selection of the GSSP has a long history, and the K/T working group wished to remain as close as possible to traditional definitions of the Danian and Maastrichtian stages in designating the GSSP. The Danian Stage, erected by Desor in 1846 as 'terrain Danien', which he considered Cretaceous in age, has preference over the slightly later erected Maastrichtian Stage (Dumont 1849). Included in Desor's Danian are from top to bottom the Faxe chalk, the Cerithium limestone and the Fiskeler or Fishclay (Johnstrup 1876). Thus in whatever section the GSSP would have to be placed, the obvious lithostratigraphic position should

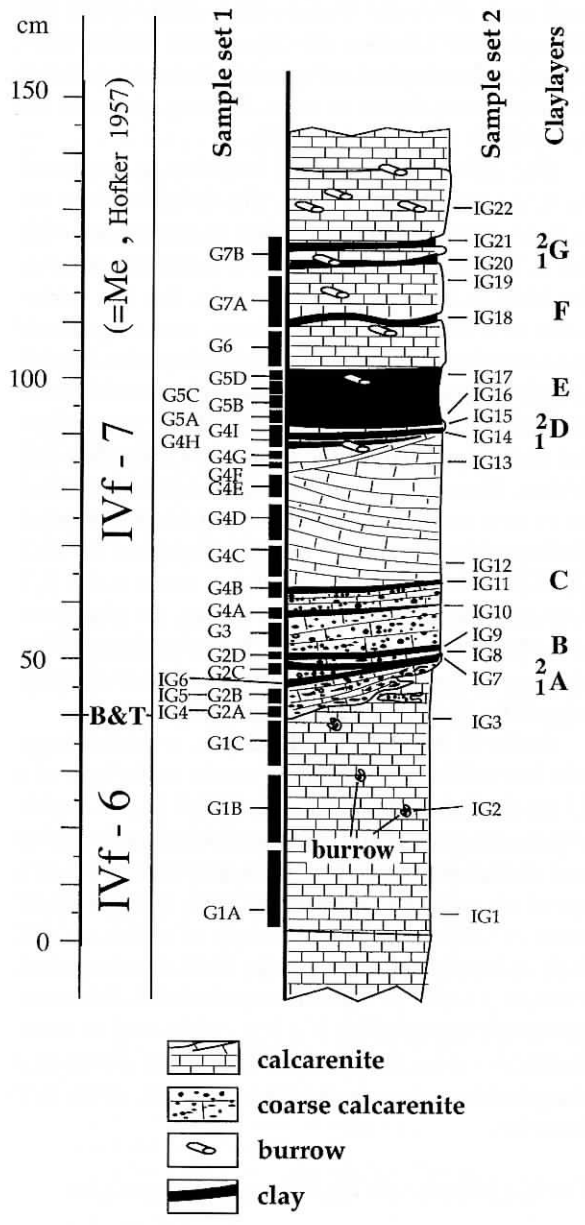
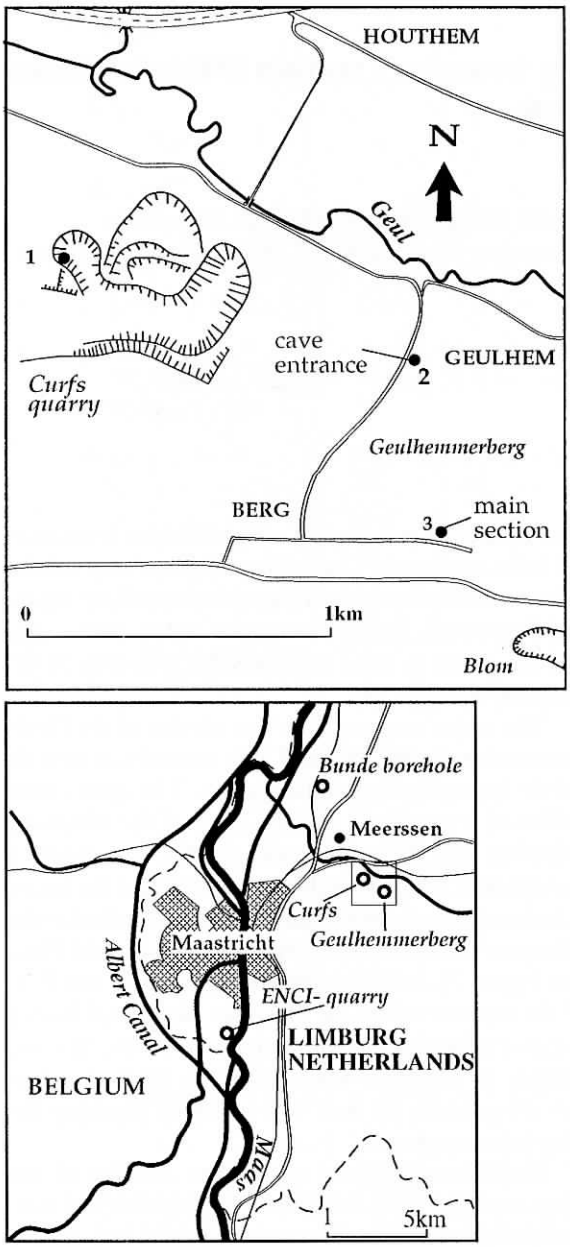


