Sections across the Cretaceous/Tertiary (K/T) boundary in a shallow marine setting above wave-base, without a significant hiatus at the boundary are almost non-existent. A few continuous sections are known such as Poty (NE Brazil; Albertao et al. 1994), the Brazos River. Texas (US Gulf Coast; Mancini & Tew 1993) and Stevns Klint (Denmark; Schmitz et al. 1992). However, such sections are clearly below wave base.

Sections in a carbonate platform sequence or clastic sequences above wave base are invariably incomplete, with a hiatus of variable magnitude at K/T boundary. Therefore, it came as a pleasant surprise that decimetre-thick clay layers were discovered near the boundary in man-made caves in the Geulhemmerberg[1] , 7 km ENE of Maastricht in the south of the Netherlands (Fig. 1). The discovery was made by Jaques Severijns and Rudi Dortangs of the Nederlandse Geologische Vereniging and reported to Werner. M. Felder[2]. Felder mentioned the clays to A.J.T. Romein[3] , H. Brinkhuis[4] and J. Jagt[5] during a fieldtrip in 1990 to the Curfs quarry. Romein, Brinkhuis and Jagt were sampling the Curfs quarry in the course of project 750.610.01 of the foundation of Geologische, Oceanografische en Atmosferische wetenschappen to investigate dinoflagellate distributions across the K/T boundary and to test the presence of alleged Danian nannofossil index markers in 'Upper Maastrichtian' strata of the Meerssen chalk Member of the Maastricht Formation. Preliminary analyses of the first samples of the clay revealed basal Paleocene dinoflagellate and nannofossil assemblages. After Felder and Severijns found new localities in the caves with up to seven successive claylayers, Henk Brinkhuis started the ' Deep Dark Hole' project. He invited scienistst from different disciplines to investigate splits of the same sample set that was taken at one of the best accessible locations (Fig. 2, sample series IG 1-22 and G1-G7). Their reports make up the bulk of this issue.

The caves were made in the interior of the Geulhemmerberg in the 18th and 19th century as result of the quarrying for building-stones. The quarry-men followed a specific 3m-thick layer of the Meerssen member, just below a hardground, which is visible in the roof of the caves. At some places, in

---

[1] The KTB crops out some 15 min walking from the entrance of the caves. The caves are closed to the public. Due to the danger of cave-ins, excursions involving a larger amount of people cannot be allowed. Scientists interested in studying the caves have limited acess, and should ask permission at the Neth. mijnwezen, p.o.box xxx Heerlen>??

[2] R.G.D. Voskuilenweg 131 6416AJ Heerlen

[3] NAM assen

[4] Lab paleobot/palynol, RUU, Heidelberglaan 10 utrecht

particular where relatively thick clay layers are present, the roof has collapsed exposing the clay layer sequence. Samples used for the analyses of which the results are presented in this issue were taken in 1991 from a section in which the clay layers are thickest, and the sequence appeared to be most complete (Fig. 2). The main sample set was taken from the center of one of the deeper depressions, where the highest number of clay layers was recorded (Fig 3.).

Shallow marine sequences are sedimentologically complex in comparison with deep marine sequences. Sediments are usually wave-transported and highly bioturbated. Therefore, in shallow water sequences it is often hard to discriminate between global and regional events that may have happened at the K/T boundary. The Geulhemmerberg sections are no exception to that rule. As the reader can infer from the following chapters, many of the conclusions drawn are inequivocal, and open for alternative interpretations. Yet, the mere presence of clay layers at the K/T boundary in Geulhemmerberg is unique in such a shallow marine environment, and those clays contain a wealth of information about the K/T event.

Traditionally, the K/T boundary in Limburg is equated with the Vroenhoven horizon, which can be traced over a large area, see e.g. (Jagt & Janssen 1988). This seemed firmly based on paleontological and to a lesser degree on lithological data. The (macro)fossil content directly below the Vroenhoven horizon is dominantly of Cretaceous aspect, and the lithology of the chalks below the Vroenhoven horizon appears more similar to the Maastrichtian Meerssen chalk, than to the Danian Geulhem chalk. About 3-4m below the Vroenhoven horizon, however, another persistent hardground surface, the Berg en Terblijt horizon occurs (Fig 1). The interval between these hardgrounds is well exposed in the Curfs quarry, where it contains several discontinuous horizons rich in clay, usually as rip-up clasts. The distance between the two horizons is variable, and sometimes both horizons merge, further complicating correlations. The interval between the hardgrounds, both in the caves and in the Curfs quarry, contains *C. primus,*an undisputed(?) marker for the basal Danian (Mai et al. 1994), suggesting that the K/T boundary is not at, but distinctly below the Vroenhoven horizon, possibly at the Berg en Terblijt horizon.

