The northernmost marine Cretaceous–Tertiary boundary section: Nuussuaq, West Greenland

Gregers Dam, Henrik Nøhr-Hansen and W. James Kennedy

A new northern high-latitude Cretaceous–Tertiary (K–T) boundary section has been studied at Annertuneq on the north coast of Nuussuaq, central West Greenland (Fig. 1). This boundary section (Fig. 2) is the northernmost marine boundary section recognised so far (placed at palaeolatitude 58°N by Smith *et al.* 1981) and has been studied with respect to palynology, palaeontology, sedimentology, rare earth elements, magnetic susceptibility and carbon isotopes in order to describe and provide the context for the marine floristic changes across the K–T boundary in high northern latitudes (Nøhr-Hansen & Dam 1997; Kennedy *et al.* in press). The present paper is a summary of a research project on the K–T boundary section at Annertuneq, supported by the Carlsberg Foundation.

The K–T boundary

Palynological data have provided critical evidence in testing the meteorite impact hypothesis of the terminal Cretaceous extinction event (Alvarez *et al.* 1980). This hypothesis has been in the forefront of the discussion in geology and palaeontology because of the change in palynomorphs and extinction of the dinosaurs, discovery of iridium enrichment and shocked quartz at K–T boundaries in North America and the presence of the postulated major meteorite crater in Chicxulub, Mexico (e.g. Alvarez *et al.* 1980; Nichols 1996). Alternatively, it has been suggested that sulphuric acid and volcanic dust from the Deccan Trap volcanism in India could have led to climatic deterioration causing the major extinction at the K–T boundary (e.g. Officer *et al.* 1987). The palynological record of the event and its effects on terrestrial plants and dinoflagellate cysts, as well as the association of palynomorphs with the iridium anomaly, have been described and summarised in several papers (e.g. Nichols 1996; Sweet *et al.* 1990; Moshkovitz & Habib 1993; Elliot *et al.* 1994; Brinkhuis & Schøiler 1996). Most of the K–T boundary sections occur in low and mid-palaeolatitudes. Studies on a large number of terrestrial mid- and high-northern localities in North America have been summarised by Nichols (1996) who concluded that the K–T boundary transition in high northern latitudes is complex and involved more than a single event and that extinctions were superimposed on floristic alterations already in progress due to various climatic and environmental fluctuations. In North America high-latitude marine Cretaceous–Tertiary sediments are known only from Bylot Island and Devon Island, Canadian Arctic Archipelago (Ioannides 1986), but unfortunately a major unconformity eliminates the K–T boundary there (Benham & Burden 1990).

The section at Annertuneq appears to be complete and therefore it provides important new information about the marine floristic changes across the boundary in high northern latitudes. Preliminary studies indicate that complete boundary sections may also occur at Kangilia and in the section penetrated by an exploration well (GRO#3; Fig. 1). However, palynomorph assemblages are not as well preserved there as at Annertuneq.

Geology at Annertuneq

The work of Birkelund (1965), Rosenkrantz (1970) and Hansen (1980) forms the basis of our knowledge of the stratigraphy on the north coast of Nuussuaq. However, during the Survey's petroleum geological studies onshore West Greenland since 1991 a number of detailed sections were measured at Annertuneq and Kangilia (Fig. 1). One result of these studies was a new detailed Upper Cretaceous palynostratigraphy for the north coast outcrops established by Nøhr-Hansen (1996). Rosenkrantz (1970) placed the Cretaceous–Tertiary boundary on Nuussuaq at an unconformity between the 'undifferentiated marine Cretaceous shales' and the

