Acta Geologica Polonica, Vol. 48 (1998), No. 3, pp. 247-263

The occurrence of four interglacials younger than the Sanian 2 (Elsterian 2) Glaciation in the Pleistocene of Europe

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ABSTRACT:

LINDNER, L. & MARCINIAK, B. 1998. The occurrence of four interglacials younger than the Sanian 2 (Elsterian 2) Glaciation in the Pleistocene of Europe. *Acta Geologica Polonica,* **48** (3), 247-263. Warszawa.

Documented examples indicate the occurrence of four interglacials younger than the Sanian 2 (= Elsterian 2, Okanian) Glaciation in the Pleistocene of Europe. These are, from the oldest, the Mazovian (= Holsteinian), Zbójnian (= Reinsdorf), Lubavian (= Schöningen?) and Eemian interglacials. These interglacials are characterised by different vegetation successions, and occasionally marine deposits resulting from the global sea level rise are present in the region surrounding the English Channel, North Sea and Baltic Sea. Palaeosol horizons within loess sections in the Ukraine also correspond to these interglacials.

INTRODUCTION

Marine deposits are stratigraphically the most important in the geology of pre-Quaternary formations, as they are characterised by a wide lateral distribution, as well as by relatively well preserved faunal remains and largely continuous sedimentation. These remains are represented both by index species and by faunal assemblages that characterize particular stratigraphic periods or zones (GIGNOUX 1950).

In the Quaternary, where the main stratigraphic units are attributed to the rhythm of global climatic changes (*see* RÓŻYCKI 1980, LINDNER 1992), marine deposits also play an important role (*see* FLINT 1947, WOLDSTEDT 1969, CHALINE 1972, WEST 1977, BOWEN 1978). However, marine deposits of Quaternary age seldom occur in continental sections, mainly because of the more or less similar extent of older and recent seas in the Quaternary. Such deposits are most typical for interglacial periods, during which the disappearance of an ice-sheet was of a longer duration, and the released water caused a rise of global sea level (*see* NILSSON 1983, LINDNER 1992, MOJSKI 1993, EHLERS 1996). Marine transgressions on low-lying land areas took place at that time as in the Holocene, which is considered to be a model of interglacial conditions (STARKEL 1990).

Until quite recently, only two well documented marine transgressions were acknowledged in Europe (excluding the Mediterranean area) in the Middle and Younger Pleistocene (*see* LINDNER 1988, 1991, 1992). Traces of an older transgression were discovered for the first time as interglacial marine deposits in the Lower Elbe drainage system area, particularly in the area of Schleswig – Holstein, from which the term Holsteinian Interglacial (Sea) is derived (*see* GOTTSCHE 1897, GRAHLE 1936, WOLDSTEDT 1969, WOLDSTEDT & DUPHORN 1974, BEHRE & *al.* 1979). Marine deposits of a younger transgression were discovered for the first time in the Eem river drainage system at the Dutch coast of the North Sea (*see* Madsen & *al.* 1908, ZAGWIJN 1961, JELGERSMA & *al.* 1979), which gave the name to the Eemian Interglacial.

For many years both interglacials (Holsteinian = Mazovian = Likhvin and Eemian = Mikulinian) were considered to be not only the most typical but also the only ones in the post-Elsterian 2 (= post-Sanian 2, = post-Okanian) part of the Pleistocene (*see* WOLDSTEDT 1969, CHALINE 1972, BOWEN 1978). This opinion was questioned by discovery of the two new interglacial units, an older termed the Dömnitz-Warmzeit and a younger one termed the Rügen-Warmzeit (?) in the Pleistocene of north-eastern Germany (*cf.* CEPEK 1967, CEPEK & ERD 1982, ERD 1973, 1978).

An important argument supporting this discovery was the determination in marine deposits from this part of the Pleistocene (*see* SHACKLETON & OPDYKE 1973) traces of four climate warmings designated as **O**xygen **I**sotope **S**tage (OIS) 11, dated at 440-367 ka; OIS 9, dated at 347-297 ka; OIS 7, dated at 251-195 ka; and OIS 5e, dated at 128-118 ka. The oldest of these stages (OIS 11) was correlated by the majority of workers with the Holsteinian Interglacial, and the

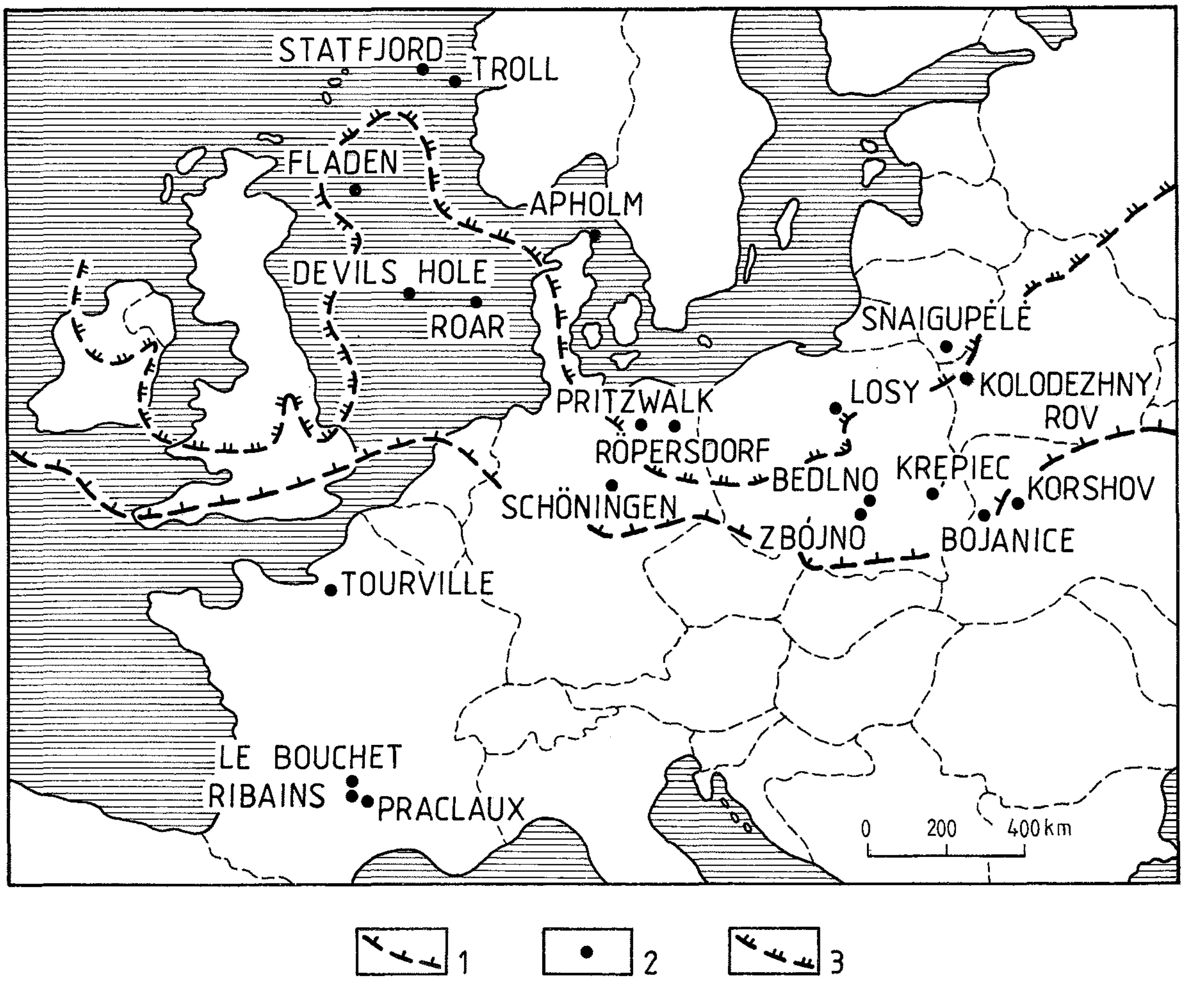

Fig. 1. Location of some important post-Sanian 2 (= post-Elsterian 2) interglacial sites in Europe
1 – maximum extent of the ice sheet during the Sanian 2 (Elsterian 2) Glaciation; 2 – cited interglacial sites; 3 – maximum extent of the ice sheet during the Vistulian (= Weichselian = Valdaynian) Glaciation

youngest one (OIS 5e) with the Eemian Interglacial (*see* BOWEN & *al.* 1986). The remaining stages (OIS 9 and 7) are correlated with the Dömnitz and Rügen interglacials respectively (*see* WIEGANK 1982).

Taking into account the above-mentioned facts, this paper presents further evidence to support this concept. The paper includes the results of investigations from 21 sites with deposits younger than the Sanian 2 Glaciation (= Elsterian 2, = Okanian) and older than the Vistulian Glaciation (= Weichselian, = Valdaynian) from Europe (Text-fig. 1). The results of investigations from four sites with interglacial lake deposits (Krępiec, Zbójno, Losy and Bedlno) from Poland (Text-figs. 2-6) with palynological data from most of them (Text-fig. 6), as well as two loess sites containing interglacial paleosols (Bojanice and Korshov) from the north-western Ukraine (Text-fig. 7) are presented in more detail. A tentative chronostratigraphic scheme of the four post-Sanian 2 (= post-Elsterian, = post-Okanian) lithostratigraphic units of Europe is presented on the basis of all the described sites (Text-fig. 8).

INTERGLACIAL SITES WITH LAKE DEPOSITS

Four sites in Poland with lake deposits (Krępiec, Zbójno, Losy and Bedlno) of four interglacials (Mazovian, Zbójnian, Lubavian and Eemian) with different floral successions are presented.

Krępiec

The geomorphological and geological setting of lake deposits at Krępiec (Text-figs 1 and 2), located east of Lublin in the northern part of the Lublin Upland, was described by HARASIMIUK & HENKIEL (1981). The deposits were assigned to the Mazovian Interglacial on the basis of palynological (JANCZYK-KOPIKOWA 1981) and diatom data (MARCINIAK 1980, 1983).

According to the geological data (Text-fig. 2) the deposits in borehole 16 are over 20 metres thick and occur as a series of silt and diatomite with a peat intercalation (bed 6 on Text-fig. 2) as well as peat and gyttja on top (bed 7). These deposits rest on fluvial sand and gravel, 4 to 8 metres thick (bed 5) and further down on till, up to 10 metres thick (bed 4). Thermoluminescence (TL)-dates of 511 ka and 502 ka allow correlation of the till with the Sanian 2 Glaciation *sensu* LINDNER (1988, 1992) or with the Wilgian Glaciation *sensu* MOJSKI (1993). Older Pleistocene deposits in this section are ice-dammed silt, 4-6 metres thick (bed 3), from the period of the ice-sheet advance of this glaciation and pre-Pleistocene (pre-Glacial) debris, clay and waste-clay (bed 2), covering the Cretaceous marls (bed

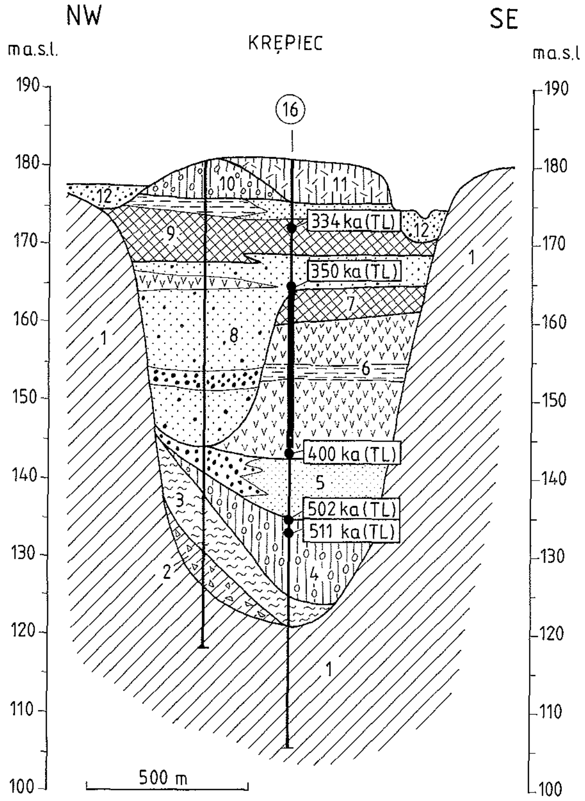

Fig. 2. Geological cross-section through the Mazovian (= Holsteinian) Interglacial deposits at Krępiec near Lublin, *after* HARASIMIUK & HENKIEL (1981), with TL-dates *after* HARASIMIUK & *al.* (1988), with age interpretation of the authors; Cretaceous: 1 – marl; pre-Pleistocene: 2 – rock debris, clay and waste clay; Pleistocene: Sanian 2 (?) Glaciation: 3 – ice-dammed silt; 4 – till; Mazovian Interglacial: 5 – fluvial and slope sand and gravel; 6 – silt and diatomite; 7 – peat and gyttja; Liviecian (?) Glaciation and Zbójnian Interglacial: 8 – fluvial sand and gravel with diatomite (silt?) intercalation; 9 – humic sand with silt and peat intercalations and silt and sand in uppermost part; Odranian Glaciation: 10 – till; Vistulian Glaciation: 11 – loess; Holocene: 12 – fluvial sand and gravel; part of the section 16 with palynological (*see* JANCZYK-KOPIKOWA 1981) and diatom data (*see* MARCINIAK 1980) is marked with bold line

1) that are occasionally exposed in the investigated area.

Lake deposits of the Mazovian Interglacial have been TL-dated in their lower part at about 400 ka (Text-fig. 2). Palynological analysis (JANCZYK-KOPIKOWA 1981, 1991) shows that accumulation took place during four periods (M I – M IV) of vegetation development, with the climatic optimum in period M III being marked by the presence of *Vitis* and the predominance of *Carpinus* and *Abies* (Text-fig. 6A). According to diatom analysis (MARCINIAK 1980, 1983), the lower part of the deposits is characterised by the predominance of nannoplanktonic diatoms (*Stephanodiscus* and *Cyclotella*). The middle part, in turn, shows an increase in the number of littoral and rheophilous species, while forms pointing to a further shallowing and overgrowing of the lake by macrophytes dominate in the upper part.

By the end of the Mazovian Interglacial these deposits were cut by a river, creating a channel filled with sand and gravel with a diatomite intercalation, over 20 m thick in total (bed 8 on Text-fig. 2). TL-datings from their upper part reveal about 350 ka, pointing to their accumulation during the Liviecian Glaciation and/or Zbójnian Interglacial (Lindner 1992). The overlying humic sand with silt and peat intercalations, reaching a total of 10 m (bed 9) and TL-dated at about 334 ka, as well as the silt and sand on top, should correspond to the Zbójnian Interglacial.

