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Sedimentological aspects of the K/T boundary at Geulhemmerberg, Zuid Limburg, the Netherlands

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Abstract

Traditionally, the K/T boundary in Zuid Limburg is placed at the Hardground of Vroenhoven between the Maastricht and Houthem Formations. The finding in the Curfs quarry and Geulhemmerberg of possible Paleocene microfossils below this hardground in a coarse-grained, well-bedded calcarenite unit with thin clay intercalations or clay pebbles excited new interest in the mode of deposition of this unit. The latter fills an irregular paleorelief, developed as a heavily burrowed hardground (Hardground of Berg en Terblijt), marking a hiatus at the top of the Maastichtian calcarenites. In galleries in the Geulhemmerberg, the fill of this paleorelief consists of a thinning-up and fining-up sequence of 1) coarse-grained fossil hash with thin clay intercalations, 2) debrisflow-like coarse calcarenites, 3) well-laminated HCS-like calcarenites, and 4) alternating clay and calcarenitic flaser-bedding. The inferred process of infilling is episodic storm-wave activity in ca 20–40 m waterdepth.

The scarcity of burrowing in the unit below the traditional K/T boundary in an otherwise heavily burrowed section of Maastrichtian and Paleocene calcarenites, and the preservation in the unit of delicate sedimentary structures and relatively thick clay layers point to extraordinary sedimentary circumstances. These are difficult to explain, but not incompatible with deposition shortly after the Chicxulub impact.

Introduction

The Cretaceous-Paleocene coccolith chalk and calcarenites around Maastricht in the southernmost Netherlands are part of a large-scale transgressive-regressive succession of 200 m thickness (Jagt et al., this issue). The transgression started in the Santonian-Campanian with deposition of quartz sands and smectitic clays over local continental deposits with browncoal layers and over abraded and karstified, folded Paleozoic sediments of the Ardennes Massif (W.M. Felder 1975; Zijlstra 1994). The middle part of this succession (Gulpen Formation) is formed by Campanian-Maastrichtian coccolith mudstones (chalk) with flint nodule layers. It is overlain by Maastrichtian and Danian calcarenites with hardgrounds (Maastricht Fm and Houthem Fm, respectively).

In this contribution the sedimentological aspects of the transition from the Maastricht to the Houthem Fm are the main issue. In order to provide a better understanding of the environment of deposition of the K/T boundary transition, a brief review of the sedimentological interpretations of the Gulpen, Maastricht and Houthem Fms will be given.

A shoaling upwards trend from Gulpen chalk to Maastricht calcarenites is already inferred by Binkhorst van den Binkhorst (1861, cit. Zijlstra 1994). The small and light-weight fossils of light-independent, suspension or deposit feeders, adapted to a soft muddy substratum, e.g. burrowing irregular echinoids, long-stemmed crinoids, thin-shelled oysters and inoceramids (cf. summary in Zijlstra 1994), suggest a deep-water environment for the Gulpen Fm. This fauna contrasts with that of the Maastricht Fm, which contains remains of larger and heavier, sessile, partly light-dependent suspension feeders, adapted to a mobile, calcarenitic or rocky substratum (hardgrounds), e.g. regular echinoids, asteroids, seagrasses, corals, rudists, large thick-shelled oysters, gastropods and pelecypods.

Upward shoaling from the Gulpen to the Maastricht Fm was also inferred by Van Harten (1972) from the increase of the grain size of tourmaline in heavy-mineral residues and the increase of the coarser M-association (andalusite, kyanite and staurolite) over the finer S-association (rutile, tourmaline and zircon). Likewise, a general increase in the number of coarse bioclasts (1 to 2.4 mm) per kilogram sample may be interpreted as a shoaling trend (P.J. Felder 1988). This trend is not gradual as is indicated by discontinuities at the boundaries of the Gulpen, Maastricht and Houthem Fms, with an abrupt increase of the amount of insoluble residue at the base of each of these formations followed by a gradual decrease (Villain 1977, cit. Zijlstra 1994).

Despite the evidence for a general shoaling as summarized by Zijlstra, he himself (1994: 88, 89 and 111), favours a very shallow mudflat environment for the deposition of the Gulpen Fm and a deeper (shelf) environment for the Maastricht Fm, to account for the respectively symmetric and asymmetric storm beds in these formations (see below). However, we think the evidence in favour of the older view outweighs Zijlstra's arguments and we prefer a deeper muddy shelf environment for the Gulpen Fm and a shallower shelf environment, generally above normal wave base, for the Maastricht Fm.

Rhythmic variations in grain size and in the amount of flint, and a bundling of flint layers in groups of five led Zijlstra (1994) to infer the presence of Milankovitch precession cycles of 21 000 years. Periodic variation due to latitudinal shifts of the caloric equator would lead to periodic increase and decrease of storm activity (with deposition of larger and smaller grains respectively), and in times of slow deposition to an increase of the amount of authigenic minerals (smectite, glauconite, pyrite, carbonate cement) and flint. These cycles would be symmetric, coarsening-up to fining-up, in the Gulpen Fm, and asymetric, fining-up, in the coarser-grained Maastricht Fm. The coarse-grained bases of the cycles of the Maastricht Fm are bounded by wavy erosion surfaces and often contain cross-stratification, which resembles hummocky cross-stratification (HCS) and which is interpreted as generated by storm waves. The fine-grained tops are homogeneously bioturbated calcisiltites with silicifications or carbonate-cemented hardgrounds, which in times of non-deposition were bored and encrusted (Zijlstra 1994: 128 and refs therein).

The boundary between the Late Maastrichtian Maastricht Fm and the Danian Houthem Fm is generally marked by a conspicuous hardground. This so-called Hardground of Vroenhoven (W.M. Felder 1975) is overlain by the very fossiliferous, soft, fine to coarse-grained glauconitic calcarenites of the Houthem Fm. Burrows in the Vroenhoven Hardground usually yield an infill of Danian fossils (Voigt 1959: 143; also Bless 1988, citing Deroo 1966). The walls of the burrows in this hardground are not encrusted by Bryozoa, as are those in hardgrounds of the underlying Maastricht Fm in the Curfs quarry near Geulhem (Figures 1, 2), but are lined by black illitic clay (Voigt 1959: 131, 143–145). Otherwise, the Maastricht and the Houthem Fm are not very different lithologically. Illustrative in this respect is that before 1912 both formations were reckoned to the 'Maastrichts Krijt' and illustrative is also a quote from Bless (1988: 27): 'However, where the Hardground of Vroenhoven is absent, it may be difficult to distinguish in the field between the Meerssen Member (= highest member of the Maastricht Fm) and Houthem Fm, since both consist of