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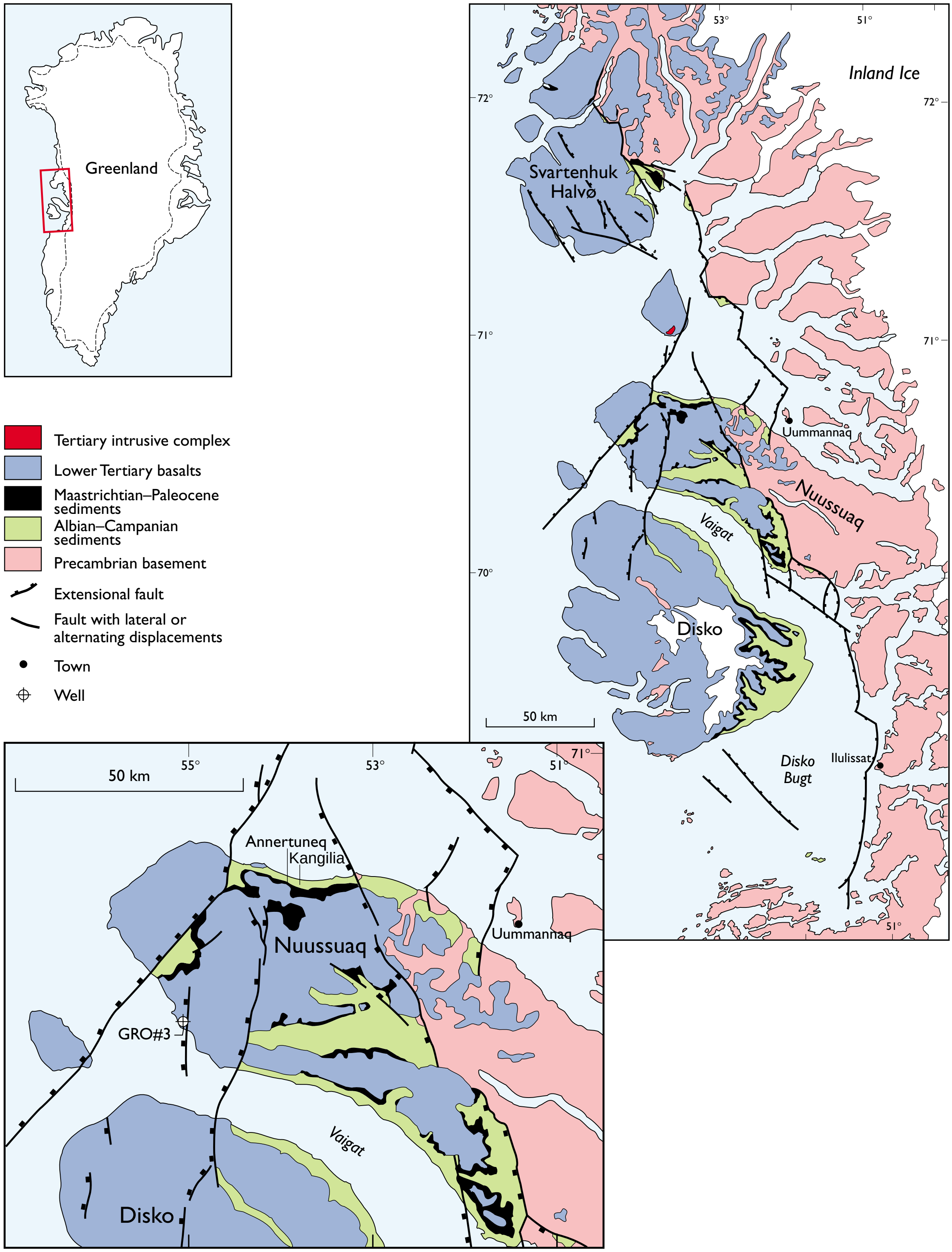

Fig. 1. Simplified geological map of West Greenland showing the Annertuneq locality. Based on published Survey maps.

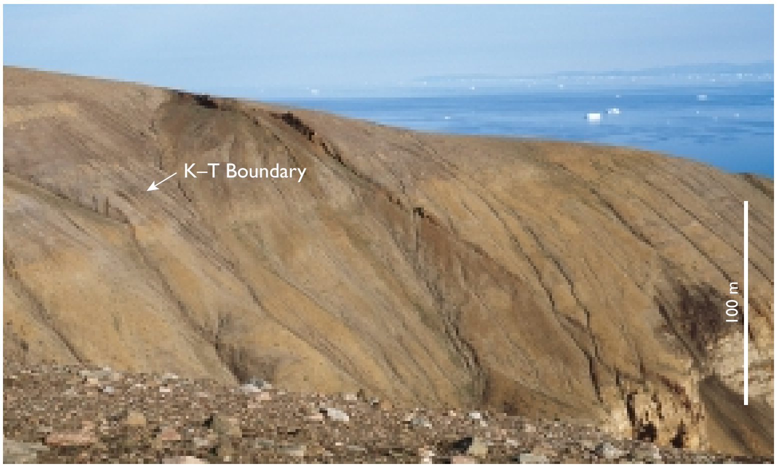

Fig. 2. The K–T boundary section at Annertuneq, Nuussuaq, central West Greenland.