The overlying till, about 6 m thick (bed 10 on Text-fig. 2) has been interpreted as a remnant of the Scandinavian ice-sheet till covering the area during the Odranian = Drenthian = Dnieperian Glaciation (LINDNER & *al.* 1991). The overlying loess, up to 7 m thick (bed 11), is most probably the so-called younger loess, (MARUSZCZAK, 1996) of the Vistulian = Weichselian Glaciation. The youngest Quaternary deposit in the area is the Holocene fluvial sand and gravel, 8 m thick (bed 12 on Text-fig. 2).

Zbójno

The geomorphological and geological setting as well as the palynological data of the deposits from the Zbójno site (Text-figs 1 and 3), north-east of Przedbórz in the western part of the Holy Cross Mts. region, discovered by

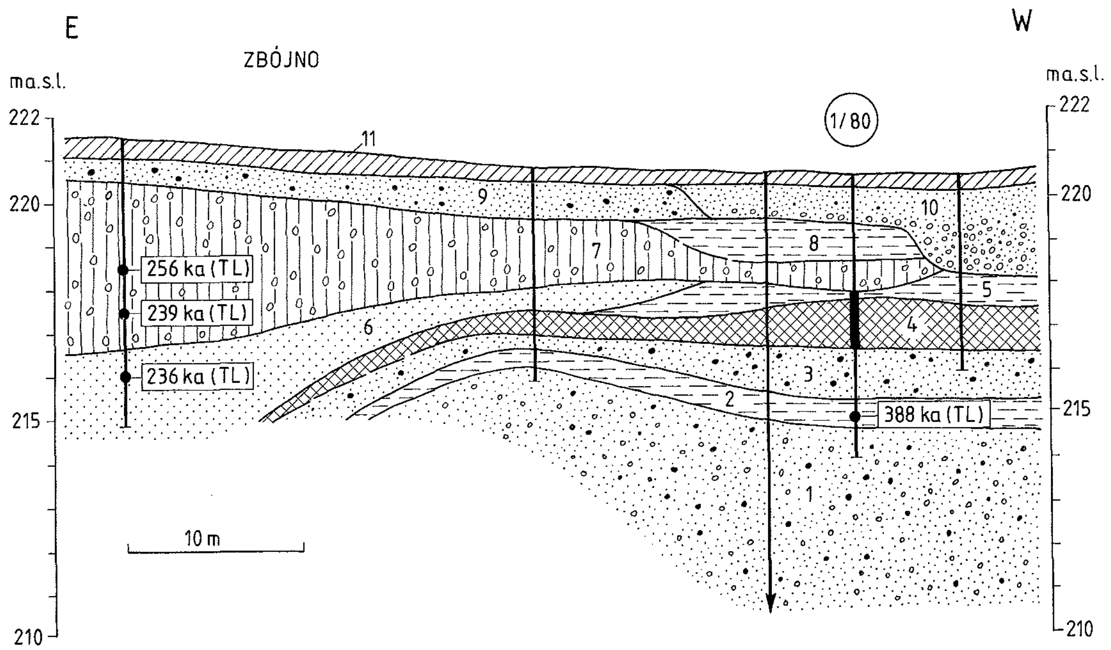

Fig. 3. Geological cross-section through the Zbójnian (= Reinsdorf) Interglacial deposits at Zbójno near Przedbórz, with TL datings; Mazovian Interglacial: 1 – fluvial sand with gravel; Liviecian (?) Glaciation: 2 – ice dammed silt; Zbójnian Interglacial: 3 – fluvial sand with gravel; 4 – peat; 5 – peaty silt; Odranian Glaciation: 6 – glaciofluvial sand; 7 – till; 8 – ice-dammed silt; 9 – glaciofluvial sand with gravel; Holocene: 10 – sand with gravel and lag deposit in its lowermost part (fluvial); 11 – recent soil; part of the section 1/80 with palynological data (*see* LINDNER & BRYKCZYŃSKA 1980) is marked with bold line

JURKIEWICZ (1962, 1968), were described by LINDNER & BRYKCZYŃSKA (1980).

The geological data reveal that the deposits rest on sands with gravel (bed 1 on Text-fig. 3) and silts (bed 2). They reach up to 3 m thick and consist of fluvial sand with gravel (bed 3 on Text-fig. 3), peat (bed 4) as well as peaty silt (bed 5) on top. The ice-dammed silt (bed 2) below was TL-dated at about 388 ka and derives from the Liviecian Glaciation or the terminal part of Mazovian Interglacial. Fluvial sand with gravel (bed 1) is probably of the Mazovian Interglacial age.

Palynological analysis of the peat (bed 4 on Text-fig. 3) from borehole 1/80 reveals four periods of floral development (Zb I – Zb IV) representing a succession different from that of the preceding Mazovian Interglacial. The Zb I period (Text-fig. 6B) is characterised by pine forests with a small admixture of *Betula, Quercus* and *Corylus*. During the climatic optimum, along with the decrease of pine, a rapid development of *Tilia* took place, reaching 48% (Zb IIa), and – following a decrease of *Tilia* to 20% – an increase of *Alnus, Carpinus, Picea* and *Corylus* with the presence of *Quercus* (Zb IIb). The post-optimum period of the interglacial is characterized at first (Zb III) by domination of coniferous trees, followed by a further increase of pine content (Zb IV). Comparison of the position of these deposits with the lake series of the Mazovian Interglacial preserved near Sewerynów, east of Przedbórz (*see* JURKIEWICZOWA & MAMAKOWA 1960), shows that these deposits are younger than this interglacial (*see* LINDNER 1982, MARKS & *al.* 1995) and belong to the Zbójnian Interglacial.

In the site under discussion, lake and marsh deposits of the Zbójnian Interglacial were eroded at the top by glacial meltwater during the advance of the subsequent ice-sheet. This is shown by an up to 2 m thick sand (bed 6 on Text-fig. 3), TL-dated at about 236 ka. The sand, as well as older interglacial deposits are covered by till, from 0.5 to 4.0 m thick (layer 7), TL-dated at 239 and 256 ka. The geological setting of the above-mentioned glacial deposits, in a larger area (see LINDNER 1982), and their TL dates allows them to be correlated with the older Middle Polish Glaciation, determined as the Odranian = Drenthian = Dnieperian Glaciation (LINDNER 1988; LINDNER & *al.* 1991; LINDNER & MARKS 1994). The accumulation of ice-dammed silt preserved above (bed 8 on Text-fig. 3) and sand with gravel covering it (bed 9) can also be attributed to this glaciation. The youngest Quaternary is represented by Holocene sand with gravel and lag deposits in its lowermost part (bed 10 on Text-fig. 3) as well as recent soil (bed 11).

Losy

The geomorphological and geological setting of the lake deposits from the Losy site (Text-figs 1 and 4), near Lubawa on the western slope of the Lubawa Elevation in the western part of the Masurian Lakeland, as well as the palynological data, were investigated by KRUPIŃSKI & MARKS (1985, 1986).

The collected data reveal that these deposits, discovered by JENTSCH & MICHAEL (1902), rest on glaciofluvial sand (bed 1 on Text-fig. 4), TL-dated at 273 ka, which probably represents the terminal part of the Odranian Glaciation. They are developed as two beds of lake marl visible at the bottom and on the slopes of the exposure. The older layer is a grey lake marl (bed 2), 2 to 5 m thick, while the younger one is a yellow-orange lake marl (bed 3) up to 10 m thick.

Palynological analysis of both the beds of lake marl penetrated in boreholes L2 and L3 (Text-fig. 4) shows that the preserved plant remains document four (Lu I – Lu IV) periods of interglacial vegetation development. In the Lu I period (Text-fig. 6C), birch scrubs or forests with *Pinus* and *Larix* dominated, while in the Lu II period these plants were accompanied by trees with higher thermal requirements (*Picea, Quercus, Ulmus*) as well as *Typha latifolia*. The Lu III period was characterized at first by mixed forests, followed by oak-birch forests with occasional *Tilia*. Period Lu IV, besides a wide occurrence of *Quercus*, was characterized by the appearance of *Corylus*, together with *Ulmus, Alnus*, and *Tilia*.

According to KRUPIŃSKI & MARKS (1985, 1986) the much later appearance of *Corylus* pollen compared to that of *Tilia*, and a large admixture of *Larix* and *Ulmus*, distinguishe this succession from that typical of the Eemian, as well as from those characterizing other interglacials known in Poland. This distinctive pollen diagram allows the recognition of a new interglacial – the Lubavian Interglacial. The deposits from this site also reveal diatom assemblages (TUSZYŃSKA-GRUZA 1984 and B. MARCINIAK,

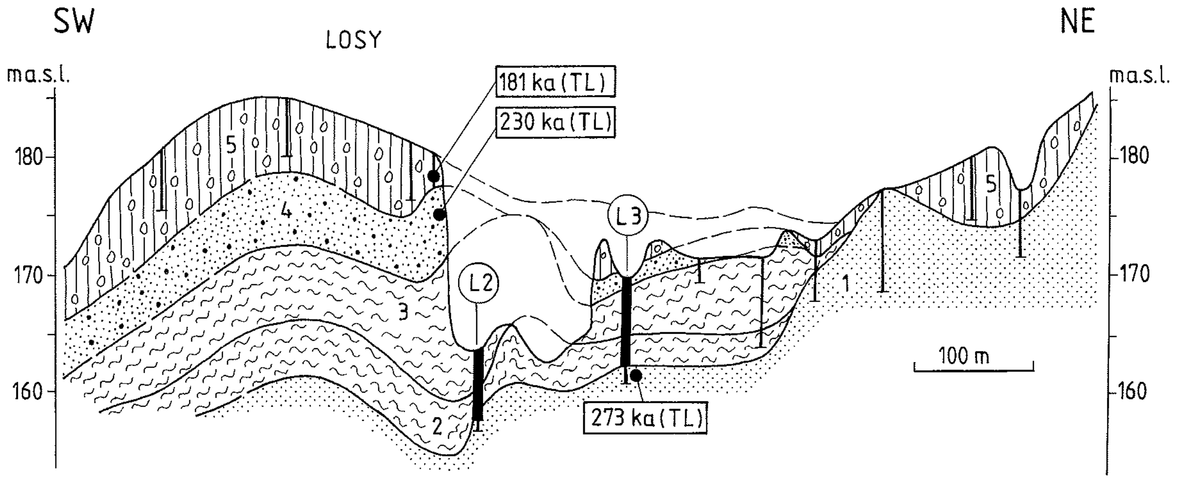

Fig. 4. Geological cross-section through the Lubavian (= Lublinian, Schöningen ?) Interglacial deposits at Losy near Lubawa with TL datings, *after* KRUPIŃSKI & MARKS (1986, *modified*); Odranian Glaciation: 1 – sand; Lubavian Interglacial: 2 – grey lake marl; 3 – yellow-orange lake marl; Wartanian Glaciation: 4 – sand with gravel; 5 – till; parts of the sections L2 and L3 with palynological data (*see* KRUPIŃSKI & MARKS 1986) are marked with bold line

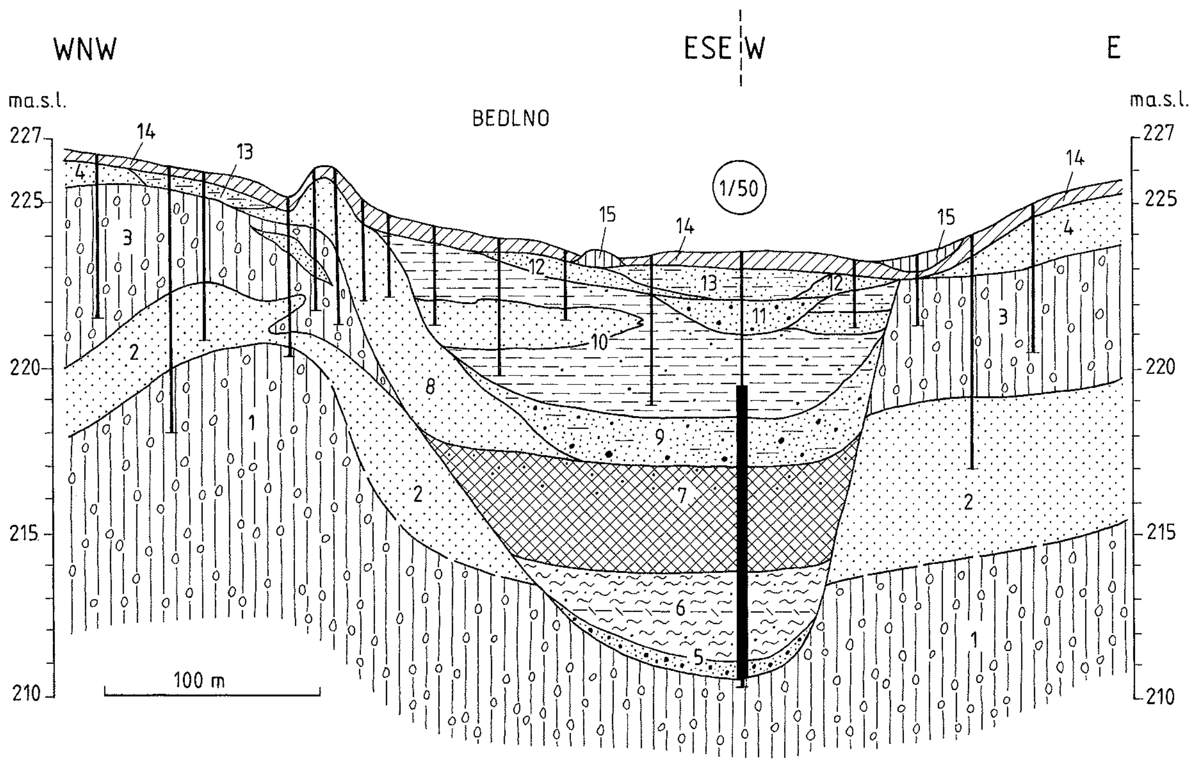

Fig. 5. Geological cross-section through the Eemian Interglacial deposits at Bedlno near Końskie (*after* PRAŻAK 1975 and LINDNER *in*: CIEŚLA & LINDNER 1990, 1991); Odranian (Wartanian?) Glaciation: 1 – older phase till; 2 – interphase fluvial (?) sand; 3 – younger phase till; 4 – glaciofluvial sand with fine gravel; 5 – glaciofluvial gravel with sand; Eemian Interglacial: 6 – sandy gyttja with bituminous shale intercalation; 7 – peat with gravel in its uppermost part; Vistulian Glaciation: 8 – deluvial and eolian (?) sand; 9 – silty sand with fine gravel; fluvial; 10 – silt with gravel and sand intercalations; 11 – fluvial sand with gravel; Holocene: 12 – deluvial sand; 13 – silty sand with gravel; 14 – recent soil; 15 – bank; part of the section 1/50 with palynological data (*see* ŚRODOŃ & GOŁĄBOWA 1956) is marked with bold line

unpublished data) different from those known from the lake deposits of the Eemian Interglacial (*see* MARCINIAK & KOWALSKI 1978).