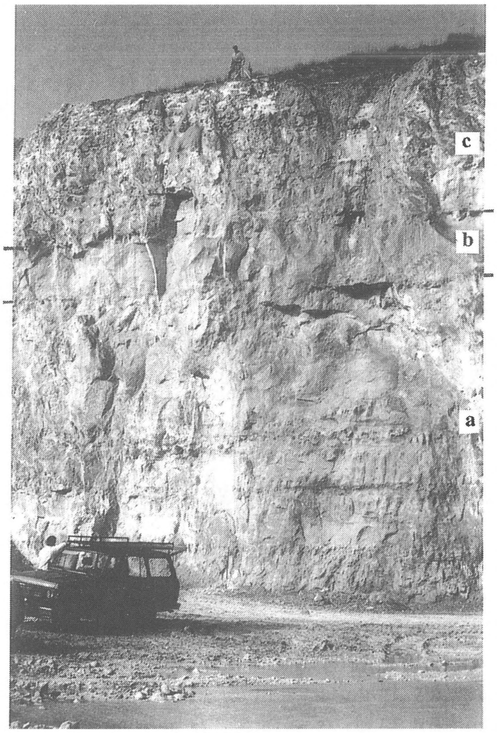

Figure 1. Curfs quarry at Geulhem showing the position of unit a (Maastricht Fm), unit b, here a bedded interval, and unit c (Paleocene, Houthem Fm). The K/T boundary is placed traditionally at the top of unit b (= Hardground of Vroenhoven). In this issue we propose that its position is more likely at the bottom of unit b. A comparable photograph was published previously by P.J. Felder (1988). The position of Figure 1 corresponds to column 6 of Figure 4 at another time of quarry wall exploitation.

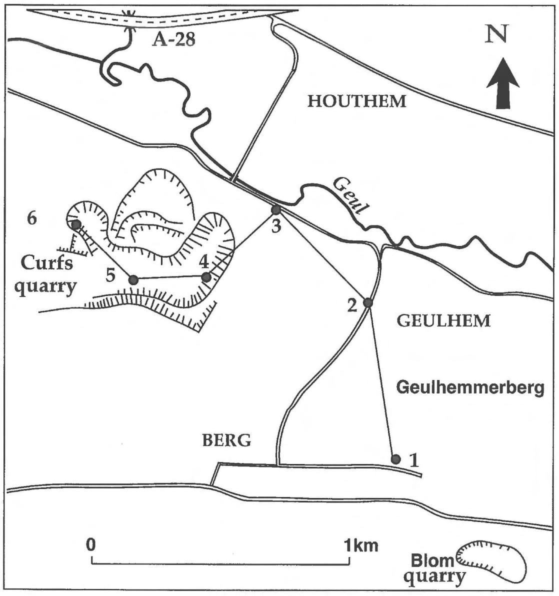

Figure 2. Map of the area around Geulhem (6 km E of Maastricht) with positions of the Curfs quarry, Geulhemmerberg and the locations 1 to 6 of the columns of Figure 4. The localities 1 and 2 occur underground in the galleries.

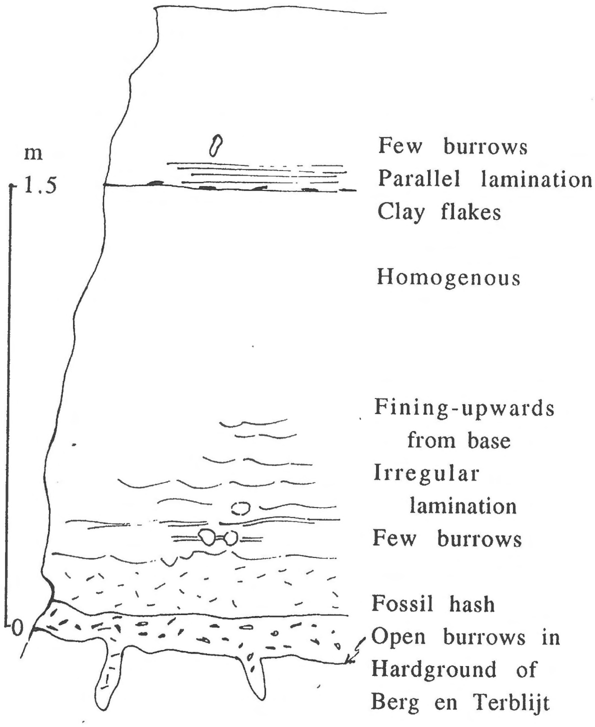

Figure 3. Sedimentological details of calcarenites of the basal part of unit b in the Curfs quarry, above the Hardground of Berg en Terblijt (locality 6 of Figure 2).

medium to coarse-grained biocalcarenites with fossil grit lenses and 'hardgrounds' of limited lateral extension'. According to Bless (1988 and refs therein), the Hardground of Vroenhoven marks a hiatus, that relates to a eustatic sea-level fall between the latest Maastrichtian and earliest Danian (cf. Smit and Brinkhuis, this issue). A subsequent Danian sea-level rise restored the previous Late Maastrichtian depositional conditions, as is indicated by the similarity in sediments, carbonate content, grain size, gamma-ray spectrum and bioclast composition and by the more or less same percentage of ornamented ostracods. This indicates the same energy levels for both formations, but not necessarily the same depth. The large change in ostracod faunas across the K/T boundary is explained by Bless by the regression which cut off the sea-way between Tethyan and Boreal Europe (rather than by effects of an impact).

Van Harten (1972) noticed a well-developed hardground at the top of the Maastricht Fm, which at places is channelled by erosion. Near Vroenhoven along the Albert Canal (ca 3 km SW of Maastricht), these channels have a width of 1.2 to 2.5 m and a depth of 0.7 to 1.7 m. The channel fills consist of coarse oyster fragments and cobble-sized hardground fragments up to 20 cm in size, pointing to 'very shallow if not actually emerging conditions' (Van Harten 1972: 69). According to Van Harten, the Geulhem Member (= basal part of the Houthem Fm) is not unsimilar to the underlying Md (= upper part of the Maastricht Fm). He noticed, however, that the Geulhem Member tends to be finer calcarenitic, has more lateral facies contrasts and even contains clayey intercalations. The slight increase of the finer-grained S-association of heavy minerals (see above) could point to slightly deeper conditions in the Geulhem Member. The fluctuations in grain size, however, rather point according to Van Harten (1972: 70) to a shallow marine environment with local elevations such as shoals, reefs or barriers.