'Conglomerate Member' at the base of the Kangilia Formation (Fig. 2) and it was believed that the K–T boundary strata were not preserved. However, during the Survey's geological studies several loose fragments of ammonites were discovered above the 'Conglomerate Member' in small ravines in the neighbourhood of Annertuneq. In 1994 ammonites were found *in situ* in a concretionary layer *c.* 200 m above the base of the conglomerate (442 m a.s.l.). This locality was not recorded in the extensive work on the Late Cretaceous ammonites of West Greenland by Birkelund (1965). In 1995 the location was revisited, with financial support

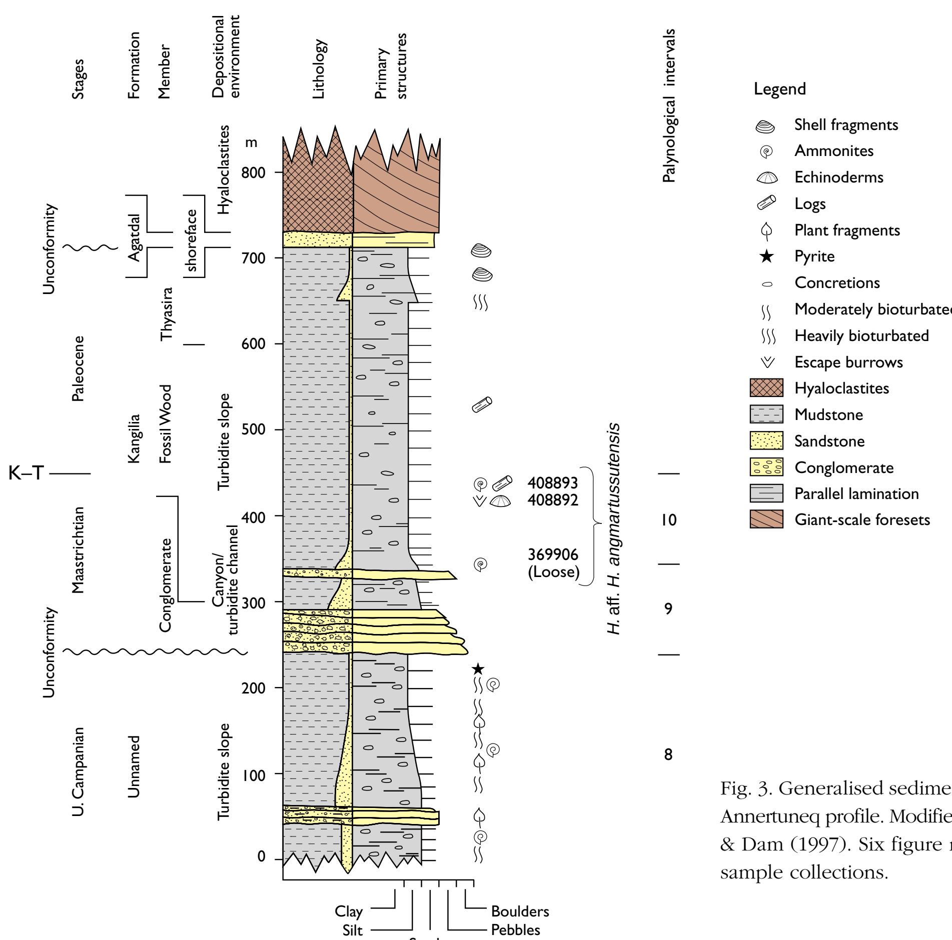

Fig. 3. Generalised sedimentological log of the Annertuneq profile. Modified from Nøhr-Hansen & Dam (1997). Six figure numbers are Survey sample collections.

from the Carlsberg Foundation, and the section was closely sampled in order to locate the K–T boundary.

The exposed sedimentary succession at Annertuneq is *c.* 725 m thick and consists of Upper Campanian to Paleocene turbidite slope and shoreface deposits (Fig. 2). Two tectonically controlled unconformities are present in the succession: at the base of the Upper Maastrichtian – lowermost Paleocene Kangilia Formation, which is marked by a submarine canyon conglomerate, and at the base of the shoreface sandstones of the Paleocene Agatdal Formation. The sedimentary succession is overlain by thick hyaloclastites and flood basalts. The K–T boundary is placed at 452 m above sea level in the Fossil Wood Member of the Kangilia Formation (Fig. 3). The Fossil Wood Member consists of mudstones interbedded with very thin and thinly bedded fine- to coarse-grained sandstones. Calcite concretions are common. The mudstones are poorly laminated, and some of the laminae appear to be graded. The sandstones have a sharp base and are usually normally graded. They are structureless or parallel laminated and escape burrows penetrate some of the sandstones. A 5 cm thick pebbly sandstone occurs just above the K–T boundary (Fig. 4). The pebbles consist of well-rounded quartzite clasts, less than 2 cm across.