The Lubavian Interglacial deposits at Losy are covered by sand with gravel (bed 4 of Text-fig. 4), the accumulation of which caused erosional shearing of the upper part of the lake chalk. The sand was TL-dated at 230 ka while the covering till (bed 5) at about 181 ka. These dates as well as the geomorphological – geological setting of the surrounding area allow the sand with gravel and the overlying till to be linked to the Wartanian Glaciation, while the older deposits of the Lubavian Interglacial represent the time span separating this glaciation from the Odranian Glaciation (KRUPIŃSKI & MARKS 1985, 1986).

Bedlno

The geomorphological and geological setting of the lake-marsh deposits from the Bedlno site (Text-figs 1 and 5), west of Końskie in the north-western part of the Holy Cross Mts., was investigated in detail by PRAŻAK (1975) and LINDNER (*in*: CIEŚLA & LINDNER 1990, 1991). The palaeobotanical picture of these deposits, discovered by PASSENDORFER (1931), was presented by ŚRODOŃ & GOŁĄBOWA (1956).

All the obtained data show that the lake-marsh deposits of this site, noted in section 1/50 (Text-fig. 5), are represented by sandy gyttja with a bituminous clay intercalation (bed 6 on Text-fig. 5) as well as by overlying peat with gravel at the top (bed 7). They are over 5 m thick and infill a depression, in older glacial and fluvioglacial deposits.

Palynological and macrofloral analysis of the deposits has shown four periods (E I – E IV) of development of an interglacial flora. Period E I (Text-fig. 6D) is characterised by the presence of pine-birch forests with traces of trees of higher thermal requirements (*Quercus, Ulmus, Tilia, Carpinus, Corylus, Alnus*). Period E II represents forests of the climatic optimum with the predominance of *Quercus, Corylus, Tilia* and the first traces of *Picea*. In period E III *Picea* and *Abies* dominate, with an admixture of *Alnus* as well as *Pinus* and *Betula*, while period E IV is characterised by pine-birch forests with *Picea* and *Larix*. According to ŚRODOŃ & GOŁĄBOWA (1956) the deposits from Bedlno comprise, apart

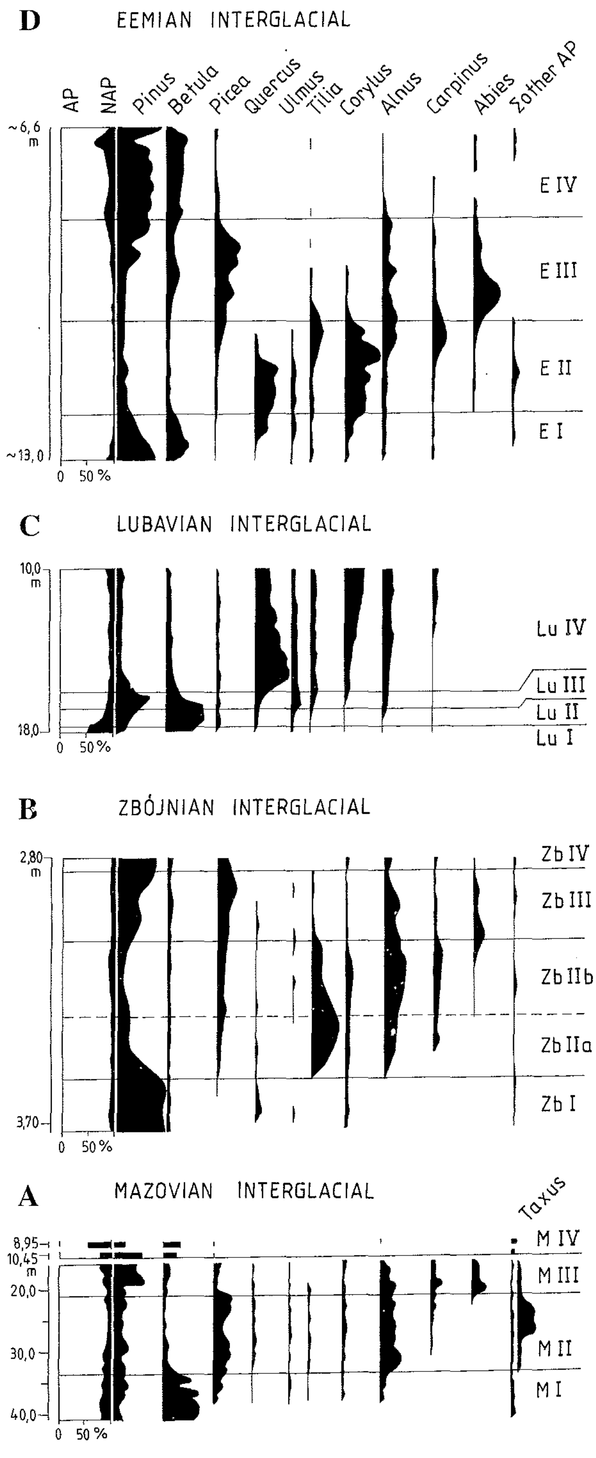

Fig. 6. Synthetic diagrams of four post-Sanian 2 (= post-Elsterian 2) interglacial pollen successions in Poland: Mazovian Interglacial (JANCZYK-KOPIKOWA 1981), Zbójnian Interglacial (LINDNER & BRYKCZYŃSKA 1980), Lubavian Interglacial (KRUPIŃSKI & MARKS 1986) and Eemian Interglacial (ŚRODOŃ & GOŁĄBOWA 1956); compiled by JANCZYK-KOPIKOWA (1991) and the authors

from the Eemian Interglacial (E I – E IV), tundra plants from the terminal part of the older glaciation as well as tundra vegetation from the Vistulian Glaciation.

Deposits older than the Eemian Interglacial are till (bed 1 on Text-fig. 5) of the older phase of the Odranian (Wartanian ?), fluvial sand (bed 2) of the younger interphase, till (bed 3) of the younger phase of this glaciation and glaciofluvial sand with gravel (bed 4). Immediately below the Eemian deposits there is glaciofluvial gravel with sand (bed 5) resulting from erosion during the Odranian (Wartanian?) Glaciation. From the Vistulian Glaciation there is sand (bed 8 on Text-fig. 5) of deluvial and eolian (?) origin as well as fluvial sand with gravel (bed 9), valley silt with gravel and sand intercalations (bed 10) as well as fluvial sand with gravel (bed 11). The Holocene is represented by deluvial sand (bed 12) and silty sand with gravel (bed 13) as well as by recent soil (bed 14) and a bank (bed 15).

SITES WITH INTERGLACIAL PALEOSOLS

Four paleosol horizons are preserved in both of the loess sections (Bojanice and Korshov) presented below, giving the possibility of inter-correlation in spite of frequent cutting by ice-wedge pseudomorphoses. In the first section (Bojanice), the paleosols occur above till of the Okanian Glaciation, unequivocally correlated in central and western Europe with the Elsterian 2 = Sanian 2 Glaciation (LINDNER 1988, LINDNER & MARKS 1994, EHLERS & *al.* 1995).

Bojanice

The loess section at Bojanice (Text-figs 1 and 7), situated west of Sokal in the western part of the Volhynia Upland (NW Ukraine), has been known for about twenty years (*see* BOGUTSKY & *al.* 1980, BOGUCKI & RACINOWSKI 1994, BOGUCKI & *al.* 1994, 1995; MARUSZCZAK 1994, 1996; NAWROCKI & *al.* 1996; LINDNER & *al.* 1998).

The section (Text-fig. 7) comprises Pleistocene deposits up to 25 m thick and exposed over several hundred metres. These deposits rest on Cretaceous marls and comprise two loess horizons, each 1-3 metres thick. The older loess probably belongs to the Donian (?) = Elsterian 1 (?) Glaciation, while the younger – TL-dated at 496 ka, together with the overlying till – TL-dated at 473 ka and 530 ka – corresponds to the Okanian (= Sanian 2) Glaciation. The loesses are separated by a layer of sand with lag deposits in its lower part, TL-dated at 523 ka and probably derived from the Ferdynandovian (?) = Voigtstedt (?) = Lubny (?).

A forest paleosol of the Sokal horizon (Pl. 1, Fig. 4) correlated with the Mazovian = Holsteinian = Likhvinian Interglacial (MARUSZCZAK 1996, NAWROCKI & *al.* 1996, LINDNER & *al.* 1998), occurs above an Okanian Glaciation till. A thin chernozem, TL-dated at 342 ka, occurs in the uppermost part of the paleosol. It is covered by a thin loess correlated with the Liviecian Glaciation in Poland and with the accumulation of the Orel Loess in Central Ukraine (*see* GOZHIK & *al.* 1995). A forest paleosol is developed on this loess, the parent rock of which was TL-dated at 326 ka. The paleosol corresponds to the Luck horizon (Pl. 1, Figs 3-4), and is correlated with the Dömnitz Interglacial in Germany (GOZHIK & *al.* 1995) and with the Zbójnian Interglacial in Poland (MARUSZCZAK 1996, NAWROCKI & *al.* 1996, LINDNER & *al.* 1998). Two loess horizons of the Middle Polish Glaciations as well as another forest paleosol horizon (complex) separating the loesses (Text-fig. 7) occur above the paleosol. The older loess – TL-dated at 318 ka and 360 ka, as well as at 277 ka and 280 ka – represents the Odranian = Dnieperian = Drenthian Glaciation, while the younger (with chernozem in its lowermost part) – TL-dated at179 ka and 167 ka – corresponds to the Wartanian Glaciation. The loesses, up to several metres thick, are separated by a paleosol complex of the Korshov horizon (Pl. 1, Fig. 2), the parent rock of which was TL-dated at 243 ka and 238 ka as well as at 180 ka, and which was connected with the Lubavian = Lublinian Interglacial. A forest paleosol of the Horokhov horizon (Pl. 1, Fig. 1, 2) is developed on the younger loess, which is correlated with the Eemian Interglacial (MARUSZCZAK 1996, NAWROCKI & *al.* 1996, LINDNER & *al.* 1998). The paleosol is covered by loess of the Vistulian = Weichselian = Valdaynian Glaciation, with a chernozem horizon in its lower part, as well as with initial tundra paleosols in the upper part of the section. This loess, 6-8 m thick, was TL-dated at about 120 ka to about 22 ka (Text-fig. 7).

Korshov

The Korshov loess section, south of Luck in the central part of the Volhynia Upland (NW

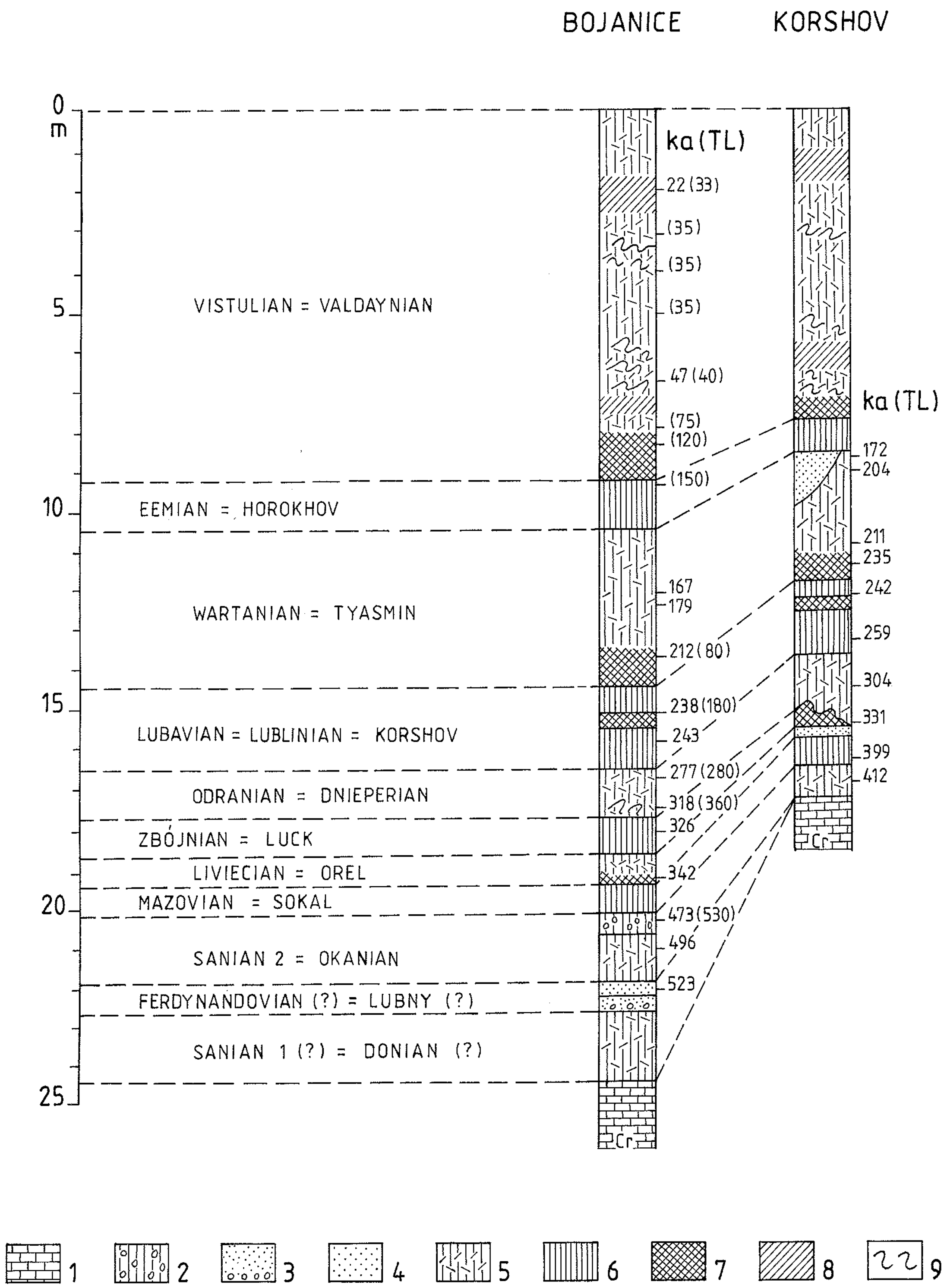

Fig. 7. Stratigraphical position and TL datings of the loess section at Bojanice and Korshov near Lvov, *after* LINDNER & *al.* (1998) 1 – Cretaceous marl; Pleistocene: 2 – till; 3 – sand and gravel with lag deposit in the lowermost part; 4 – sand; 5 – loess and loess--like deposit; 6 – forest paleosoil illuvial horizon (B); 7 – chernozem; 8 – tundra soil; 9 – solifluction deformations; numbers along the section indicate Tl-age in ka *after* BUTRYM (BOGUCKI & *al.* 1995, SHELKOPLAYS & *al.* 1985, in parentheses *after* SHELKOPLYAS (SHELKOPLYAS & *al.* 1985, SHELKOPLYAS & KHRISTOFOROVA 1987).