Figure 4. Lithostratigraphic column at measuring point 251 of the Geulhemmerberg K/T boundary section. Indicated are the clay layers A to G, and the position of the sample series IG1–22 and G1–7 analysed in this issue. B&T = Berg en Terblijt Horizon.

correspond in age with the base of the Fishclay. The Fishclay has been described in detail by Christensen et al. (1973). It includes a basal layer, later found to be highly enriched in iridium (Alvarez et al., 1980) and other platinum group elements (Ganapathy, 1980), shocked minerals (Bohor and Glass, 1995), soot (Wol-



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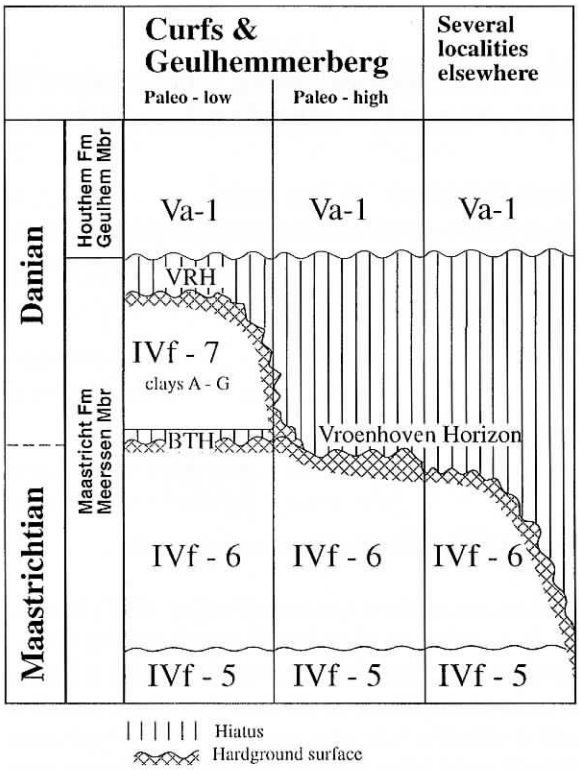

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bach et al., 1985) and altered microkrystites (Smit and Romein, 1985). Such a clay layer, with similar lithological, mineralogical and geochemical characteristics has since been shown to occur in many places in the world (Smit and Romein, 1985).

The definition of the K/T boundary, as requested by ICS, is purely lithological. The definition does not include criteria often mentioned in connection with the K/T boundary, such as a mass-extinction horizon, the iridium anomaly, $\delta^{13}C$ anomaly, the first occurrence of a Paleocene flora or fauna, soot, or peaks in concentration of microtektites, microkrystites, Ni-rich spinels or shocked quartz. All those characteristics are derived characters, are excellent tools for correlation, but do not form part of the formal K/T boundary definition. However, each of the correlation tools used on its own may lead to problems and misplacement of the boundary. Particularly in outcrops around the Gulf of Mexico, where thick sand layers occur at the K/T boundary (Smit et al. 1996, in press), the placement of the boundary is problematic. It can be placed either above or below the thick sand layers, and consequently may differ by as much as 8 m stratigraphically.