Apart from *Teredo*-bored fossil wood, the Fossil Wood Member is poor in fossils. However, ammonites, echinoderms, and fossil wood are present in an *in situ* calcite concretionary layer, 25–30 cm thick, *c.* 10 m below the K–T boundary (Figs 3, 4).

The thinly interbedded sandstones and mudstones are interpreted as deposits of traction and fall-out processes associated with various stages of sedimentation from waning, low-density turbidity currents. Part of the mudstones may also have been deposited from suspension. The pebbly sandstone was deposited from sand- and pebble-rich turbidity currents. Deposition took place in a marine slope environment.

Ammonites

The ammonites collected at Annertuneq occur in loose concretions collected 50 m above the top of the conglomerate and *in situ* at 112 m above the conglomerate (10 m below the K–T boundary; Fig. 3; Kennedy *et al.* in press). All determinable specimens can be referred to what Birkelund (1965) called *S. (D.)* aff. *S. angmartussutensis*, referred to *Hoploscaphites* Nowak, 1911 by Kennedy *et al.* (in press). The relationship of the *H.* aff. *H. angmartussutensis* sequence to the dinoflagellate succession was refined by the examination of dinoflagellates from the matrix of additional identifiable ammonites. The specimen of *H.* aff. *H. angmartussutensis* collected loose from 50 m above the conglomerate at Annertuneq and those from 10 m below the K–T boundary, all yielded assemblages of the *Wodehouseia spinata* interval 10 of Nøhr-Hansen (1996) (Kennedy *et al.* in press). None of the material from the ammonites examined contain the dinoflagellates *Palynodinum grallator* or *Disphaerogena carposphaeropsis* which, according to Nøhr-Hansen & Dam (1997), represent the uppermost Maastrichtian in West Greenland. The affinities of the ammonite fauna do not indicate a link from West Greenland to the Western Interior of North America during the Maastrichtian; rather there are indications of an open marine link to the North Atlantic region.

Samples

Samples were collected at 10 cm intervals from 441.9 to 456.5 m above sea level and at 20 cm intervals from 427.2 to 441.6 m above sea level at Annertuneq (Figs 3, 4). All samples were analysed for their palynomorphs and magnetic susceptibility. Across the boundary, 20 samples were analysed for organic carbon isotopes and 30 samples for rare earth elements. All samples are stored at the Survey in Copenhagen, Denmark.

Palynology

The palynomorph assemblages place the K–T boundary at Annertuneq within a 10 cm interval between 451.9 and 452.0 m, just below a thin (5 cm) pebbly sandstone deposited from a turbidity current (Fig. 4; Nøhr-Hansen & Dam 1997). The late Maastrichtian assemblage is characterised by the presence of the dinoflagellate cysts *Laciniadinium arcticum*, *Isabelidinium majae*, *Palynodinium grallator*, *Disphaerogena carposphaeropsis*, and *Manumiella* spp. and the spores and pollen *Wodehouseia quadrispina*, *W. spinata*, *Aquilapollenites* aff. *A. spinulosus*, *Aquilapollenites* spp., *Striatocorpus* spp. and *Myrtipites scabratus* (Fig. 4). Three new species belonging to the genera *Striatocorpus* and *Aquilapollenites* have been recorded throughout the latest Maastrichtian deposits. One has affinities to the Paleocene species *Aquilapollenites spinulosus* and may be its latest Maastrichtian precursor. The earliest Danian