Ukraine), occurs beyond the extent of the Scandinavian glaciations (Text-fig. 1 and 7). It has been known for about 20 years (BOGUTSKY & *al.* 1980, MARUSZCZAK 1994, RACINOWSKI & BOGUCKI 1995, LINDNER & *al.* 1998).

The section comprises loesses resting on Cretaceous marls and exposed over several hundred metres, together with intercalated forest paleosols (Text-fig. 7). The accumulation of the oldest loess, over 1 m thick and TL-dated at 412 ka, is correlated with extraglacial conditions of the Sanian 2 = Okanian Glaciation. Recently discovered fragments of forest paleosol of the Sokal horizon occurring above have been correlated with the Mazovian = Holsteinian = Likhvinian Interglacial. The upper (Text-fig. 8) part of the paleosol contains a thin layer of sand (from the Liviecian? Glaciation) as well as remains of a forest paleosol of the Luck horizon occurring above, correlated with the Zbójnian Interglacial and dislocated along the slope under periglacial conditions.

Above the paleosol there are two loess horizons of the Middle Polish Glaciations, which are separated by an analogous horizon (complex) of forest paleosol to that in the previous section. The older loess – TL-dated at 331 ka and 304 ka – corresponds to the Odranian = Dnieperian = Drenthian Glaciation. The younger loess – TL-dated at 211 ka, as well as 204 ka and 172 ka – and sand occasionally preserved in its uppermost part, corresponds to the Wartanian Glaciation and to the accumulation event of the Tyasmin loess in central Ukraine (GOZHIK & *al.* 1995). The forest paleosol (complex) of the Korshov horizon (Pl. 1, Figs 5-6) separating the loesses, as in the case of the Bojanice section was correlated with the Lubavian = Lublinian Interglacial. A forest paleosol of the Horokhov horizon (Pl. 1, Fig. 5), usually correlated with the Eemian = Mikulinian Interglacial, overlies the younger of the two loesses. The upper loess in this section is 6-8 m thick and, as in the previous section, contains chernozem in its lower part, and traces of initial tundra soils and periglacial deformations towards the top.

TENTATIVE CORRELATION

The studies of CEPEK (1967) and ERD (1973, 1978) cited in the first part of this paper regarding the identification of four interglacials younger than the Elsterian 2 Glaciation in Germany, as well as those of JERSAK (1973) and MAKOWSKA (1977) regarding a possible interglacial within the Middle Polish Glaciation in Poland, inclined RÓŻYCKI (1978, 1980) as well as LINDNER (1978, 1980) to divide the Middle Polish Glaciation into two separate glaciations (Odranian, Wartanian) with the Lublinian Interglacial in between. This division, as well as the investigation of organic deposits from Zbójno (LINDNER & BRYKCZYŃSKA 1980) older than this glaciation and younger than the Mazovian Interglacial, as well as a later study of organic deposits from Losy near Lubawa (KRUPIŃSKI & MARKS 1985, 1986), of different age from the Eemian Interglacial, have been the basis of distinguishing four interglacials in Poland as well: Mazovian, Zbójnian, Lubavian = Lublinian and Eemian, correlated with the Oxygen Isotope Stages 11, 9, 7 and 5e of deep-sea deposits (LINDNER 1984, 1988).

This interpretation of the stratigraphy of the post-Sanian 2 (= post-Elsterian 2) part of the Pleistocene, in which the above-mentioned interglacials are separated by the Liviecian, Odranian and Wartanian glaciations, has gained wide acceptance (*i.e.* BARANIECKA 1990, SŁOWAŃSKA & MAKOWSKA 1991, KRZYWICKI & LISICKI 1993, LISICKI 1996). An additional strong argument in support of this interpretation is the occurrence of four forest paleosols above the till of the Sanian 2 (= Okanian) Glaciation intercalated with loesses, which documents four interglacial periods younger than this glaciation in the Bojanice section in the Volhynia Upland (BOGUTSKY & *al.* 1990; MARUSZCZAK 1994, 1996; NAWROCKI & *al.* 1996; LINDNER & *al.* 1998).

The stratigraphy presented here is a basis for correlation of the four last interglacials in the post-Sanian 2 (= post-Elsterian 2, = post-Okanian, = post-Anglian) part of the Pleistocene of Europe (Text-fig. 8).

Mazovian (Holsteinian, Oxygen Isotope Stage 11) Interglacial

The first (oldest) of these interglacials, distinguished in Poland as the Mazovian Interglacial (Text-fig. 2), is correlated with the Holsteinian Interglacial in Europe, both in areas within the range of Scandinavian glaciations (*i.e.* Pritzwalk, Schöningen, Devils Hole and Fladen sections on

Text-fig. 1), as well as in extraglacial areas (*i.e.* Praclaux section on Text-figs 1 and 8). Deposits of the Swanscombe unit in the British Isles, correlated with the OIS 11 (*see* BOWEN & *al.* 1989), can also be equated with this stratigraphical position. In the eastern part of the Baltic Sea basin the equivalents of this climatic warming are marine and continental deposits of the Likhvinian s.s. Interglacial = Butenai (ZUBAKOV & BORZENKOVA 1990). In loesses of the NW Ukraine (Bojanice and Korshov sections) this interglacial corresponds to the period of development of interglacial forest paleosol of the Sokal horizon (Text-fig. 7), while in the North Sea area it most probably equates with the Devils Hole Interglacial, correlated with the OIS 11 (Text-fig. 8).

The Alexandrian Interglacial in Belarus is correlated with the Mazovian Interglacial (*i.e.* YELOVICHEVA 1997). In Lithuania its equivalent is the Butenai Interglacial, Electron Spin Resonance (ESR)-dated at 400-300 ka (GAIGALAS & MOLODKOV 1997), and corresponds to the stratigraphical position of the bi-optimal Holsteinian (s.l.) Interglacial (*see* SATKUNAS 1997). In all probability, the first (main, old) climatic optimum of this interglacial from the Kolodezhny Rov (Text-fig. 1) in Belarus should be correlated with the Holsteinian Interglacial s.s. (*see* YAKUBOVSKAYA 1976). On the Russian Plain, in the Chekalin section the main interglacial optimum corresponds to lake deposits of the Likhvinian s.s. Interglacial (*see* BOLIKHOVSKAYA & SUDAKOVA 1996).

During the younger climatic cooling (Fuhne, Liviecian), the Scandinavian ice sheet probably reached only the area of NE Poland and, possibly, NE Germany as well (LINDNER & MARKS 1994). The remaining area of N and NW Europe was subjected at this time to periglacial conditions, favouring the accumulation of loess (LINDNER 1991, MARUSZCZAK 1996).

Zbójnian (Reinsdorf, OIS 9) Interglacial

The second of the identified interglacials is known in Poland as the Zbójnian Interglacial and, in Germany (*i.e.* Schöningen, Pritzwalk sections on Text-fig. 1), as the Reinsdorf Interglacial (Text-fig. 8) or as the Dömnitz (= Wacken) Interglacial (NILSSON 1983). In the Netherlands the climatic warming of the Hoogeveen and Bantega inter-

Age		OIS Bowen & al. (1986) (ka)		NORTH - SEA Zagwijn (1979), Oele & Schüttenhelm (1979) Sejrup & Knudsen (1993)	FRANCE NORMANDY Lautridou (1982), Balescu & al. (1997)	FRANCE MASSIF CENTRAL de Beaulieu & Reille (1995)	GERMANY LOWER SAXONY Urban & al. (1991), Urban (1995)	POLAND Lindner (1988), Baraniecka (1990)	UKRAINE NORTH-WEST Bogucki & al. (1994)
QUATERNARY	HOL.		1	HOLOCENE	HOLOCENE	HOLOCENE	HOLOZÄN	HOLOCENE	HOLOCENE
	PLEISTOCENE	13	2-5d	WEICHSELIAN	WEICHSELIAN	WÜRM	WEICHSEL	VISTULIAN	loess
			5e	EEMIAN	ELBEUF 1	RIBAINS	EEM	EEMIAN	HOROKHOV
		128	6	SAALIAN	SAALIAN	RISS	SAALE: WARTHE	MIDDLE POLISH GLAC.: WARTANIAN	loess
		195	7	HOLSTEINIAN	ELBEUF 2 (TOUD)	LE BOUCHET	SCHÖNINGEN ?	LUBAVIAN	KORSHOV
		251	8	ELSTERIAN			DRENTHE	ODRANIAN	loess
		297	9	NORWEGIAN TRENCH	ELBEUF 3 (TOUB)	LANDOS	REINSDORF	ZBÓJNIAN	LUCK
		347	10	?			FUHNE	LIVIECIAN	loess
		367	11	DEVILS HOLE	HOLSTEINIAN	PRACLAUX	HOLSTEIN	MAZOVIAN	SOKAL
		440	12		ELSTERIAN		ELSTER 2	SANIAN 2	OKANIAN

Fig. 8. Stratigraphical correlation of the post-Sanian 2 (= post-Elsterian 2) interglacial and glacial units in Europe

stadials (ZAGWIJN 1986) can possibly be correlated with the Zbójnian Interglacial, while in the North Sea, it corresponds to the Norwegian Trench Interglacial (in the Troll section on Text-fig. 1), correlated with the OIS 9 (Text-fig. 8), (SEJRUP & KNUDSEN 1993). In France, in the Massif Central (the Praclaux section on Text-fig. 1), the Landos Interglacial is located at this stratigraphical position (Text-fig. 8), while in Normandy (the Tourville section on Text-fig. 1) the global sea-level rise associated with this interglacial is recored in the horizon Elbeuf 3 (= TOUB) (Text-fig. 8). TL datings of these deposits are to 313± 33 ka, while Infrared Stimulated Luminescence (IRSL) datings give results of 314 ±32 ka (BALESCU & *al.* 1997). The stratigraphical position of the Zbójnian Interglacial may correspond, in the British Isles to the Hoxnian Interglacial, the deposits of which are correlated with the OIS 9 (BOWEN & *al.* 1989). In the Russian plain the Zbójnian Interglacial is located at the stratigraphical position of the Chekalinian Interglacial (ZUBAKOV & BORZENKOVA 1990, BOLIKHOVSKAYA & SUDAKOVA 1996), while in Belarus it probably corresponds (?) to the Smolensk Interglacial (*i.e.* YELOVICHEVA 1997). In the Kolodezhny Rov section (Text-fig. 1) its possible equivalent is the second climatic optimum of the Alexandrian Interglacial (*see* YAKUBOVSKAYA 1976). In the loess section of NW Ukraine (Bojanice, Korshov) the development of a forest interglacial paleosol of the Luck horizon took place at that time (Text-fig. 8).

The younger glaciation is named in Europe the Odranian (= Drenthian, = Dnieperian) Glaciation. Glacial deposits of this age spread from the Netherlands through Germany, Poland, Czech Republic, Belarus and Ukraine to Russia (LINDNER 1988). Its equivalent in the British Isles is the Wolstonian Glaciation. Beyond the extent of the ice sheet of this glaciation, the accumulation of a loess horizon took place (LINDNER 1991, MARUSZCZAK 1996).

Lubavian (Schöningen?, OIS 7) Interglacial

The third of the identified interglacials, known in Poland as the Lubavian = Lublinian = Pilician Interglacial, corresponds in NE Germany (in the Röpersdorf section on Text-fig. 1) to the Uecker Interglacial (ERD 1987) and, in eastern Lower Saxony (the Schöningen section on Text-fig. 1) possibly to the Schöningen Interglacial. The deposits of this unit have been Uranium/Thorium (U/Th)-dated at 180 ka and 227 ka (HEIJNIS *in*: URBAN 1995). This period is documented in Lithuania (in the Snaigupele section on Text-fig. 1) as the Snaigupele Interglacial (KONDRATIENE 1996). In France, the Le Bouchet Interglacial in the Massif Central (the Le Bouchet section on Text-fig. 1) should correspond to this stratigraphic position, while in Normandy (the Tourville section on Text-fig. 1) its equivalent is the next marine transgression expressed by deposits of the Elbeuf 2 (= TOUD) horizon (Text-fig. 8). The TL age of these deposits is 198 ±26 ka, and the IRSL age is 196 ± 23 ka (BALESCU & *al.* 1997). In the North Sea (the Devils Hole section on Text-fig. 1), their equivalents are marine deposits which, according to SEJRUP & KNUDSEN (1993), correspond to the Holsteinian Interglacial and are correlated with OIS 7 (Text-fig. 8). The Stanton Harcourt deposits are correlated with this stage in the British Isles (BOWEN & *al.* 1989). In loess sections of NW Ukraine (Bojanice, Korshov), this interglacial is documented by a forest paleosol (complex) of the Korshov horizon (Text-fig. 9), while in Belarus it should correspond to the Shklovian Interglacial (*i.e.* YELOVICHEVA 1997). In Lithuania its equivalent is probably the Snaigupele Interglacial (KONDRATIENE 1996; GAIGALAS 1997; SATKUNAS 1997). In the Mediterranean Sea basin the warming caused the appearance of a marine malacofauna of Senegal type with *Strombus bubonius,* U/Th-dated at about 210 ka (BUTZER 1975). Most probably the Pre-Tyrrhenian transgression, U/Th dated in the region of Almeria (Spain) at about 180 ka, can be also placed in this period (HILLAIRE-MARCEL & *al.* 1986).

The following Wartanian Glaciation occurs in Germany, Poland and Belarus as a distinct, separate advance of the Scandinavian ice sheet. However, recent investigations in Poland suggest that the ice sheet advanced more to the south than usually accepted and that it occasionally occupied a larger area than the previous glaciation (*see* MARKS & *al.* 1995).