The K/T boundary in the Curfs quarry

In the Curfs quarry the uppermost 13 m of the Maastricht Fm are exposed. They are topped by the Hardground of Vroenhoven and overlain by the Geulhem Mb. In the field a threefold division can be easily made.

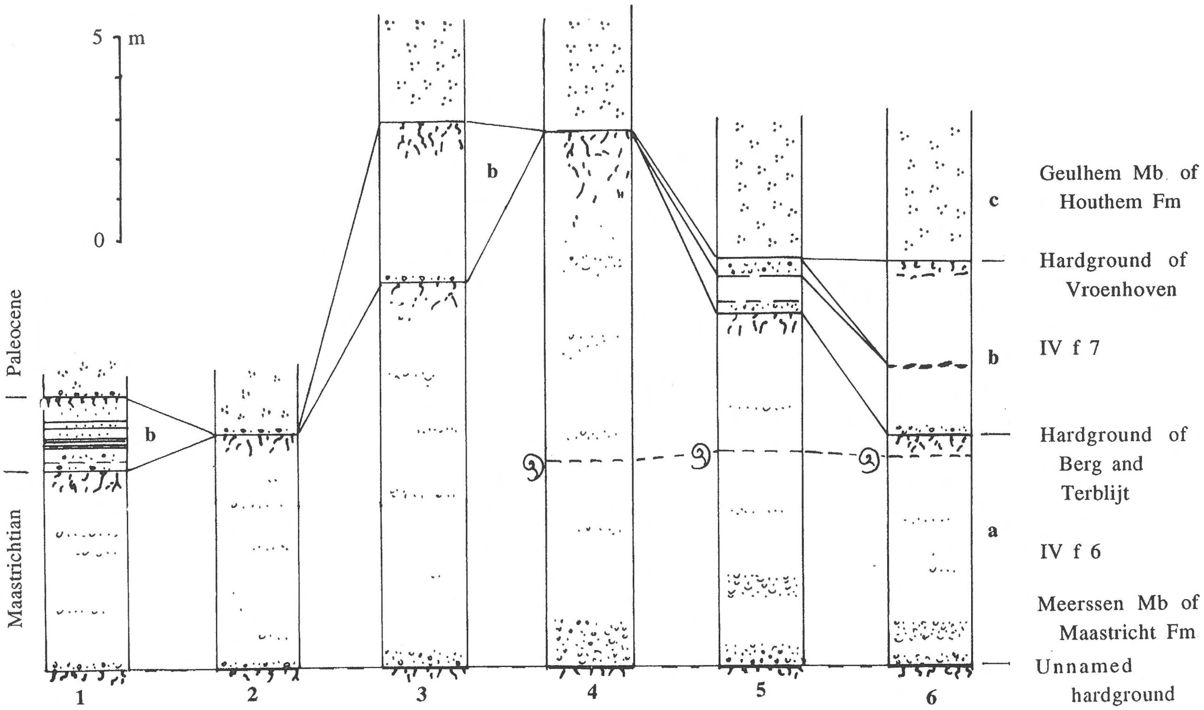

Figure 4. Lithological columns from the Geulhemmerberg galleries to the Curfs quarry, showing a buried topography of highs and flanking lows filled by unit b and part of unit c (after W.M. Felder 1993, unpublished). For the position of the columns see Figure 2 and for lithological details see Jagt et al., this issue: Figure 9.

For convenience we will call the units: a, b and c (Figure 1).

Unit a. At the base of the quarry, strongly bioturbated, light-coloured calcarenites occur with 'saucer'-shaped hardgrounds overlain by graded calcarenitic layers starting with coarse fossil hash. The 'saucers' cut each other and have dimensions of 1 to 3 m thickness and a few tens of metres length (P.J. Felder, personal communication). As pointed out before, the hardgrounds are clearly synsedimentary cementations. This can be deduced from borings and encrustations. It seems that the saucers are the lower parts of some kind of undulating large-scale bed form, from which the tops have been eroded. These bed-forms could have been large hummocks or low sand waves and probably result from episodic storm waves. Higher up-section, the saucers and hardgrounds are less conspicuous and some metres above the last inoceramids and directly above the last Cretaceous ammonites (for a single exception see below) unit b appears.

Unit b. This unit (in the situation of 1994) measures at the most ca 4 m in thickness and ends with the conspicuous Hardground of Vroenhoven. The unit is identical with unit IVf-7 of the Meerssen Mb (W.M. Felder 1975) and overlies the so-called Hardground of Berg en Terblijt (W.M. Felder and Bosch 1996). In contrast to units a and c, this unit is clearly bedded, due to less intensive burrowing. In the quarry, the unit has a somewhat smooth face compared to the other units, and is either slightly protruding or recessive. Usually, two to five bedding-planes may be seen. On closer inspection, fossil hash from its base is seen to fill partly the open burrows of the Hardground of Berg en Terblijt. The coarser layers consist of broken and rounded macrofossils which all have a Maastrichtian age; most belemnites are rounded and transported. In the thicker fine-grained beds, also well-preserved fossils occur, including belemnites, *Inoceramus* doublets and a single ammonite (J.W.M. Jagt and W.M. Felder, personal communication). In one place, a few decimetres of graded fossil hash occur, overlain by fine calcarenites with irregular wavy laminations and isolated

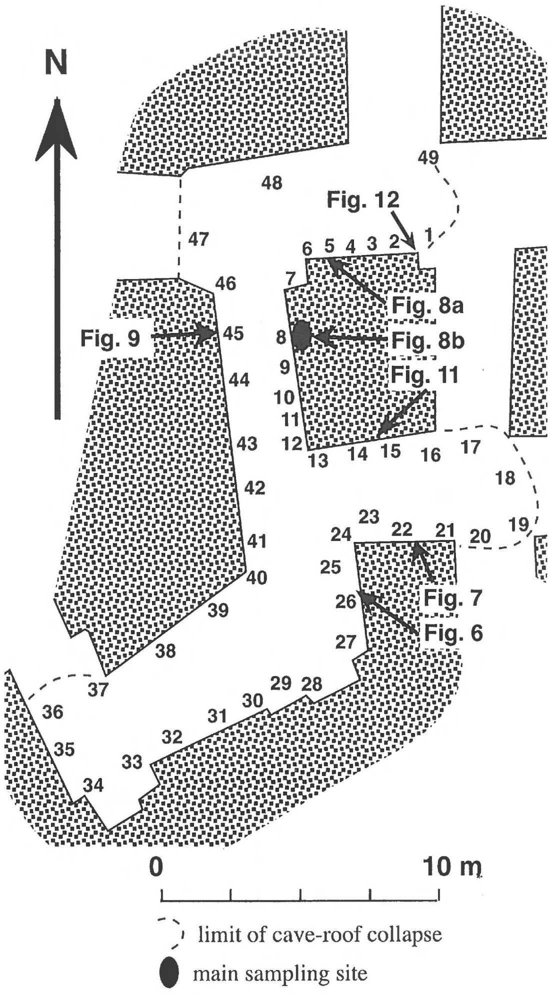

Figure 5. Map of part of the underground galleries of the Geulhemmerberg, with positions of the main sampling site (just N of photo 8), photos (1–49) and Figures 6–12. The area shown corresponds to locality 1 of Figure 2.