The top of the Maastrichtian stage is not present in its type locality in the ENCI quarry in the Pietersberg, because the Meerssen chalk, the highest Maastrichtian lithological unit, is truncated and disconformably overlain by Oligocene sands of the Tongeren fm. However, if one includes the entire Meerssen chalk also outside the ENCI quarry in the definition of the Maastrichtian stage, including the interval between the Berg en Terblijt and Vroenhoven horizons, then there is a formal problem: The top Maastrichtian might -chronostratigraphically- be correlative to the base of the Danian. A similar hypothesis was raised earlier by Hofker (1966), who correlated the Md member with the Danian. This hypothesis was rejected by e.g. Berggren (1962, although the correlation problem may one on the ranges of nannofossil index taxa (see Romein, this volume).

A little History of the K/T Boundary.

As member of the former Working group on the Cretaceous/Paleogene boundary of ICS/IUGS (K/T Wg.), the senior author (J.S.) has actively been involved in the selection of the K/T boundary type locality, to be precise the Global Stratotype Section and Point (GSSP). The definition of the GSSP of the K/T boundary (formally K/Pg boundary, but leading journals such as Nature continue to use K/T) is now "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, marine or terrestrial.
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" -although he considered it Cretaceous in age- has preference over the slightly younger Maastrichtian stage (1848). Included in the Danian are the Faxe chalk, the Cerithium limestone and the Fiskeler (Fishclay) (Johnstrup 1876).
Thus in whatever section the GSSP would have to be placed, the obvious position for the K/T boundary should be at the base of the equivalent of the Fishclay. The Fishclay has been described in detail by (Christensen et al. 1973). The Fishclay 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 et al. 1985), soot (Wolbach et al. 1985) and altered microkrystites (Smit & Romein 1985). Such a claylayer, with similar lithological, mineralogical and geochemical charteristics has since been shown to occur in many places in the world (Smit & Romein 1985).
Note that 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, $\partial\ ^{13}C$ 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, and are excellent tools for correlation, but do not form part of the formal K/T boundary definition. However, each one of the correlation tools used on its own may lead to problems and misplacement of the K/T boundary. In particularly in outcrops around the Gulf of Mexico, where thick sandlayers occur at the K/T boundary (Smit et al. 1994, Smit 1995 in press), the placement of the K/T boundary is

and consequently may differ by as much as 8m.

In the Kef GSSP section, a reddish layer of a few mm thickness occurs at the base of a 23cm 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 same layer marks a major mass-extinction event, although the precise details of the extinction are still hotly debated (Smit 1994, Speijer 1994, Ginsburg et al. 1995 in prep). The first occurrence of new Paleocene taxa is a few cm to some dm above the lamina. The base of the red layer, a sharp bedding plane, is the "Golden Spike" of the K/T boundary.

So where should the K/T boundary be placed in the Geulhemmerberg and Curfs quarries? Using the above criteria, one should think that would be an easy matter. However, in practice every choice has its problems.

In correlating the K/T boundary from El Kef to the Geulhemmerberg section, there are several options. Obviously, an iridium peak would greatly facilitate the correlation, but neither an iridium anomaly nor shocked quartz, nor remains of microkrystites (Ni-rich spinels) and tektites have been found thus far (Smit et al., this volume). Remain lithological and biostratigraphic criteria. On lithological grounds, the K/T boundary is best positioned at the base of the clay layers, on top of the Berg en Terblijt hardground horizon. Biostratigraphically (see chapters inside), on the basis of the presence of rare *C. primus*, *B. sparsus*, *N. romeinii* and *N. parvulum*, the K/T boundary should be drawn below the clay layers. The planktic foraminifers argue for a Maastrichtian age for the clay layers, because the foraminiferal fauna is 100% Cretaceous. Also, the vast majority of the macrofossils in between the two hardgrounds, is of Maastrichtian affinity and include well preserved *Tenuipteria* and *Baculites* shells.

What is the significance of the clay layers?

Previous studies elsewhere have shown that the K/T boundary event is worldwide marked by a short period of strongly decreased ocean surface productivity. This short period is characterized by deposition of a detrital clay layer (Smit & Romein 1985), and sharply reduced $\partial\ ^{13}C$ values in carbonate shell material in the base of the clay (Zachos et al. 1989). The detrital clay layer is deposited directly on top of the mm thin Ir-enriched ejecta 'fall-out' lamina, as can be shown in the few non-bioturbated sequences (Stevns Klint, Denmark; El Kef, Tunisia; Caravaca, Agost, Zumaya, Spain).

Therefore, it is expected that the clay layers of the Geulhemmerberg caves provide important insight in the K/T boundary (impact) event, in particular in the recovery phase just after the mass-extinction event.

The clay layers were analysed on a variety of aspects, and the preliminary results of this multidisciplinary analysis are presented in this volume.