Eemian (OIS 5e) Interglacial

The fourth and last of the described interglacials is known from the Netherlands through Germany, to Poland and the North Sea as the Eemian Interglacial (Text-fig. 8). In many sites it is documented by both continental and marine deposits, correlated by the majority of workers with the OIS 5e. In the North Sea area (the Apholm, Roar and Statfjord sections on Text-fig. 1), they have been recognised by SEJRUP & KNUDSEN (1993). In the eastern part of the North Sea basin their continental equivalent are the Mikulinian Interglacial deposits. In France, in the Massif Central (the Ribains and Le Bouchet sections on Text-fig. 1) the Ribains Interglacial (de BEAULIEU & REILLE 1995) is situated at this stratigraphic position, while in Normandy, in the Tourville section (BALESCU & *al.* 1997), (Text-fig. 1) it corresponds to the Elbeuf 1 deposits (Text-fig. 8). In the British Isles the period is known as the Ipswichian Interglacial (BOWEN & *al.* 1989). In the loess sections of NW Ukraine (Bojanice, Korshov) this interglacial is documented by a forest paleosol (complex) of the Horokhov horizon (Text-fig. 8), while in Belarus it is represented by the Muravinian Interglacial (*see* YELOVICHEVA 1997). In Lithuania it corresponds to the Merkine Interglacial (KONDRATIENE 1996, SATKUNAS 1997). The global sea level rise caused older Tyrrhenian transgression in the Mediterranean Sea basin expressed, among other criteria, by re-invasion of the marine malacofauna of Senegal type, U/Th-dated at about 127 ka (LALOU & *al.* 1971) and at about 128 ka (HILLARE-MARCEL & *al.* 1986).

The last Pleistocene Glaciation (Vistulian, Weichselian, Valdaynian, Ipswichian) was a period during which glacial deposits, loesses, fluvioglacial or deluvial deposits covered the Eemian Interglacial deposits in Europe.

FINAL REMARKS

The data presented here allow the identification of traces of four interglacials younger than the Sanian 2 (= Elsterian 2, Okanian) Glaciations in the Pleistocene of Europe. From the oldest they comprise: 1 – Mazovian (= Holsteinian, Likhvinian, Praclaux); 2 – Zbójnian (= Reinsdorf, Landos, Chekalinian); 3 – Lubavian (= Schöningen?, Le Bouchet); 4 – Eemian (= Ribains, Mikulinian). They are characterized by different vegetation succession, and their sections in the region of the English Channel, North Sea and Baltic Sea contain marine deposits documenting a global sea level rise.

In the light of the present state of knowledge on Pleistocene climatic changes registered in deep marine deposits, the Mazovian (= Holsteinian) Interglacial corresponds to OIS 11, the Zbójnian (= Reinsdorf) Interglacial to OIS 9, the Lubavian (= Schöningen?) Interglacial to OIS 7, while the Eemian (= Ribains) Interglacial corresponds to OIS 5e. Similar correlation was recently presented for the Netherlands and Germany (*see* URBAN 1997). Each of the interglacials also correspond to the forest paleosols preserved in loess sections.

The succession of the above-mentioned interglacials also support the interpretation that during the Liviecian (= Fuhne) Glaciation, separating the Mazovian Interglacial from the Zbójnian Interglacial, the Scandinavian ice sheet did not reach western and eastern Europe (LINDNER 1988). Recently collected data from the German – Polish Lowland (*see* MARKS 1991, MARKS & *al.* 1995, URBAN & *al.* 1991, URBAN 1995) suggest that during the Odranian (= Drenthian, Dnieperian) Glaciation the Scandinavian ice sheet could have had only a very limited extent. Glacial deposits from the Netherlands to Russia typically considered as belonging to this glaciation may actually represent an older, pre-maximum stadial of the Wartanian Glaciation.

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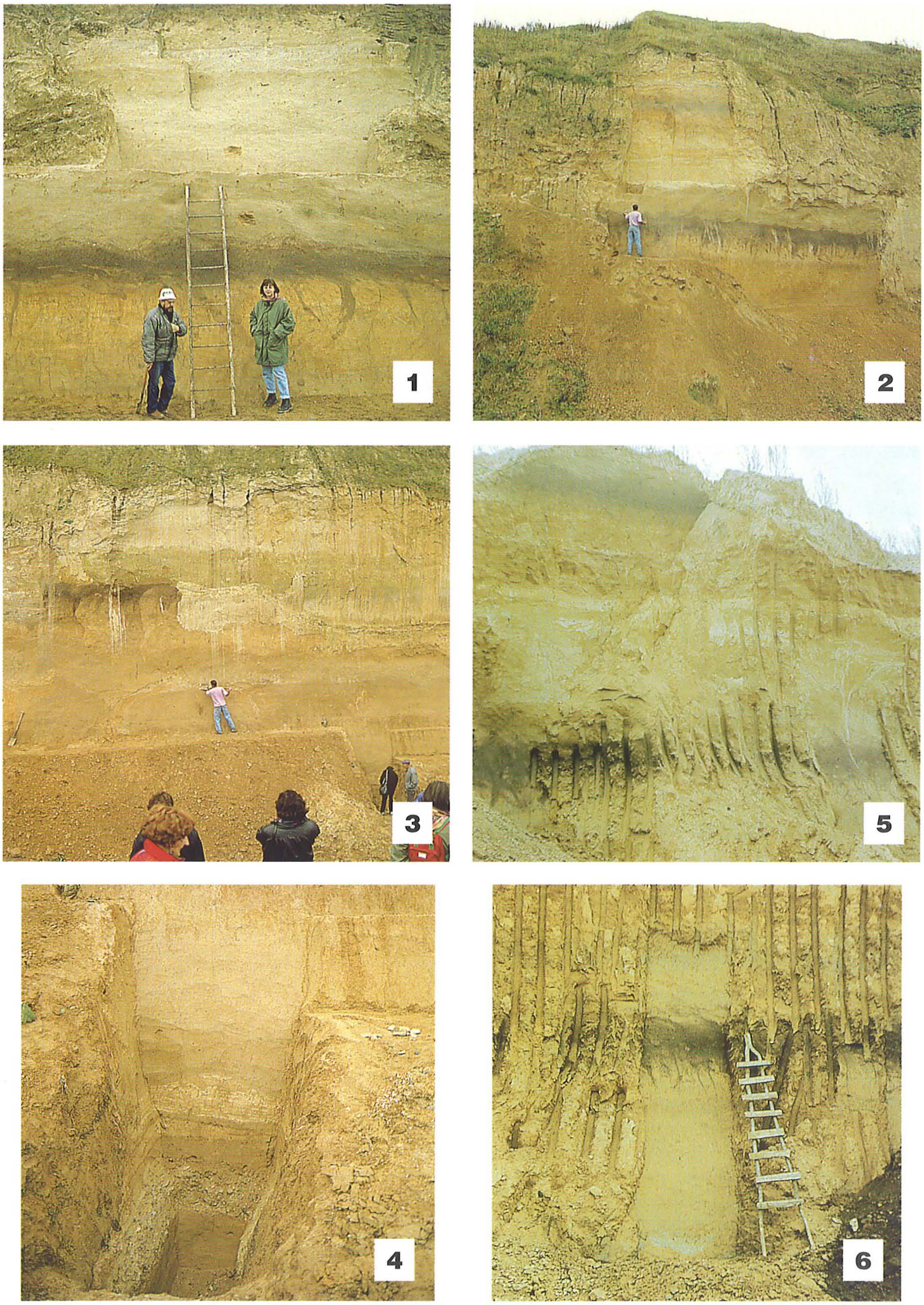
PLATE 1

Bojanice loess section:

1 – Horokhov paleosol complex
2 – Horokhov (upper) and Korshov (lower) paleosol complex
3 – Horokhov paleosoil complex (upper) and Luck paleosol (lower)
4 – Luck (upper) and Sokal (lower) paleosols

Korshov loess section:

5 – Horokhov (upper) and Korshov (lower) paleosol complex
6 – Korshov paleosol complex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Acta Geologica Polonica, Vol. 48 (1998), No. 3, pp. 265-284

Evidence for a shallowing event in the Upper Turonian (Cretaceous) *Mytiloides scupini* Zone of northern Germany

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ABSTRACT:

WIESE, F. & KRÖGER, B. Evidence for a shallowing event in the Upper Turonian (Cretaceous) *Mytiloides scupini* Zone of northern Germany. *Acta Geologica Polonica,* **48** (3), 265-284. Warszawa.

Based on the evidence of a regression in the Late Turonian (Cretaceous) *scupini* Zone of the Münsterland Cretaceous Basin (Westphalia), the exposures Nettlingen and Groß-Flöthe are investigated in order to discover whether or not a comparable event can be observed in Lower Saxony. The lithological and faunal investigation of the two localities show this to be the case. This regressive event is interpreted to be the expression of a sequence boundary, separating two 3rd order sea-level cycles. The lower sequence, the base of which is located above the main *Hyphantoceras* Event in the middle Late Turonian of northern Germany, is termed the "*flexuosum* Sequence". The sequence above the sequence boundary, which ranges into the Lower Coniacian *Cremnoceramus deformis* Zone, spans approximately the reported range of *Didymotis costatus*. It is, therefore, named the "*Didymotis* Sequence". It can be shown that the observed sequence boundary can also be recognized in Spain, southern England, Poland and the Czech Republic.

Dedicated to the 65th birthday of Prof. Dr. E. HERRIG

INTRODUCTION

In the Upper Turonian of the Münsterland Cretaceous Basin (Westphalia, northern Germany), the glauconitic greensands of Soest (Soester Grünsand; BÄRTLING 1921, SEIBERTZ 1977, 1979; KAPLAN 1994), in the south, and the greensands of Rothenfelde and Timmeregge as well as the conglomeratic iron-ores of Borgholzhausen, in the north (SCHLOENBACH 1869, ELBERT 1902, BÄRTLING 1921, KAPLAN & BEST 1984), mark a significant change of facies: Pläner-limestones, representing a more distal environment, locally glauconitic, are overlain with a comparatively sharp contact by sediments that represent a shallower environment. The Soest Greensand comprises autochthonous/parauthochthonous sediments of a shallow marine setting north of the Rhenish massiv. The greensands grade progressively up into distal, monotonous marl-limestone alternations (Grau-Weiße-Wechselfolge: **G**rey and **W**hite **A**lternation, GWA; FRIEG & *al.* 1989) that can be readily correlated between the Münsterland and the Lower Saxony Basin (ERNST & *al.* 1983) and reflect, therefore, a period of high relative sea-level with widespread uniform sedimentation. The allochthonous greensands of Timmeregge and Rothenfelde (debrites/turbidites) were shed as apron-like bodies from a palaeohigh in the north (VOIGT & HÄNTZSCHEL 1964), the Nordwestfälisch-Lippische Schwelle of HAACK (1925), located close to the present-day Teutoburger Wald. Their microfacies represent a shallow marine environment that is not preserved due to erosion of the source area (MESTWERDT 1930, VOIGT & HÄNTZSCHEL 1964). Of the same age are lenticular accumulations of clay iron-stones (iron-ores of Borgholzhausen) that erosively cut deep into the underlying Pläner limestones and, locally, interfinger with greensands time-equivalent to that of Rothenfelde. These clay-ironstones may derive secondarily from conglomeratic Neocomian sandstones that yield clay-ironstone geodes reworked from the Lias, or may even derive directly from the Lias (BÄRTLING 1921). In any case, the lithological composition of these iron deposits indicates deep erosion that cuts at least as far down as into the Lower Cretaceous. These deposits are also overlain by the GWA, indicating a transgressive development.

BÄRTLING (1921) noted already that the greensands reflected a major regression and the interpretation of the greensands as shallow marine in origin ("Seichtwasserbildungen") can also be found in STILLE (1908) and MESTWERDT (1930). Interpreting the comparatively rapid facies change from the more distal Pläner limestones below and the transgressive greensands above in terms of sedimentology, the contact between these two lithologies can be considered to indicate a sequence boundary between two 3rd order cycles *sensu* VAN WAGONER & *al.* (1988).

The first dating of the greensands was done by SCHLOENBACH (1869), who could prove that they fell stratigraphically into the so-called "Scaphiten-Schichten" (*Scaphites* beds) of the late Late Turonian (for a discussion of the stratigraphic significance of the Scaphiten-Schichten see PRESCHER 1963). KAPLAN & BEST (1984), KAPLAN (1994) and KAPLAN & KENNEDY (1996) demonstrated that the greensand occurrences of Soest in the south and of Rothenfelde/Timmeregge in the north fall into the late Late Turonian *Mytiloides scupini* inoceramid Zone (the former *Inoceramus* aff. *frechi* Zone of German workers, *e.g.* WOOD & *al.* 1984), or into the lowermost part of the *Prionocyclus germari* ammonite Zone, respectively. They are, therefore, of the same age.

No evidence for a similar regression has so far been reported in time-equivalent strata in Lower Saxony and Saxony-Anhalt. This interval appears to be characterized here by monotonous Pläner limestones without any significant lithological and sedimentological features. Therefore the question arises, whether this regressive event is restricted to the Münsterland Basin, or whether it can also be identified in other areas of northern Germany or, perhaps, elsewhere in Europe.

AIMS AND METHODS

Since no direct evidence for a late Late Turonian sequence boundary in Lower Saxony and Saxony-Anhalt can be obtained from the literature, the scope of this paper will be to investigate the time-equivalent strata of the Westphalian greensand occurrences (basal *Mytiloides scupini* Zone, Late Turonian) by means of lithology, sedimentology and faunal development. Unfortunately, strongly glauconitic sediments and/or conglomeratic deposits that might indicate the occurrence of a shallower environment and a corresponding regressive event, are not known in Lower Saxony and Saxony-Anhalt in Late Turonian times. There, most exposures exhibit the typical Upper Turonian Pläner limestone facies, consisting of apparently little diversified marl/limestone alternations of white to greyish limestones with intercalated dark marl seams. Sedimentary features, suggestive of shallower water environments, such as channel-fills or reworking horizons are of only local occurrence. (ERNST & WOOD 1995). To recognise a shallowing in such environments, VOIGT (1959), HANCOCK (1989), ERNST & *al.* (1996) and GALE (1996) suggested that hardgrounds, nodular limestones and lag-deposits, in particular, could be used to recognize regressive developments in Pläner limestone and chalk environments. Allochthonous deposits as predicted by the sequence stratigraphic model (VAN WAGONER & *al.* 1988) can also occur. ERNST & *al.* (1996) presented a list of criteria that are inferred to occur within a sea-level cycle in Boreal and pelagic shelf carbonates. Based on their model (ERNST & *al.* 1996, p. 90, Fig. 4), the following features are inferred to be indicative of a regressive development:

i) hardgrounds,
ii) nodular limestones,
iii) calcarenites ["Grobkreide"],
iv) increased content of macrofauna [fossil accumulations, bio-events],

v) allochthonous deposits,
vi) low keeled/unkeeled planktonic foraminifera ratio,
vii) low ratio of benthic *versus* planktonic foraminifera,
viii) glauconite.

Microfacies analyses can also aid the recognition of environmental changes in these Pläner limestones as has been shown by NEUWEILER & BOLLMAN (1991) and HORNA & *al.* (1994).

Using all these features listed above, an attempt is made to provide an analyses of facies and faunal development in the investigated interval. The question of a possible sequence boundary in this interval is additionally discussed.