burrows (Figure 3). Higher in the section, the calcarenites have a more homogenous aspect due to dewatering, or to diagenetic processes in the slightly better sorted calcarenites of this level. At 1.5 m above the base, small very thin clay flakes occur, directly overlain by parallel-laminated slightly coarser calcarenites, with isolated burrows.

On blocks from the base of unit b, we saw an HCS-like structure above the basal fossil hash with clay flakes. This structure consisted of swelling and thinning laminations of a few centimetres thickness, each showing inverse grading.

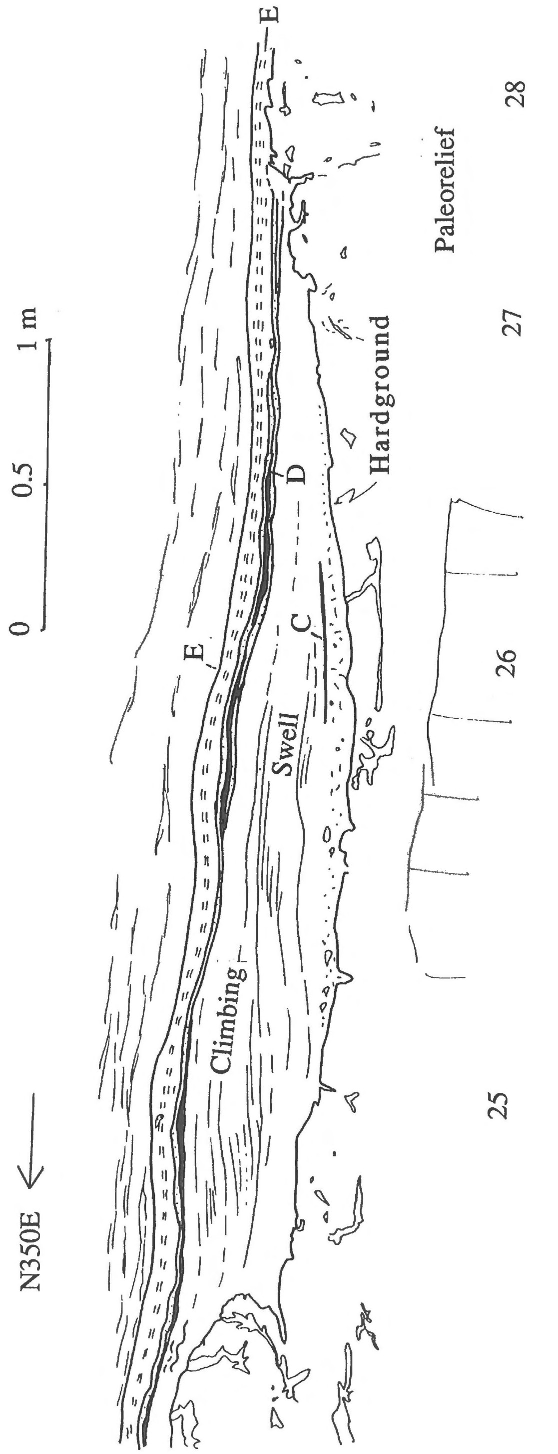

Figure 6. Burrowed surface of the Hardground of Berg en Terblijt, with infilling of the depression by unit b. Note fossil hash at the base, thinning towards the left, and C clay inclined towards the left, pointing to infilling in that direction. The overlying calcarenites show swelling and climbing laminations. The E clay extends over the paleorelief. The position of the numbered photos (25–28) is indicated in Figure 5.

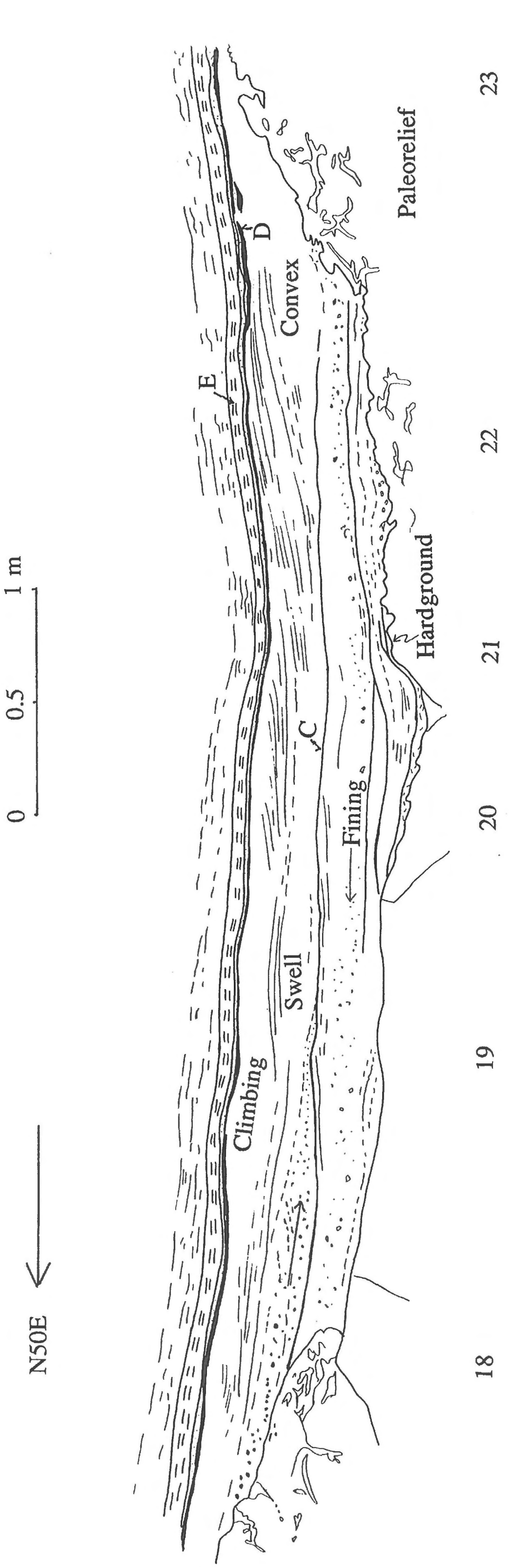

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Figure 7. Same depression as Figure 6, at right angles, with similar wedge-shaped infilling towards the left, and minor infilling to the right.