In the El Kef K/T GSSP section, a reddish layer of a few millimetres thickness occurs at the base of a 23 cm-thick dark 'boundary clay'. This layer is highly enriched in iridium, and contains shocked quartz grains and altered microkrystites, including skeletal Ni-rich spinel crystals. The base of the layer marks a major mass-extinction, the precise details of which are still hotly debated (Smit 1994; Speijer 1994, Ginsburg et al. 1996, in press). The first occurrence of new, Paleocene planktonic foraminifera is a few centimetres to some decimetres above the red layer. The base of this layer, a sharp bedding plane, is the 'Golden Spike' of the K/T boundary.

The K/T boundary in the Maastrichtian type area

Following the studies of Hofker (1955, 1956, 1966) and Felder (1975), the K/T boundary in Limburg has been equated with the Vroenhoven Horizon, a hardground which can be traced over much of the area (Jagt and Janssen 1988; see also Figure 2). This seemed firmly based on paleontological and to a lesser degree on lithological data (see Jagt et al., this issue). The (macro)fossil content of the sediments directly below the Vroenhoven Horizon (unit IVf-7) has a strong Maastrichtian aspect. Moreover, lithologically, the upper part of the Meerssen Member (unit IVf-7) resembles more closely the older units IVf-5 and 6 than the overlying Geulhem Member of the Houthem Formation, which is undisputedly Danian in age (Figure 2). At the bottom of unit IVf-7, about 3 to 4 m below the Vroenhoven Horizon, however, another horizon, in places developed as hardground, the aforementioned Berg en Terblijt Horizon, occurs (Figure 2).

The interval between the Berg en Terblijt and Vroenhoven hardgrounds is well exposed in the Curfs quarry, where it contains several discontinuous horizons rich in clay, usually as rip-up clasts. At Curfs, the distance between the two horizons is variable, and sometimes both merge, which complicates correlations. The interval between the horizons, both in the Geulhemmerberg caves and in the Curfs quarry, contains *Cruciplacolithus primus*, a presumed calcareous nannofossil marker for the basal Danian (A.J.T. Romein personal communication; Mai et al. 1994). This suggests that the K/T boundary can occur below the Vroenhoven Horizon, possibly at the Berg en Terblijt Horizon. Not surprisingly, the Curfs or 'Curfs-Ankerpoort' quarry (Figure 1) plays an important role in some of the contributions to this issue.

The top of the Maastrichtian Stage is not present in its type locality in the ENCI quarry in the Pietersberg near Maastricht, because the Meerssen Member, the highest member of the Maastricht Formation, is truncated and disconformably overlain by Oligocene sands of the Tongeren Formation. However, if the entire Meerssen Member also outside the ENCI quarry is included in the definition of the Maastrichtian Stage, including the unit IVf-7 between the Berg en Terblijt and Vroenhoven horizons, then there is a formal problem. The uppermost part of the Maastricht Formation might correlate chronostratigraphically with the lower part of the Danian. A similar hypothesis was raised earlier by Hofker (1966), who correlated not only his unit Me (= IVf-7), but also the Md with the Danian. This hypothesis was rejected by Meijer (1959) and Berggren (1962, 1964). Now, in revised form, the idea makes a comeback, although the problem may be caused by diachronous ranges of nannofossil index taxa (see Romein et al., this issue).

The Geulhemmerberg K/T boundary section

Shallow-marine sequences are sedimentologically complex in comparison with deep-marine sequences. Their sediments are usually wave-transported and highly bioturbated. Therefore, in shallow water sequences it is often hard to discriminate between glob-

al and regional events that may have happened at the K/T boundary. The Geulhemmerberg section (Figure 4) is no exception to this rule. As the reader can infer from the contributions to this issue, some of the conclusions drawn are not unequivocal, and open for alternative interpretations. Yet, the mere presence of clay layers at (or close to) the K/T boundary in Geulhemmerberg is unique in such a shallow-marine environment, and those clays may be expected to contain a wealth of information about the K/T mass extinction and notably the subsequent recovery phase.

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Visits to the Geulhemmerberg K/T boundary; a note of caution

The clay layers crop out some 15 min walking from the entrance of the Geulhemmerberg caves. The caves are closed to the public. Due to the danger of caveins, excursions involving a larger number of persons cannot be allowed. Following written consultation with 'Staatstoezicht op de Mijnen' and 'Stichting De Rotswoning Geulhem', and their approval, it is possible for small groups of *geoscientists* to visit and sample the sections exposed in the caves. For further information please contact John W.M. Jagt, Dienst KCO, Natural History Museum Maastricht, P.O. Box 882, 6200 AW Maastricht, fax +31.43.3505475.

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