PREVIOUS WORK ON SEDIMENTARY SEQUENCES IN THE TURONIAN OF NORTHERN GERMANY

In the Upper Turonian of northern Germany, data on sequence stratigraphy are limited. ERNST & WOOD (1995) presented a cycle chart for Lower Saxony. Those authors, however, did not report a high Turonian sequence boundary in the investigated interval. In the comparative cycle chart between Spain and northern Germany of ERNST & *al.* (1996, p. 89, Fig. 3), a sequence boundary in the *scupini* Zone was recognized but no horizon or locality data were given. WIESE (1997) tried to compare his cycle chart for Turonian and Lower Coniacian strata of northern Spain (Santander area, Cantabria) with data from Westphalia and equated his sequence boundary in the *Mytiloides scupini/Prionocyclus germari* Assemblage Zone (*Mytiloides scupini* Zone of northern Germany) with that below the Westphalian Soest and Rothenfelde greensands. Based on the succession of macrofaunas in the limestone quarry of Hoppenstedt (Saxony-Anhalt), HORNA & WIESE (1997) suggested that there may be evidence to support shallowing in the early *scupini* Zone.

The sequence stratigraphic subdivision, presented in the figures to this text, are based on literature and our own unpublished field data.

GEOLOGICAL FRAMEWORK AND CHOICE OF THE LOCALITIES

The study area lies within the Lower Saxony Basin (ZIEGLER 1988). The best researched

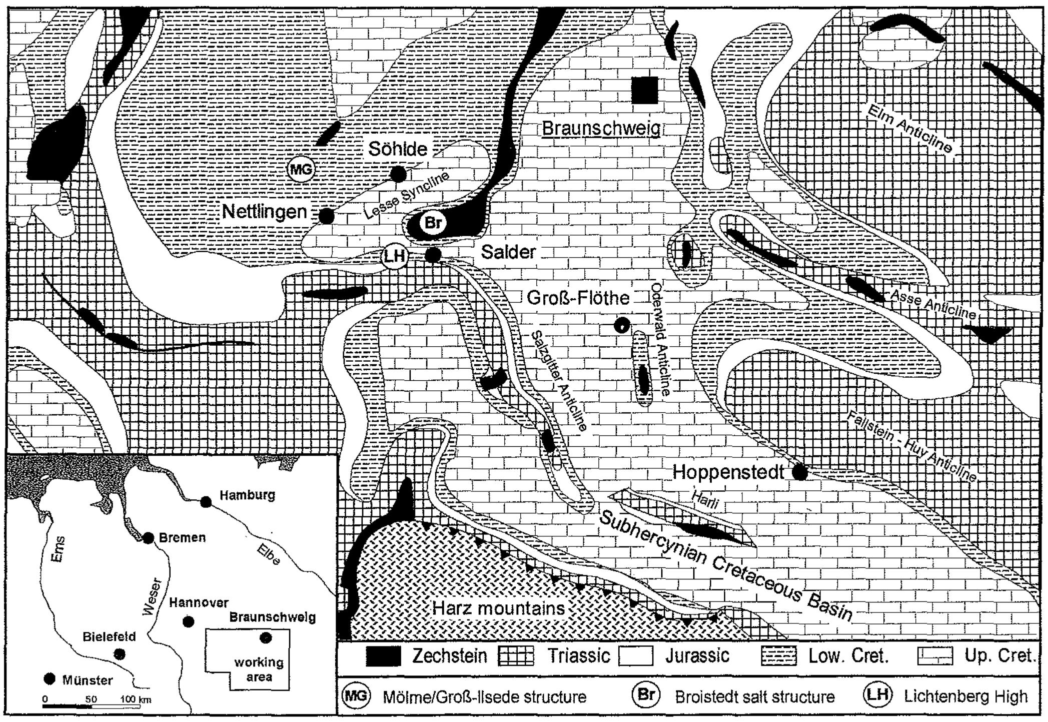

Fig. 1. Simplified geological sketch-map of the study area in Lower Saxony

sections exhibiting Upper Turonian strata are the sections in the limestone quarries of Salzgitter-Salder and Söhlde in the the Lesse Syncline (Text-fig. 1; WOOD & *al.* 1984, ERNST & WOOD 1995, WOOD & ERNST 1997, KAUFFMAN & *al.* 1996). Salzgitter-Salder is located within a structurally complex depositional area, being influenced both by the rim syncline of the uprising Broistedt salt structure in the north and the marginal trough of the Lichtenberg High in the south. It is characterized by high accumulation rates. The exposures around Söhlde are positioned close to the salt-structure of Broistedt and show, presumably due to a migrating rim syncline, strongly differing rates in subsidence over time: Although the interval around the *Hyphantoceras* Event (*Subprionocyclus neptuni* Zone, Text-fig. 2) falls within an hiatus (VOIGT & HILBRECHT 1997), the exposed part of the *Mytiloides scupini* Zone shows in the Grey and White Alternation accumulation rates comparable to those of Salder (ERNST & WOOD 1995), indicating renewed accelerated subsidence. Due to the comparatively high accumulation rates, these two localities, at first sight, do not exhibit any significant facies changes that might permit the detection of a sequence boundary. Therefore, the sections of Nettlingen (close to the Mölme/Groß Ilsede salt structure) and Groß-Flöthe (Oderwald structure) were selected for this investigation (Text-fig. 1). Their inferred position close to or over positive structures seem to be more appropriate for the recognition of a possible sequence boundary because a relative sea-level change and its resulting impact on the sedimentary record should be easier to recognize in shallower environments. In fact, the investigated localities do actually exhibit shallower environments as indicated, to some extent, by the lower accumulation rates and the presences of distinct faunal assemblages. These points will be discussed in detail below.

The exposures of Nettlingen and Groß-Flöthe are abandoned limestone quarries, and the sections are already covered to a large extent by talus. The work on these sections presented here serves to preserve information on successions that would otherwise be lost.

STRATIGRAPHY

Biostratigraphy

Biostratigraphic subdivision in Lower Saxony and Saxony-Anhalt is based on inoceramids. In this paper, the subdivision of the Upper Turonian into three inoceramid (assemblage) zones of WOOD & *al.* (1984) is, with slight modifications, adopted [in ascending order: *Inoceramus*

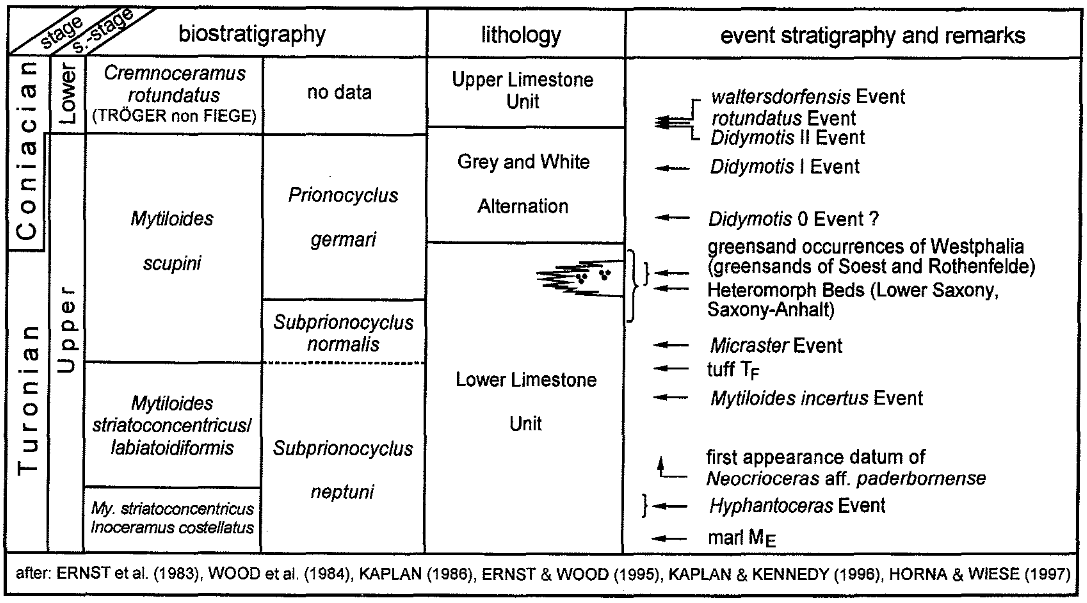

Fig. 2. Generalized multistratigraphic subdivision of the upper Upper Turonian in northern Germany (Saxony-Anhalt, Lower Saxony, Westphalia)

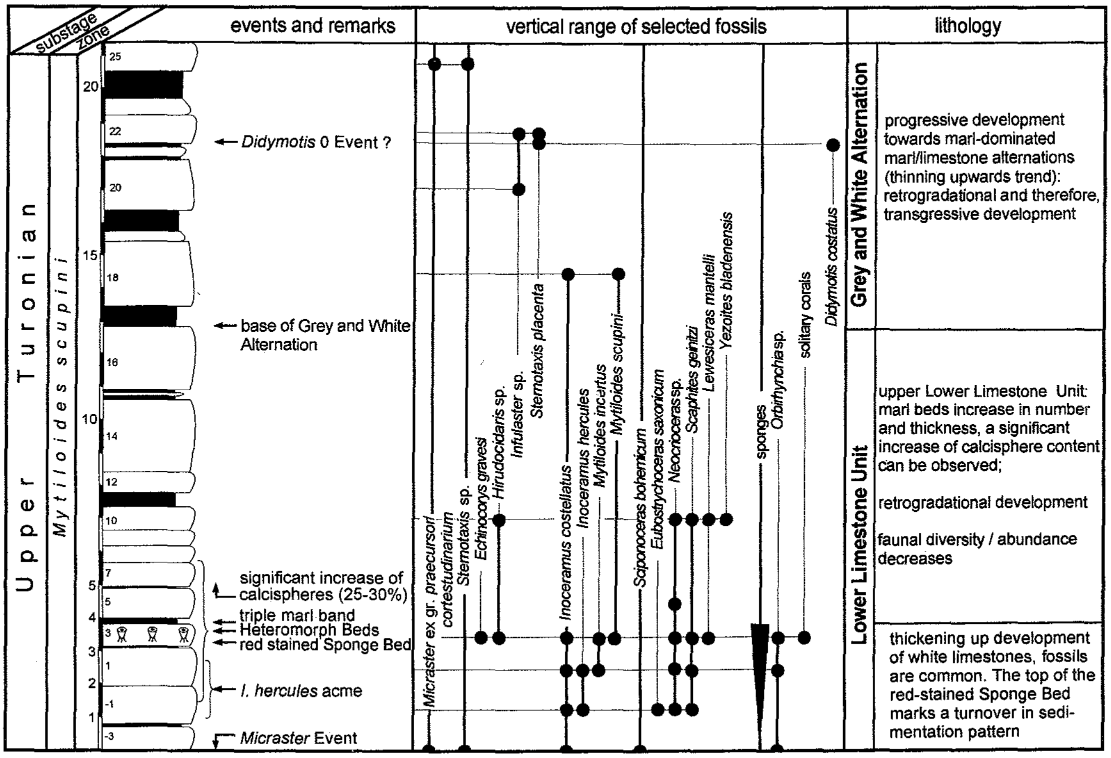

Fig. 3. Lithology and vertical range of selected fossils in the lower *Mytiloides scupini* Zone at Nettlingen

inaequivalvis/stuemckei/cuvierii/costellatus Assemblage Zone, *Mytiloides striatoconcentricus/labiatoidiformis* Assemblage Zone, *Mytiloides scupini* Zone (that is the *Inoceramus* aff. *frechi* Zone of WOOD & *al.* 1984; for discussion see WALASZCZYK & TRÖGER 1997)]. KAPLAN (1986) and KAPLAN & KENNEDY (1996) presented an ammonite zonation for the Upper Turonian of Westphalia and applied it to the inoceramid zonation.

Within this stratigraphic framework, the investigated interval can be shown to fall, respectively, into the late Late Turonian *Mytiloides scupini* Zone or into the lowermost part of the *Prionocyclus germari* Zone (Text-fig. 2). In Westphalia, the base of the latter zone lies just below the greensand occurrences of Rothenfelde and Soest (KAPLAN & KENNEDY 1996). HORNA & WIESE (1997) discussed the possibility that the **f**irst **a**ppearance **d**atum (FAD) of a heteromorph ammonite resembling *Neocrioceras* sp. could be used to define the base of the *germari* Zone in Lower Saxony. As shown below (Text-figs 2-3), this is not the case. However, the base of the first peak occurrence of this genus may well approximate the base of the *germari* Zone and, therefore, aid in recognizing the time-equivalent strata to the Westphalian greensands in Lower Saxony (Text-fig. 2).

It should be mentioned here that KAPLAN (1986) established a *Subprionocyclus normalis* Zone in Westphalia, the base of which equates with that of the inoceramid zone of *Mytiloides scupini*. The *normalis* Zone was abandoned later (KAPLAN & KENNEDY 1994) in favour of a *Prionocyclus germari* Zone with its base located in the lowest part of the *scupini* Zone. Finds of *Subprionocyclus normalis* (ANDERSON) from the lowermost *scupini* Zone (approximately 50 cm above the *Micraster* Event, Text-figs 2-3; Pl. 2, Fig. 5) at Groß-Flöthe fit the data from Westphalia and provide, therefore, additional stratigraphic information.

Event stratigraphy

In order to delimit the investigated interval more accurately, the event-stratigraphic framework of ERNST & *al.* (1983) will be applied (Text-fig. 2). Based on this work, the interval starts with a so-called "event-bundle". This consists of two marker horizons of different origin, namely the tuff layer T_F and the *Micraster* Event. The latter is characterized by the first flood occurrence of "modern" *Micraster* of the *praecursor/cortestudinarium* lineage and serves as an excellent marker between Saxony-Anhalt, Lower Saxony and Westphalia (BRÄUTIGAM 1962, WOOD & *al.* 1984, HORNA 1996). T_F can be recognized in Westphalia and Lower Saxony (WRAY 1995, WRAY & WOOD 1995, WRAY & *al.* 1995, WRAY & *al.* 1996), and marks the base of the *scupini* Zone. In this context, the base of the interval studied is taken at the *Micraster* Event and falls, therefore, into the early Late Turonian *scupini* Zone.