Traditionally, the K/T boundary was placed at the top of this unit b at the Hardground of Vroenhoven (W.M. Felder 1975). Now it seems more probable that the K/T boundary is to be placed below unit b. at the Hardground of Berg en Terblijt (Brinkhuis and Smit; Smit and Brinkhuis, this issue).

Unit c. Overlying the distinct top of unit b (= the Hardground of Vroenhoven) is a strongly bioturbated, somewhat softer and thinner-bedded unit. The bedding is less conspicuous than in the other two units and the colour is slightly darker. This is the Geulhem Mb of the Houthem Fm.

Unit b between the Curfs quarry and Geulhemmerberg galleries

In 1993, W.M. Felder produced a number of unpublished columnar sections from the Curfs quarry to the nearby Geulhemmerberg galleries, showing the situation around the K/T boundary (Figure 4). These sections suggest a paleorelief of 7.5 m height, if one uses as horizontal reference the ammonite level below the Hardground of Berg en Terblijt and a lower lying unnamed hardground (above the Hardground of Caster). At either side, east and west, of the topographic high depressions occur, now exposed in the Curfs quarry and the Geulhemmerberg galleries. The surface of this paleorelief originally was formed by a heavily burrowed hardground (Hardground of Berg en Terblijt), with most intense burrowing at its higher parts, pointing to a subaqueous relief. The depressions at either side subsequently were filled irregularly with unit b sediments (0 to 4 m, locally according to W.M. Felder even 5 m thick) and part of the Geulhem Mb.

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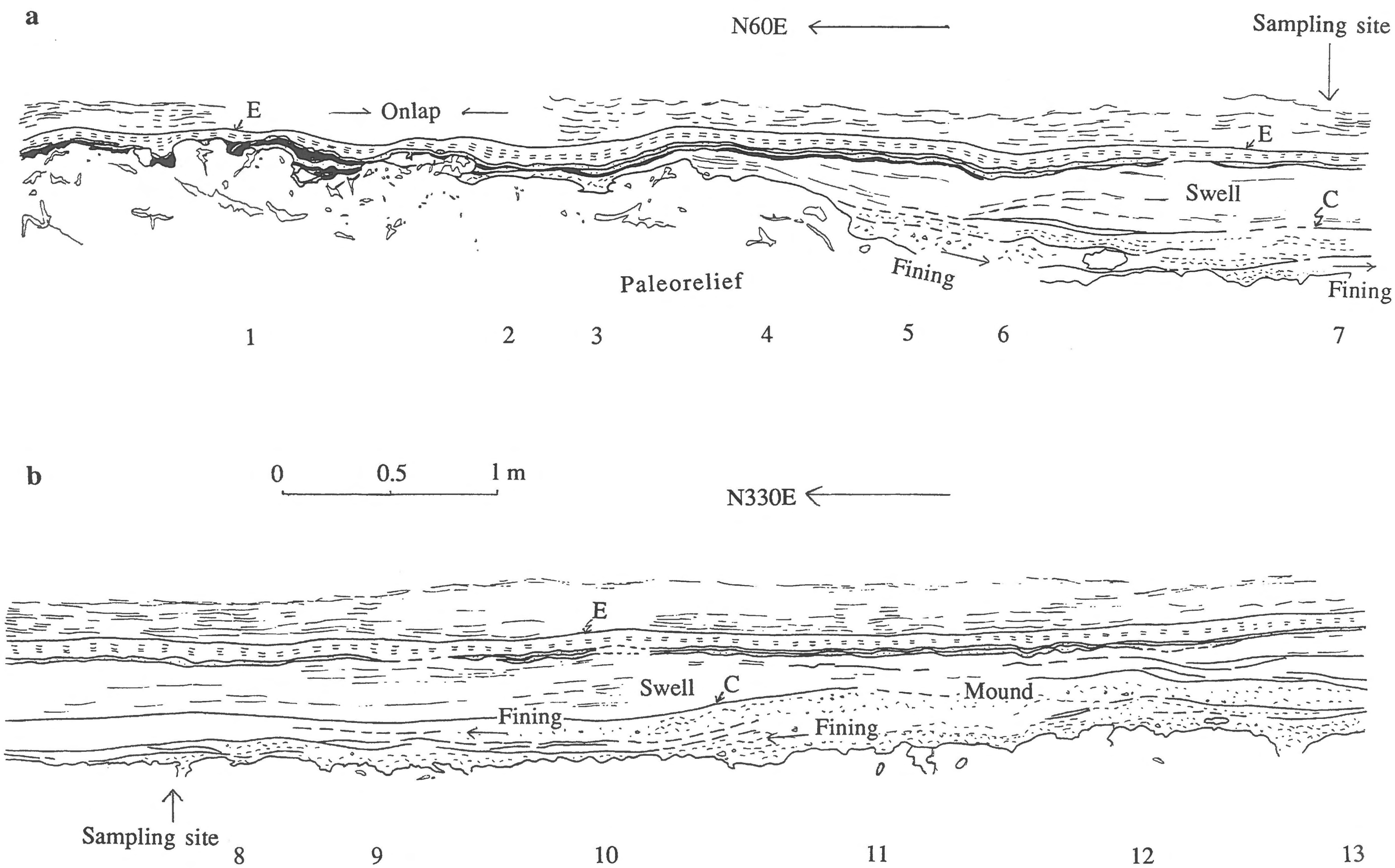
Figure 8. Depression infilling. Figures 8a and b are at right angles to each other (see Figure 5). a) Onlap to left and right over the paleorelief. A detail of the paleorelief (photo 2) is portrayed in Figure 12. b) At the right, a mound-shaped superposition of pebbly calcarenitic debris-flow tongues, thinning and fining towards the left, indicates the direction of infilling. The mound-shape is delineated by the C clay.


a
N60E
Sampling site
E
Onlap
E
Swell
C
Fining
Paleorelief
Fining
1
2
3
4
5
6
7
b
0
0.5
1 m
N330E
E
Swell
C
Mound
Fining
Fining
Sampling site
8
9
10
11
12
13

Three points may be noted from these columnar sections:

1. In the higher part of the paleorelief, the Hardground of Berg en Terblijt merges with the Hardground of Vroenhoven; whereas in the deeper parts these hardgrounds are separated by unit b sediments.
2. In the Curfs quarry, the fossil hash layers in unit b thin and split up in a westerly direction away from the paleorelief, which indicates transport in that direction, probably by storm waves.
3. In the Geulhemmerberg galleries, W.M. Felder found in unit b, here 1.8 m thick (Figure 4 column 1), an alternation of fossil hash and coarse calcarenites and up to nine clay layers. This points to alternating agitated and quiet periods.