<u>Figures</u>

Fig. 1 location map with localities mentioned in this issue. (1) K/T boundary oucrop in the Curfs quarry (2) Entrance to the Geulhemmerberg caves.
(3) Location of the main sampling site within the caves.
Fig. 2 Map of the sector of the caves where the main section has been sampled (sample series IG 1-22, G1-G7)
Fig. 3 Lithostratigraphic column of the main section of the Geulhemmerberg K/T boundary section. Indicated are the different labelled (A-G) clay layers, and the position of the sample series IG1-IG22 and G1-G7 analysed in this issue.

References

Albertao, G.A., E.A.M. Koutsoukos, M.P.S. Regali, M.A. Jr & P.P. Martins 1994 The Cretaceous-Tertiary Boundary in Southern low latutude regions: preliminary study in Pernambuco, northeastern Brazil - Terra Nova 6: 366-376

Alvarez, L.W., W. Alvarez, F. Asaro & H.V. Michel 1980 Extraterrestrial cause for the Cretaceous-Tertiary extinction - Science 208: 1095-1108

Berggren, W.A. 1962 Some planktonic foraminifera from the Maastrichtian and type Danian stages of southern Scandinavia - Stockh. contr. Geol. 9: 1-106

Berggren, W.A. 1964 The Maestrichtian, Danian and Montian stages and the cretaceous tertiary boundary - Stockh. Contr. Geol. 11: 103-176

Bohor, B.F., E.E. Foord & P.J. Modreski 1985 Shocked quartz and microspherules: indicators of extraterrestrial impact at the K-T boundary - "Rare Events in Geology" Gwatt Conference

Christensen, L., S. Fregerslev, A. Simonsen & J. Thiede 1973 Sedimentology and depositional environment of Lower Danish Fish Clay from Stevns Klint, Denmark - Bulletin of the Geological Society of Denmark 22: 193-212

Cowie, J.W., W. Zieger & J. Remane 1989 Stratigraphic Commission accelerates progress, 1984-1989 - Episodes 112: 79-83

Ganapathy, R. 1980 A major meteorite impact on the Earth 65 million years ago: evidence from the Cretaceous-Tertiary boundary clay - Science 209: 921-923

Ginsburg, R., G. Keller, J. Smit, X. Orue-Etxebarria, I. Canudo, R.D. Olsson & B.M. Masters 1995 in prep Blind tests at the
boundary at El Kef, Tunisia. - Marine Micropaleontology .

Hofker, J. 1966 La Position stratigraphique du Maestrichtien type - Rev. de Micropal. 8: 259-264

Jagt, J.W.M. & A.W. Janssen 1988 Faunal and stratigraphical aspects of the Early Paleocene (Danian) in the SE Netherlands and NE Belgium, In: Backhuis, D.W. (ed.): Mededelingen van de werkgroep voor Tertiaire en Kwartaire geologie. E. J. Brill, -Leiden: 223

Johnstrup, F. 1876 Om Gronsandet I Sjaelland - Vid. Medd. fra den Naturhist. for.i Kobenhavn: 1-32

Mai, H., A.J.T. Romein & H. Willems 1994 Coccospheres of a rare nannofossil species: *Biantholithus sparsus* Bramlette and Martini, 1964 - Mar. Micropal. 24: 1-2

Mancini, E.A. & B.H. Tew 1993 Eustacy versus subsidence: Lower Paleocene depositional sequences from southern Alabama, eastern Gulf Coastal plain - Bull. Geol. Soc. Am. 105: 3-17

Meijer, M. 1959 Sur la limite superieure de l'etage Maastrichtian dans la region type. - Bull. Acad. Roy. Belg. (Sci) 5: 316-338

Schmitz, B., G. Keller & O. Stenvall 1992 Stable isotope and foraminiferal changes across the Cretaceous-Tertiary boundary at Stevns Klint, Denmark: Arguments for long-term oceanic instability before and after bolide-impact event. - Palaeogeography, Palaeoclimatology, Palaeoecology 96: 233-260

Smit, J. 1994 Blind tests and muddy waters - Nature 368: 809-810

Smit, J., T.B. Roep, W. Alvarez, P. Claeys & A. Montanari 1994 Comment: Deposition of channel deposits near the Cretaceous-Tertiary boundary in noprtheastern Mexico: catastrophic or "normal" sedimentary deposits? *and* Is there evidence for cretaceous-Tertiary boundary age

Smit, J. & A.J.T. Romein 1985 A sequence of events across the Cretaceous-Tertiary boundary - Earth and Planetary Science Letters 74: 155-170

Speijer, R.P. 1994 Extinction and recovery patterns in Benthic foraminiferal paleocommunities across the Cretaceous/Paleogene and Paleocene/Eocene boundaries [PhD thesis]. -University of Utrecht: 191

Wolbach, W.S., R.S. Lewis & E. Anders 1985 Cretaceous extinctions: evidence for wildfires and search for meteoritic material - Science 230: 167-170

Zachos, J.C., M.A. Arthur & W.E. Dean 1989 Geochemical evidence for suppression of pelagic marine productivity at the Cretaceous/Tertiary boundary - Nature 337: 61-64