The Heteromorph Beds of HORNA & WIESE (1997) in the lower *scupini* Zone (Text-fig. 2) may have event-like character. They are characterized by an abundance-peak of a nostoceratid ammonite assemblage, consisting mostly of *Neocrioceras* sp. aff. *paderbornense* (SCHLÜTER) (this species will provisionally be referred to exclusively as *Neocrioceras* sp. in this text and the figures; it is currently under investigation by WIESE, *in prep.*), *Hyphantoceras flexuosum* (SCHLÜTER), *Scaphites geinitzi* (D'ORBIGNY) and *Sciponoceras bohemicum* (FRITSCH). They are inferred to define a stratigraphic interval around the Westphalian greensand occurrences and can be shown to occur in Lower Saxony and Saxony-Anhalt (HORNA & WIESE 1997). Furthermore, the two specimen of *Neocrioceras* sp. from the Dresden/Blasewitz borehole (Saxony, Germany), figured and mistakenly identified as *Hyphantoceras reussianum* (D'ORBIGNY) by TRÖGER (1968) and TRÖGER & VOIGT (1995), prove the presence of these beds in Saxony.

The top of the investigated interval is taken at the first abundance peak of *Didymotis costatus* (FRITSCH), which is referred to provisionally as the *Didymotis* 0 Event (JÖRDENS-MÜLLER 1996, WOOD & ERNST 1997) in this text. This possible marker bed has only recently been discovered and its stratigraphic value is still under investigation. Loose finds of *Didymotis costatus* at Söhlde and Hoppenstedt (Text-fig. 1) in Saxony-Anhalt (HORNA & WIESE 1997) suggest the event to be also present there.

Lithostratigraphy

Based on event stratigraphic correlation, the strata can be shown to belong to the Upper Turonian "Untere Kalkstein-Einheit" (Lower Limestone Unit) and the lower part of the "Grauweiße Wechselfolge" (Grey and White Alternation) of ERNST & *al.* (1983). As informally proposed by HORNA & WIESE (1997), the Lower Limestone Unit can be, by means of the *Micraster* Event, lithologically subdivided into a lower part and an upper part. In this context, the base of the studied strata, therefore, corresponds to the base of the upper Lower Limestone Unit (Text-fig. 2). In Lower Saxony, the interval above the *Micraster* Event is, generally speaking, characterized by a succession of thickly bedded white to greyish limestones with intercalated marl beds. It is overlain by the Grey and White Alternation. The GWA as a whole exhibits a thickening upwards development that is terminated by thickly bedded limestones (Upper Limestone Unit, WOOD & *al.* 1984). The lower part of the GWA, which falls within the studied interval, is characterized by the predominance of marlier sediments. The transition between these two litho-units is a gradual one and the definition of a boundary is necessarily somewhat arbitrary. At Salder, it is taken at the first thick marl bed above an interval with thickly bedded limestones (Bed 14 of WOOD & ERNST 1997; Text-fig. 5 of this paper). Based on lithostratigraphic correlation within the working area, this bed is inferred to correspond to bed 17 at Nettlingen and bed 16 at Groß-Flöthe (Text-figs 3-5).

NETTLINGEN: LITHOLOGY AND FAUNA

Grid reference: GK 25: 3827 Lesse; R: 358030, H: 577990
Locality: Abandoned small limestone quarry near the Nettlingen-Berel road
References: MENZEL (1902), WOLLEMANN (1902a, 1902b, 1905), SCHRAMMEN (1910), WOLSTEDT (1933), BRÄUTIGAM (1962), ERNST & *al.* (1979), KRÖGER (1996a)

The locality Nettlingen is structurally located at the western border of the Lesse Syncline, close to the salt structures of Mölme/Groß Ilsede (Text-fig. 1). Formerly, there were many quarries around Nettlingen but these are now back-filled. They exposed Cenomanian to Upper Turonian strata, up to the *Micraster* Event, and were mentioned in WOLLEMANN (1902a, b), MENZEL

(1902) and SCHRAMMEN (1910). A detailed investigation was presented by BRÄUTIGAM (1962). The studied quarry is the only Nettlingen exposure at the moment and it was not studied by BRÄUTIGAM (1962).

The exposed section covers an interval from immediately above the *Micraster* Event (upper Lower Limestone Unit) to the lower GWA (Text-fig. 3, for key see Text-fig. 5). The *Micraster* Event itself is not exposed. However, finds of several fragments of "modern" *Micraster* ex gr. *praecursor/cortestudinarium* in grey-weathering, marly sediments from the bottom of the quarry suggest the event to be only tens of centimetres below the quarry floor. As in Salder and Groß-Flöthe, a *Didymotis* 0 Event is recognized, delimiting the upper boundary of the investigated interval (Text-fig. 3).

Upper Lower Limestone Unit (approx. 13.0 m exposed)

The upper Lower Limestone Unit above the *Micraster* Event in the quarry shows a conspicuous two-fold subdivision: The lower part consists of white, more massively bedded limestones and subordinate marl seams. The higher part is characterized by a widely-spaced marl/limestone alternations of greyish limestones and dark marls. The boundary between these two lithologies is marked by an interval rich in limonitic and strongly altered sponges (Sponge Bed), giving the sediment a reddish/brownish colouration, immediately followed by a triplet of closely spaced marl beds.

Micraster Event to the Sponge Bed (approx. 3.5-4.0 m)

Lithology: As mentioned above, the *Micraster* Event is inferred to lie just below the quarry floor. The only locally exposed marls at the base of the quarry are, therefore, the last marl seams of the marl-dominated interval around the *Micraster* Event. Further up-section, a thickening upwards trend can be recognized. It is terminated by the Sponge Bed. The latter is characterized by the abundant occurrence of pyritized and altered sponges (Pl. 2, Fig. 1), giving this layer a partially red colouration. Compared with the thickly bedded limestones below, the Sponge Bed exhibits a more flasery character. It seems to be the end-member of a thickening upwards cycle, because a facies change towards marlier sediments can be observed immediately above.

Even though the strata appear macroscopically to become coarser towards the top of this cycle, microfacies analyses show the rocks to be almost monotonous and only a small increase of bioclastics towards (bioclastic) calcisphere wackestones (Pl. 1, Fig. 1) at the top of this unit can be observed. The succession consists generally of wackestones containing calcispheres, planktonic foraminifera and, to a minor degree, inoceramid debris. Spicules of hexactinellid sponges also occur, as do scattered grains of glauconite.

Macrofauna: From the base of the quarry, some specimen of *Micraster* ex gr. *praecursor/cortestudinarium* were collected. In contrast to the microfacies, the macrofauna shows a readily recognizable, positive correlation with the thickening upwards development: While the basal exposed sediments are still poor in macrofossils, beds 2 and 3 (Text-fig. 3) yielded a rich invertebrate macrofauna. It consists of inoceramids: *Mytiloides incertus* (JIMBO), *Inoceramus costellatus* WOODS, *Inoceramus hercules* (HEINZ); ammonites: *Lewesiceras mantelli* WRIGHT & WRIGHT, *Eubostrychoceras saxonicum* (SCHLÜTER), *Scaphites geinitzi*, *Sciponoceras bohemicum*, *Neocrioceras* sp. (Pl. 2, Fig. 7); echinoids: *Echinocorys gravesi* (DESOR), *Sternotaxis* sp. (an intermediate form between *Sternotaxis plana* and *Sternotaxis placenta*), *Hirudocidaris* sp. (Pl. 2, Fig. 4); brachiopods: *Orbirhynchia* sp.; solitary corals and a diverse sponge fauna. Based on field observations by one of the authors (KRÖGER), the acme of large *Inoceramus hercules* is of special interest for regional comparison because it can also be observed in the Salder and Söhlde sections, as well as in Groß-Flöthe (Text-fig. 4). It is also of importance to note that the occurrence of *Mytiloides incertus* well above the *Micraster* Event both at this locality and Groß-Flöthe is the first evidence of the species from this interval in Lower Saxony.

Top of the Sponge Bed to the base of the Grey and White Alternation (approx. 9.0 m)

Lithology: Above the Sponge Bed, a significant change in lithofacies can be observed. Even though thickly bedded limestone bundles prevail, the colour changes from white to grey. Furthermore, marl seams begin to intercalate successively, foreshadowing the GWA. The uppermost part of the Lower Limestone Unit exhibits in this interval a considerable change from weakly bioclastic wackestones towards calcisphere wackestones (up to 25 % calcispheres; Text-fig. 3).

Macrofauna: Above the Sponge Bed, the amount of macrofauna decreases considerably. However, ammonites [*Neocrioceras* sp., *Scaphites geinitzi*, *Sciponoceras bohemicum, Yezoites bladenensis* (SCHLÜTER)], *Hirudocidaris* sp. and *Sternotaxis* sp. are still common. A sudden decrease of the macrofauna around beds 5 to 7 marks the upper limit of the Heteromorph Beds.

Grey and White Alternation

Lithology: The base of the GWA is taken here at bed 17. It represents an alternation of greyish limstones and dark marl beds. It develops gradually out of the Lower Limestone Unit and marks the further shift towards marlier sediments.The microfacies varies from (calcisphere) wackestones to bioclastic wackestones, containing common planktonic foraminifera (hedbergellids, heterohelicids, globotruncanids), inoceramid and echinoid debris and spicules of hexactinellid sponges. Towards the top of the section, above the *Didymotis* 0 Event, the first mudstones occur.

Macrofauna: With the GWA, a further decrease in abundance and diversity can be observed. The fauna is dominated by irregular echinoids (*Sternotaxis* sp., *Micraster* ex gr. *praecursor/cortestudinarium*, *Infulaster* sp.) and inoceramids, including *Inoceramus costellatus* and *Mytiloides scupini*. The *Didymotis* 0 Event in bed 22 marks the FAD of *Didymotis costatus* in this section. This interval also yielded very large specimen of *Sternotaxis* referred here to *Sternotaxis* cf. *placenta* (AGASSIZ). *Sciponoceras bohemicum* occurs scattered throughout the entire section.

Additional fauna

In the papers of WOLLEMANN (1902a, b), MENZEL (1902) and SCHRAMMEN (1910), additional lists with Upper Turonian fossils from Nettlingen were presented, including *Hyphantoceras flexuosum* (SCHLÜTER). As this species enters well above the *Hyphantoceras* event (KAPLAN 1986), it can be, also based on the associated fauna, assumed that these authors collected in the same stratigraphic interval as described above. Within this context, it is important to note that SCHRAMMEN (1910) collected a diverse sponge fauna from this interval at Nettlingen, now housed and registered at the British Museum of Natural History, London. These specimen are all three-dimensionally preserved and limonitized, as are the specimen from the Sponge Bed. Based on this information, it is highly possible that SCHRAMMEN's Nettlingen material, in fact, derived from the Sponge Bed described here.

Conulus subrotundus (MANTELL), very large *Gibbythyris subrotunda* (SOWERBY) and *Puzosia* sp. are also listed.

GROß-FLÖTHE: LITHOLOGY AND FAUNA

Grid reference: GK 3928 Salzgitter, R: 3601100, H: 5773250

Locality: Abandoned limestone quarry beside the motorway BAB 395 (Braunschweig-Bad Harzburg).

References: WOLLEMANN (1901), SCHRÖDER (1912), CARLÉ (1938), ERNST & *al.* (1979), JÖRDENS-MÜLLER (1996)

The two abandoned quarries at Groß-Flöthe are located on the western side of the N – S-trending Oderwald structure (Text-fig. 1). They exhibit an almost complete composite section from the Upper Turonian *Hyphantoceras* Event (*Subprionocyclus neptuni* Zone) to the Lower Coniacian with a minor gap in exposure of few metres in the upper *Hyphantoceras* Event. The beds dip gently at 20° to 25° to the WNW (260°).

In the north-eastern quarry, an interval from the marl layer M_E (Text-fig. 2) up to the upper part of the *Hyphantoceras* Event ist still exposed and readily accessible. In the southern quarry, an interval from the top of the *Hyphantoceras* Event to the basal Coniacian is exposed, the latter being indicated by the abundance of a typical Lower Coniacian fauna (e.g. *Cremnoceramus waltersdorfensis*, *Cremnoceramus erectus*, *Cremnoceramus deformis, Neocrioceras paderbornense*).

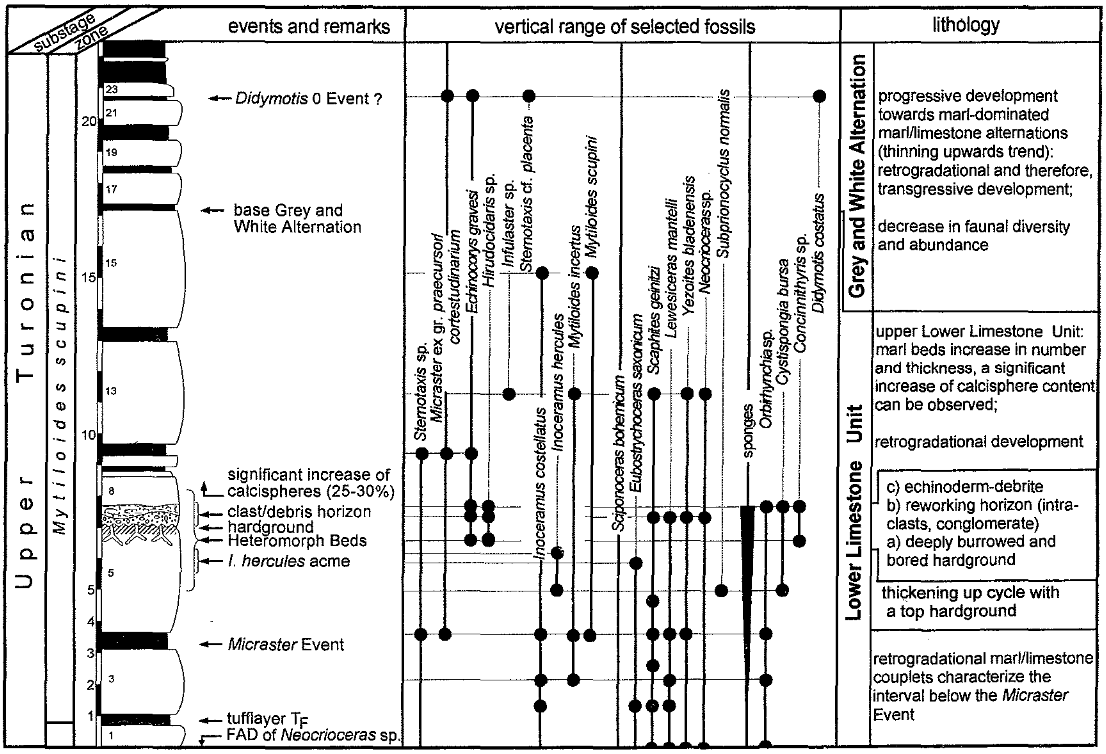

Fig. 4. Lithology and vertical range of selected fossils in the lower *Mytiloides scupini* Zone at Groß-Flöthe

The lowermost strata of the southern quarry are characterized by the common occurrence of *Lewesiceras mantelli* (Pl. 2, Fig. 6). *Hyphantoceras flexuosum* (SCHLÜTER) (Pl. 2, Fig. 8) and *Neocrioceras* sp. were also found. This fauna belongs presumably to the top of the *Hyphantoceras* Event (desmoceratid ammonite association *sensu* KAPLAN 1991). Several specimen of *Mytiloides incertus* were collected, indicating the presence of the *Mytiloides incertus* Event (KAPLAN 1991, ERNST & WOOD 1995; Text-fig. 2 of this paper). Two distinct marl seams, the higher of which contains "modern" *Micraster*, are interpreted as tuff T^F and the *Micraster* Event, respectively (Text-fig. 4). The presence of these index-markers permits good dating and a reliable correlation of the section with other localities. A short distance above the *Micraster* Event, an interval rich in *Neocrioceras* sp. occurs in the upper Lower Limestone Unit. Within this interval, there is a well developed hardground with conglomerates and debrites. The upper Lower Limestone Unit is overlain by the Grey-White Alternation.