Sedimentological details of unit b in the Geulhemmerberg galleries

The most interesting exposures of the K/T boundary in the galleries at Geulhemmerberg occur at those places where the roof has collapsed due to the presence of thick clay layers in unit b. The roof of the galleries usually consists of the Hardground of Berg en Terblijt, which the diggers for building stone avoided, because it was too hard. The hardground shows at least two types of Thallassinoid burrows: large irregular branching burrows (2–3 cm wide) down to at least 40 cm depth and a thin (up to 0.5 cm wide) and curving type. The hardground shows irregular depressions up to 0.8 m deep. These at first glance resemble channels partly filled with conglomeratic fossil hash, but no erosion and downcutting are seen. The open and irregular burrows of the hardground are partly filled with this coarse fossil debris. At an earlier stage the deeper parts of the burrows were filled by finer and sometimes very glauconitic calcarenites.

Figure 5 shows a map of the galleries of this underground exposure. The numbers indicate a series of colour photographs (Jan Smit, Vrije Universiteit) from which the drawings of Figures 6 to 9 were prepared. Figure 5, together with Figure 8a and b, also shows the position of a section, with thinner and thicker clay layers (numbered A to G), which was sampled for multidisciplinary research (see Smit and Brinkhuis, and other reports in this issue).

The infilling of the depressions of the hardground roughly shows a thinning-up and fining-up character; the clay layers thicken up to the E clay which is the first clay layer to cover both the depressions and highs of the hardground. Graded laminated calcarenites alternating with clay layers overlie the E-clay. Burrowing intensity increases towards the roof of the gallery; this roof, exposed after collapse, consists of heavily bioturbated marl and fine-grained calcarenites.

In the depressions of the hardground, up to four different units may be found (Figures 6–9) which together indicate infilling predominantly towards N20E (Figure 10). This can be inferred from the lateral thinning and fining directions of some layers and the wedge-shaped infilling marked by clay-drape C (Figures 7, 8b). Minor infilling from the opposite direction was found also. This means that the infilling process was not a unidirectional current. The four different infilling stages comprise 1) a bottom unit with crude, somewhat irregular cross-laminations or channel-like features, followed by 2) an ill-sorted pebbly calcarenite unit with the appearance of a debris-flow. Both units contain frequent thin clay intercalations, which point to episodic sedimentation events. Figures 6 and 7 show cross sections at right angles, probably of the same infilling (photos 25–28 and 18–23 respectively). In Figure 6, a steep, heavily burrowed knoll of the hardground is seen. The thinning of the coarse bottom layers and the northward inclined lowermost clay-drapes clearly indicate the northward component of the infilling process. A large intraformational block at the bottom of the depression is also displaced; its borings occur on the lower side of the block and they are much finer than those on the surrounding knolls. The higher part of the infilling is 3) a yellow, well-laminated, much better sorted medium-grained calcarenite up to a few decimetres thick. The internal laminations have an undulating pattern, but also show low-angle internal truncations. The wavelengths of the undulations seem to widen in the direction of infilling, and the undulations more or less abutt against a steep knoll of the paleorelief of the hardground. Over the shoulder of the knoll, a few clay-draped symmetrical ripples can be vaguely seen. Over the knoll, at this place, 4) a few calcarenite-flasers alternating with clay (D) were deposited. We call these sandflasers 'lazy ripples', because of their swelling and thinning low-angle relief and internal low-angle truncations. These ripples are formed under low-energetic conditions without flow separation over the crests of the ripples. Such ripples are formed by waves under waning orbital motion or (in this case less likely) by waning currents (cf. Roep et al. 1979: 144 'flat (wave) ripple flaser'). In this case the lower of the two ripple flasers tapers out in either direction away from the knoll, which suggests increased (orbital) motion and

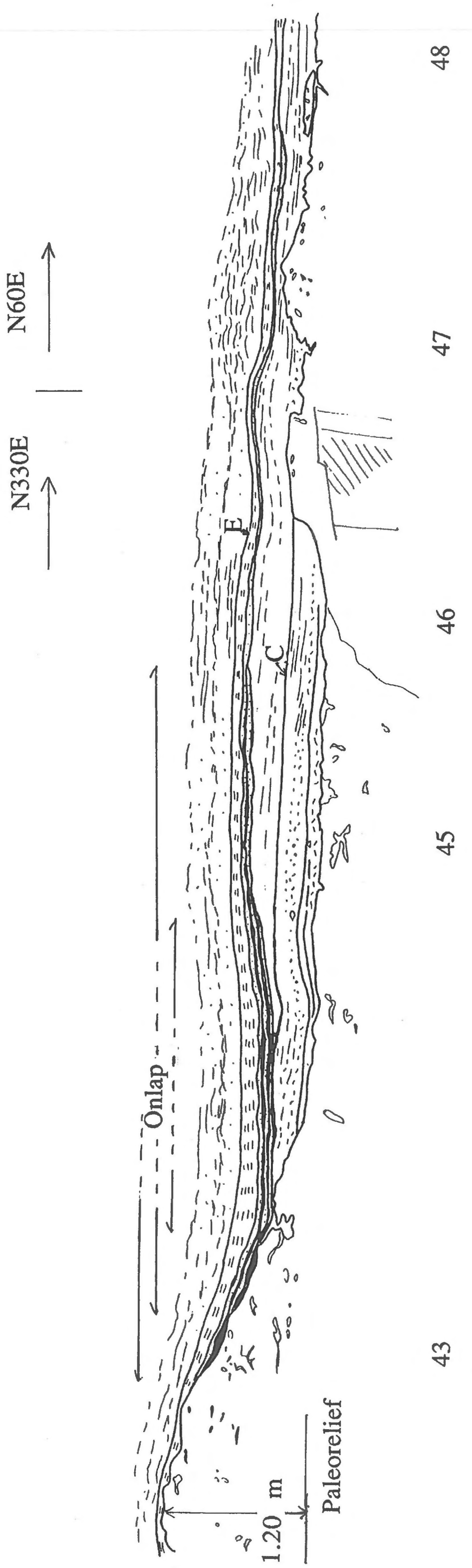


Figure 9. Wall opposite to the main sampling site (see Figure 5). The C clay merges with alternating D clay layers and lazy ripple flasers. Note the internal depression in unit b between photos 43 and 46, with the E clay thinning to both sides of the depression. Note further the onlap of lazy ripples over both sides of this depression