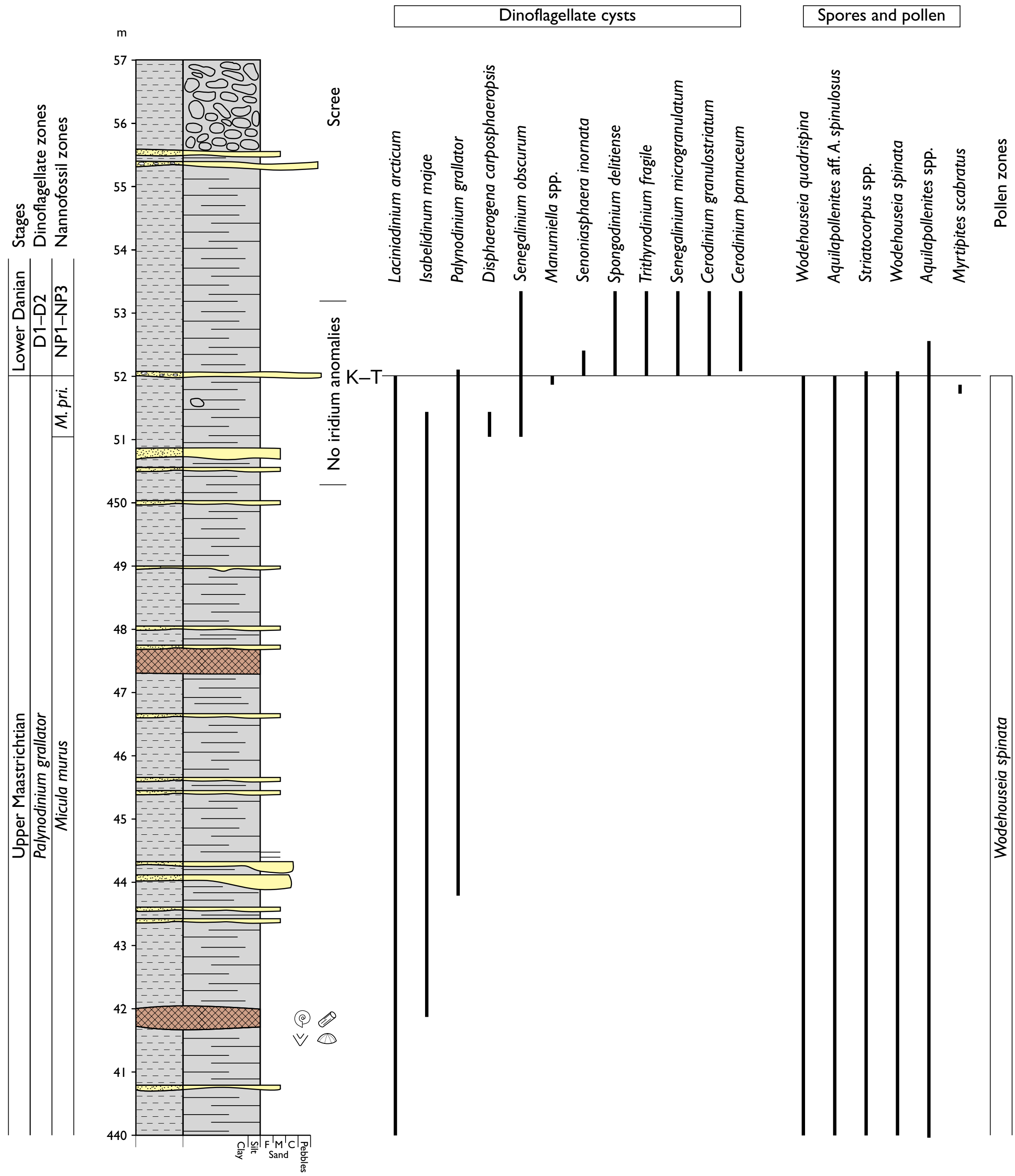

Fig. 4. Detailed sedimentological log and stratigraphic ranges of selected palynomorphs across the K–T boundary at Annertuneq. Modified from Nøhr-Hansen & Dam (1997). See Fig. 3 for legend.

assemblage is characterised by the first occurrence of the dinoflagellate cysts *Senoniasphaera inornata*, the abundance of *Spongodinium delitiense*, *Trithyrodinium fragile*, and *Senegalinium* spp., and by the disappearance of the pollen genera *Wodehouseia* and *Aquilapollenites* just above the boundary.

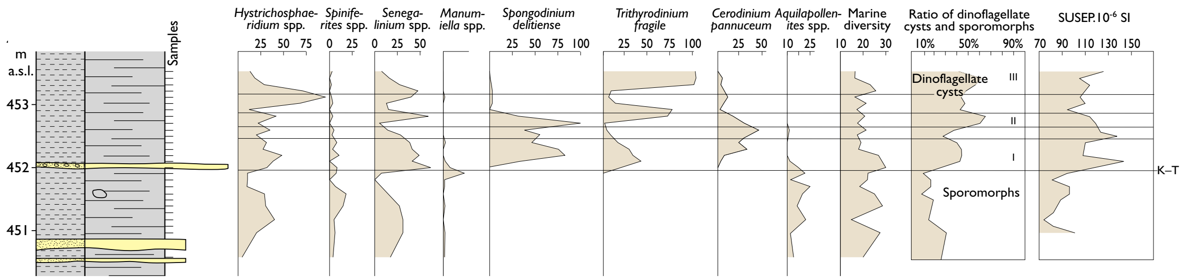

Fig. 5. Relative abundance (counted numbers) of selected palynomorphs, marine diversity (species richness), ratio of dinoflagellate cysts to sporomorphs (pollen and spores) and magnetic susceptiblity across the K–T boundary at Annertuneq. Modified from Nøhr-Hansen & Dam (1997). See Fig. 3 for legend.