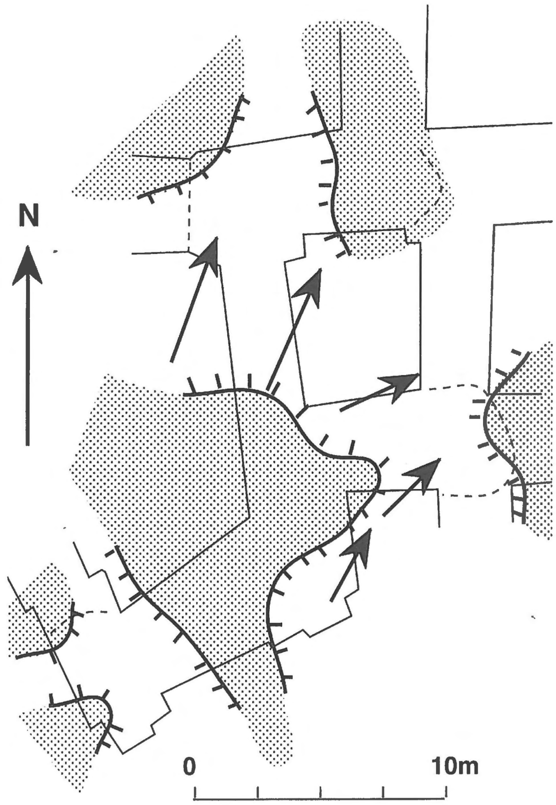


Figure 10. Scheme of the irregular pattern of highs (stippled) and lows of the Hardground of Berg en Terblijt in the Geulhemmerberg galleries (cf. Figure 5). Arrows indicate the dominant direction of infilling of the depressions.

supply over the knoll. The whole series is covered by the decimetre-thick clay layer E.

Figure 7 shows the exposure in a side gallery and probably shows the same depression as Figure 6 (see map Figure 5). Apart from one coarse fossil debris tongue at the left, most infilling layers at the bottom point to an infilling direction with a component to N50E. The well-sorted calcarenite on top of the persistent thin clay layer C shows convex low-angle cross-bedding passing laterally into undulating laminations with decreasing wavelength and height, and a climbing set. Figure 11 of the opposite wall of this gallery shows a hummocky-like upper surface of the same well-sorted unit, with low-angle cross-bedding inclined towards N100E. Internal lamination here is of millimetre and centimetre-scale, the latter suggesting an overloaded or wave-induced current. Smaller-scale erosive troughs and infillings point to waning conditions during deposition. This undulating bed strongly resembles HCS, except for its limited extent in the top of the depression and its internal asymmetry. The 'lazy ripples' on top of this unit have estimated N-S crests.

Figure 8b shows the gallery of the sampling site, with a similar setting as the previously described infillings (Figures 6, 7, 11). A special feature is a mound-shaped unit at the base, to the right of the figure. The shape of this mound could be reconstructed using clay-drape C; this indicates a main infilling direction towards N20E. A few imbricated grains in the basal part, however, point to a local (wave-induced) current towards N150E, whereas subordinate infilling towards N240E is inferred from the thinning direction of a few layers portrayed by photos 1 to 7 (Figure 8a).

Figure 9 represents the section of the gallery wall opposite to Figure 8b. Here the infilling is towards N330E. A special feature of this section is an internal depression between photos 43 and 45. This depression is filled by a thicker E clay thinning away from it. Underlying the E clay, up to three lazy ripple flasers occur, showing onlap on both sides of the internal depression, so that they successively disappear. Noteworthy is the fact that the lazy ripples touch the paleorelief. Such a feature points rather to wave activity than current activity; in the latter case turbulence increases near an obstacle and leads to scour. Further compaction of the E clay gave space for a still younger unit of alternating thinning and swelling fine calcarenites and clayey beds. This unit is heavily burrowed and also reminds somewhat of HCS, though lacking the continuity of that structure. Also this unit thins or disappears over the original paleorelief. The situation of up to three lazy ripples and intercalated mud in a depression thinning over the elevation is the reverse of the situation in Figure 6, where the lazy ripples seem to be connected with the paleorelief and to be thinning towards the depression.

In higher parts of the paleorelief, the complex infilling succession of four units is missing and only laminated-clay-filled pockets occur occasionally with thin calcarenitic laminae pinching out away from the paleorelief. The thickest clay (combined D and E) measures 39 cm and occurs near photos 29 and 31. Here extremely thin lamination was observed (Vonhof, personal communication). Finely laminated E clay-drapes also over the paleorelief indicate very quiet depositional circumstances in more shielded or deeper water. A similar setting is shown in Figure 12. Here again the lazy ripple-flasers show onlap over the paleorelief, under very quiet conditions.

In some places clay E is the highest exposed unit in the gallery walls beneath the roof; in other places, as already pointed out, pale-yellow, heavily bioturbated swelling and thinning, HCS-like, thin-bedded and fine-grained calcarenites occur (Figure 9). This unit indicates again slightly higher energetic conditions, either in shallower water or in less protected positions, compared to those of the E clay.

Conclusion

Concluding we may say that the hardground surface of Berg en Terblijt marks a submarine hiatus in the latest Maastrichtian. The irregular surface and paleorelief with knolls and depressions is inferred to be the result of bio-erosion in relatively shallow water. So far, all evidence for a wave-cut terrace with rounded pebbles is lacking in the Curfs quarry and the Geulhemmerberg galleries. W.M. Felder observed one horizon, further east in the direction of Valkenburg, with rounded pebbles from the hardground and even with terrigenous pebbles; so emerging conditions must have been present in the neighbourhood. The hardground marks a time of non-deposition. Sedimentation was resumed by a coarsely grained infilling of the depressions of the paleorelief. The grain-size contrast between the bioturbated fine-grained calcarenites below the hardground and the very coarse infilling, with boulders up to 20 cm diameter, suggest a shallower environment, less shielded against storm waves, or a temporary increase in storm energy. Masses of carbonate sand and gravel were moved from the higher parts of the hardground into the hollows. The first infilling resulted from a slightly more active process (vague channels, crude cross-bedding with graded laminae); later the infilling process was less active, depositing more massive debris flows, which are thinning and fining away from the paleohighs, in general towards N20E. The massive fabric is not quite unlike the basal part of a rip-current sequence as described from the Recent Baltic by Gruszczynski et al. (1993). The depositional processes filling the hardground depressions were episodic as can be deduced from the frequent thin clay intercalations. When the depressions were about half-filled, the infilling process again was more active, pro-

Figure 11. Oblique photo (near photo 15) of the wall opposite to the right hand-part of Figure 7, with similar infilling pattern as that on Figure 6; for position see Figure 5. Note the frequent clay intercalations in the bottom part of the infilling and the overlying HCS-like low-angle laminated structure with minor scour and truncation at its top (above the corkscrew). Note further the clays D and E with intercalated lazy ripple flaser.

ducing undulating and laminated thicker beds of better sorted, medium-grained calcarenites. These beds, at first glance, resemble HCS, but are confined to the depressions and show more irregular undulations. Widening and lowering of these undulations away from the paleorelief, could point to confinement and expansion of (wave-induced) currents.

Upward thinning and fining of the infillings up to clay E points to a deepening of the sequence (or alternatively to a more shielded position). This problem of deepening, shielding or temporartly decreased storm activity cannot be solved definitively, but we are inclined to think of a deepening environment to account for the gradual thinning and fining-up character of the infilling, for the lack of any overlying bars, barriers, shoals (apart from the mentioned irregularly bedded fine-grained calcarenites) or reefs, and for the fact that the larger paleorelief of 5 to 7.5 m between Curfs and Geulhemmerberg (Figure 4) already was present from the beginning of the infilling of the hardground depressions. Also the increase of finer-grained heavy minerals (Van Harten 1972) and reappearance of ornamented ostracods (Bless, 1988), in combination with the generally finer calcarenitic and thinner bedded aspect of the Geulhem Mb rather point to deepening conditions, although both Van Harten and Bless cautiously keep open the possibility of increased shielding. In any case the fine calcarenites overlying clay E indeed point to temporary shoaling, or less likely, a situation of more exposure to storm waves.

We think that the dominant processes around the K/T boundary are waves or wave-induced currents. Positive evidence for current activity such as current ripples or unidirectional trough-shaped, mega-cross-bedded sets or high-angle cross-lamination is clearly lacking. Occasional undulating surfaces of calcarenitic beds and irregular undulating internal laminations, low-angle mega-cross-bedding, clay drapes, lazy ripples attached to the paleorelief, and presence of a few clay-draped symmetrical ripples, rather indicate episodic storm-wave activity in deeper water with an estimated depth of 20 to 40 m.

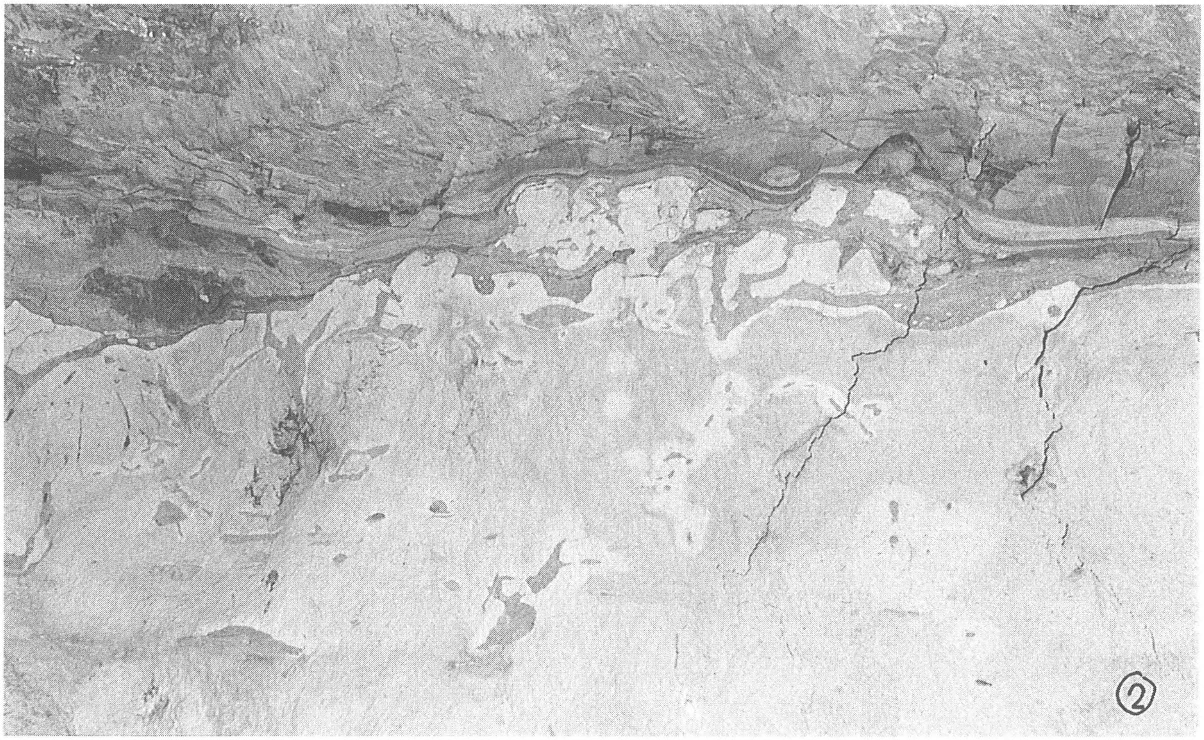


Figure 12. Detail of Figure 8a (photo 2) with onlapping lazy ripple flasers over the paleorelief of the Hardground of Berg en Terblijt. Note the veneer of coarse calcarenites in the hollows of the paleorelief and the thin clay D, sedimented even below protruding parts of the paleorelief. The picture shows about 1 m of the paleorelief in horizontal direction.

Sedimentologically, an irregular hardground surface filled by a thinning-up and fining-up sequence (unit b) with locally clay at the top and with preserved delicate sedimentary structures would simply indicate a new sedimentation phase after a break. Compared to the rest of the Maastrichtian and Paleocene sediments, the scarcity of burrows and the presence of thick clay in unit b stand out as the most conspicuous differences. These observations only get their relevance in combination with the admixture in unit b of an overwhelming amount of Cretaceous fossils and a few possibly Paleocene ones, and with its position below the traditional K/T boundary (Brinkhuis and Smit, this issue). Seen in the light of the Chicxulub impact, the environmental change in unit b and the scarcity of burrowing due to mass mortality are not inconsistent. The presence of the hardground below unit b and the lack of a clear iridium spike (Smith and Rocchia, this issue) indicate that the sedimentation stopped some time before, and was resumed sometime after the K/T boundary.

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