Environmental interpretation

The composition of the palynomorph assemblages changes significantly across the boundary. Sporomorphs (spores and pollen) dominate the assemblage below the boundary (67–90%), whereas above the boundary the percentage of dinoflagellate cysts increases (28–65%; Fig. 5). The dominance of sporomorphs below the boundary is interpreted as the response to a regressive phase in the latest Cretaceous, whereas the observed increase in dinoflagellate cysts above suggests an earliest Danian transgressive phase (Nøhr-Hansen & Dam 1997). The transgressive phase was associated with an increase in supply of nutrients and increase in oceanic circulation or warming in the earliest Danian. This overall regressive-transgressive trend across the K–T boundary appears to be a world-wide event (e.g. Moshkovitz & Habib 1993; Elliot *et al.* 1994; Brinkhuis & Schiøler 1996).

The distinct fluctuations in the proportion of dinoflagellate cysts and sporomorphs in the lower Danian sediments are interpreted as reflecting three high-frequency transgressive-regressive cycles (Nøhr-Hansen & Dam 1997). The first transgressive phase (I, Fig. 5) began with a peak occurrence of *Senegalinium* species, suggesting a period of upwelling or flooding of major land areas that caused an increase in nutrient supply to the sea. As the transgression proceeded, a peak occurrence of *Trithyrodinium fragile* occurred that could mark the incoming of low- to mid-latitude species. The middle part of the first transgressive phase is characterised by a peak occurrence of *Spongodinium delitiense,* interpreted as indicative of oceanic conditions. In the second transgressive phase (II), the same three peak occurrences are recognised, but not in the same order. The third transgressive phase (III) is similar to the first phase, except that *S. delitiense* is missing. Within transgressive phases I and III, peaks in the marine diversity curve (at 452.1 m and 453.3 m) suggest two major flooding events.

The cyclic signals and the peak occurrences of selected dinoflagellate cyst species (Fig. 5) are not reflected in the sedimentology, but may reflect changes in sea level, palaeocurrents, or palaeoenvironment (Nøhr-Hansen & Dam 1997).

Magnetic susceptibility, rare earth analysis and carbon isotope stratigraphy

Magnetic susceptibilities were measured for all samples, using the method described by Hansen *et al.* (1993). Hansen *et al.* (1993, 1996) demonstrated that identical patterns in magnetic susceptibility versus stratigraphic depth can be recognised in Upper Cretaceous sedimentary successions separated by very large geographic distances.

The method was also applied to the West Greenland sample material and the results show characteristic shapes of the peaks for 500 000 and 400 000 years before the boundary (unpublished data), which seems to correlate with the shapes from the numerous boundary sections analysed by Hansen *et al.* (1993, 1996). The shape of the peak for 300 000 years before the boundary may perhaps be recognised, whereas it has not been possible to identify the peaks for 200 000 and 100 000 years before the boundary in the present material, suggesting that the deposits representing the last 200 000 years of the Maastrichtian stage may include minor hiati.

Thirty samples taken with 10 cm spacing across the K–T boundary were analysed for rare earth elements.

Iridium values range from 0.025 to 0.290 ppb, but no anomalies were recognised to support the hypothesis of a major meteorite impact with release of iridium on the earth. However, as the samples were taken with 10 cm spacing and without knowing the precise location of the biostratigraphic position of the K–T boundary during sampling, a possible iridium layer may have been missed and the analyses are thus regarded as inconclusive.

Studies of the K–T boundary sections at several localities have also shown a negative change in carbon-isotopic composition across the boundary (e.g. Hansen *et al.* 1996). Unpublished carbon-isotopic data from the K–T boundary at Annertuneq shows no such change in $\delta^{13}C$ values.

Selected samples analysed for calcareous nannofossils were all barren.

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Authors' addresses:

G.D., H.N.-H., *Geological Survey of Denmark and Greenland, Thoravej 8, DK-2400 Copenhagen NV, Denmark.*

W.J.K., *Geological Collections, Oxford University Museum of Natural History, Oxford OX1 3PW, UK.*