Above the *Micraster* Event, a distinct sequence of lithologies can distinguished and described. These are (in ascending order): i) the *Micraster* Event, ii) thickly bedded limestones of the Lower Limestone Unit terminating in a hardground, iii) a conglomerate/debrite complex, iv) thickly bedded limestones of the Lower Limestone Unit and v) the Grey-White Alternation. As the section is already partly covered by talus, bed-by-bed logging is not possible in the lower parts. A detailed bed-by-bed sampling and fossil collecting as in the case of Nettlingen was not feasible, and a continous fossil documentation was, therefore, not always possible.

Micraster Event

Lithology: As in all other sections of Lower Saxony, the *Micraster* Event represents a short interval that is characterized by the predominance of marly sediments (BRÄUTIGAM 1962, WOOD & *al.* 1984). In those sections where detailed microfacies studies have been carried out, the interval around the *Micraster* Event is characterized by a significant decrease in calcispheres and planktonic foraminifera. Keeled forms of the planktonic foraminiferal component can reach up to 90% (KRÖGER 1996b, ERNST & WOOD 1997, WOOD & ERNST 1997). This can also be observed at Groß-Flöthe. The thin limestone beds within this interval are wackestones, in part on the boundary to mudstones. Coarse bioclastics are scarce. Only foraminifera and calcispheres occur in significant amounts.

Macrofauna: The *Micraster* Event is characterized by the first abundance peak of modern *Micraster* of the *praecursor/cortestudinarium* lineage. *Sternotaxis* sp. and *Micraster leskei* (DESMOULINS) occur as subordinate elements. The beds are otherwise poor in macrofossils with the exception of inoceramids. The taxonomic position of the inoceramids, as at Nettlingen, is unclear but they seem to characterize the stratigraphic interval well above tufflayer T_F (C. J. WOOD, *pers. comm.*), and can be compared with the fauna at Nettlingen.

Upper part of the Lower Limestone Unit (approx. 17.0 m exposed)

As mentioned above, a major hardground with conglomerates and debrites is intercalated into this interval, separating these beds into three individual parts. Therefore, the individual lithologies (Text-fig. 4) will be seperately described.

Micraster Event to the hardground (approx. 4.0 m)

Lithology: As at Nettlingen, a thickening upwards development can be recognized from the *Micraster* Event on. Even though the sediment appears to become coarser and the faunal content increases up-section, the microfacies shows only the slightest variation. The sediment consists of bioclastic wackestones (Pl. 1, Fig. 2) with fragments of calcispheres, planktonic foraminifera (hedbergellids, heterohelicids and globotruncanids). Debris of inoceramids or echinoids, as well as benthic foraminifera such as *Lenticulina* sp. are of subordinate importance. Spicules of hexactinellid sponges are common. In comparison to time-equivalent strata at Nettlingen (Pl. 1, Fig. 1), the strata yield significantly less calcispheres here.

This facies is abruptly terminated by a hardground (Text-fig. 4; Pl. 1, Fig. 4). Its surface is slightly iron-stained and strongly bioturbated by *Thalassinoides*. Bioturbation can pipe sediment down up to 30 cm. The three-dimensional preservation of the burrows and the sharp contact of burrow-walls with the infilled sediments indicate early diagenetic lithification. This is also proved by *Trypanites*-like borings (Pl. 1, Fig. 3) and fragmented areas of the hardgrounds, where sharp, angular hardground clasts are preserved in formerly open cavities.

Macrofauna: Above the *Micraster* Event, the macrofauna progressively increases up-section. *Sternotaxis* sp. and fragments of *Micraster leskei* are common. *Eubostrychoceras saxonicum*, *Hyphantoceras flexuosum*, *Scaphites geinitzi*, *Sciponoceras bohemicum* and *Subprionocyclus normalis* (Pl. 2, Fig. 5) also occur. The latter species is known to have its FAD well above the *Hyphantoceras* Event in Westphalia (KAPLAN 1986). This fits the situation as observed at Groß-Flöthe. A first peak-occurrence of *Neocrioceras* sp. about 10 to 50 cm below the hardground indicates the presence of the Heteromorph Beds at this locality. The inoceramid fauna yielded forms that resemble *Inoceramus costellatus longealatus* TRÖGER, *Mytiloides scupini* and *Mytiloides incertus*. Fragments of very large inoceramids (*Inoceramus hercules*, Pl. 2, Fig. 9) are common in this interval. It is noteworthy that at Nettlingen an accumulation of these large inoceramids can also be observed in the same stratigraphic position. The interval below the hardground is particularly characterized by *Cystispongia bursa* QUENSTEDT (Pl. 2, Fig. 2). Its occurrence may be of certain interest, because this species seems to be comparatively common both in England (*e.g.* HINDE 1883, WOOD 1992) and in Germany (*e.g.* QUENSTEDT 1877, SCHRÖDER & DAHLGRÜN 1927) in Upper Turonian strata. Where it occurs, it is linked to condensed sedimentation in shallow environments and it may, therefore, be indicative for regressive developments. The hardground surface is poor in macrofauna.

It appears that the increase of the total amount of macrofauna correlates positively with the thickening up trend.

Conglomerate/debris complex (0.10-0.45 m)

Lithology: A well developed conglomerate bed overlies the hardground with a sharp basal contact. It exhibits a red colouration and is, therefore, easy to recognize. The pebbles are mostly well rounded and reach a diameter up to 6-10 cm. Pebbles with a more angular shape also occur. They consist of different facies types, from mud/wackestones to slightly bioclastic wackestones with fragments of inoceramids, echinoids, planktonic foraminifera and calcispheres. Differences between these lithologies are only small. The composition of the matrix, however, reflects a major facies change towards a shallower environment: It consists of a bioclastic packstone that is rich in inoceramid- and echinoderm-debris (spines of *Hirudocidaris* sp., asteroid ossicles, echinoids), calcispheres, non-keeled planktonic foraminifera (hedbergellids, heterohelicids). Ostracods, bryozoans, serpulids, ostreid bivalves, spicules and *Lenticulina* sp. are common (Pl. 1, Fig. 6). The conglomerate shows latаral variation in thickness (5-30 cm), possibly reflecting an undulating erosion surface on top of the hardground that can be regarded as a primary relief. The conglomerate is overlain by a partly laminated, echinoderm wacke- to packstone of varying thickness (5 to 15 cm; Pl. 1, Fig. 7). Filling up the residual relief, it terminates this allochthonous interval, and is itself covered by "normal" autochthonous limestones that show no change in thickness within the quarry.

Macrofauna: The conglomerate is very rich in macrofossils. Inoceramids debris, large *Echinocorys gravesi*, *Concinnithyris* sp., *Orbirhynchia* sp., *Spondylus* sp. and spines of *Hirudocidaris* sp. are particularly common. Associated fragments of asteroids are scarce; however, the local superabundance of isolated asteroid ossicles confirm that asteroids (*Metopaster* sp.?; Pl. 2, Fig. 3) were an important element of the fauna. Serpulids, hexactinellid sponges and solitary corals also occur.

Uppermost Lower Limestone Unit
(approx. 9.5 m)

Lithology: Immediately above the hardground, the microfacies grades back into bioclastic wackestones with decreasing amount of coarse bioclastics (Pl. 1, Fig. 8). There is an increasing intercalation of marl beds, and the limestones turn from white to a slightly greyish colour.

Macrofauna: The beds immediately above the hardgrounds are rich in ammonites (*Neocrioceras* sp., *Yezoites bladenensis*, *Sciponoceras bohemicum*, *Scaphites geinitzi*, *Eubostrychoceras saxonicum*). Inoceramids, including large *Mytiloides incertus*, also occur. After only tens of centimetres, the macrofossil content decreases. Only *Sternotaxis* sp. and small inoceramids are common.

Grey and White Alternation

Lithology: The base of the GWA is taken at the base of bed 16, which is a marl seam (Text-fig. 4). As already described from Nettlingen, the base of the GWA marks an increase of marl beds and a decrease of macrofauna. The limestone beds are of a light grey colour and are penetrated by dark-coloured *Zoophycos* and *Chondrites*. Lithologically, the limestones can be best described as wackestones with varying amount of bioclastics (echinoids, inoceramids, planktonic foraminifera). In addition, the calcisphere content increases significantly (approx. 25 %), as already observed at Nettlingen at the same level.

Macrofauna: The Turonian part of the GWA is generally poorer in macrofauna as the strata below. However, echinoids (*Sternotaxis* cf. *placenta*, *Echinocorys gravesi*, *Infulaster* sp., *Micraster* ex gr. *praecursor/cortestudinarium*) as well as scaphitids, *Sciponoceras bohemicum* and small mytiloid inoceramids of uncertain taxonomic position occur scattered throughout the section

DISCUSSION

Lithology and microfacies

The *Micraster* Event was interpreted as a maximum flooding zone by KRÖGER (1996a). At Salder and Söhlde, it is particularly characterized by thinly bedded limestones with a very high content of keeled planktonic foraminifera (up to 90%). Above the *Micraster* Event, a short-term thickening upwards development in the upper part of the Lower Limestone Unit can be recognized both at Nettlingen and Groß-Flöthe. It is characterized by a successive decrease of marl beds and an increase in bed thickness of the limestones. Furthermore, the amount of macrofossils

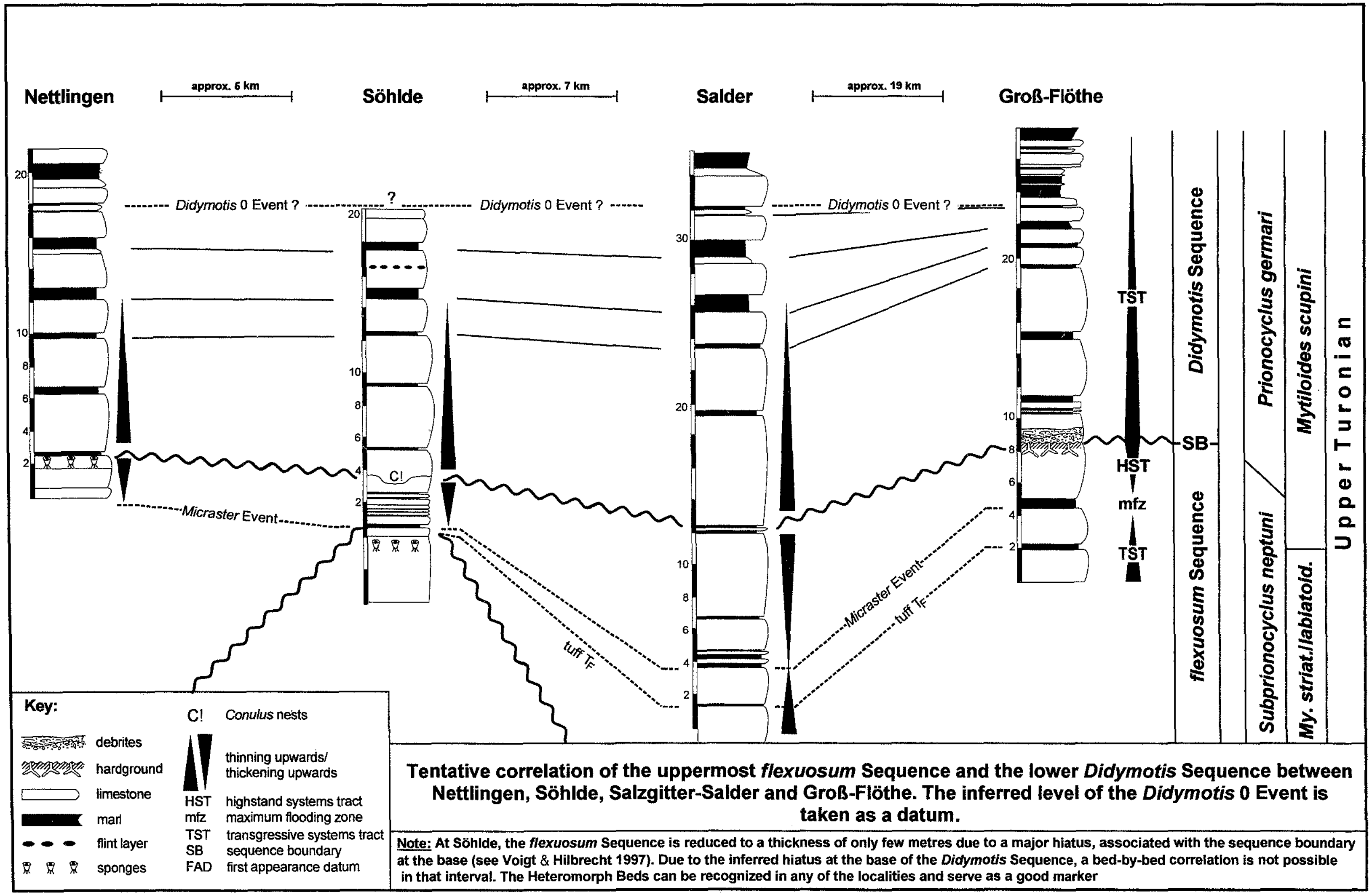

Fig. 5. Tentative, lateral correlation of the early *Mytiloides scupini* Zone between Nettlingen, Söhlde, Salder and Groß-Flöthe within a sequence stratigraphic framework

increases considerably. This is also reflected by the microfacies, which exhibits change from wackestones towards slightly bioclastic wackestones. At Nettlingen, this trend is terminated by the flasery Sponge Bed (bioclastic calcisphere wackestone, Pl. 1, Fig. 1). At Groß-Flöthe, a hardground is developed at the same level, terminating a succession of wackestones (Pl. 1, Fig. 2). Based on the data from ERNST & *al.* (1996), these features can be interpreted as marking a regressive event. Correlation and a comparison of lithological/sedimentological features between Groß-Flöthe, Salder, Söhlde and Nettlingen (Text-fig. 5) suggest that Groß-Flöthe represents the shallowest section with the hardground incorporating a small hiatus. This gives further evidence for a relative sea-level fall. It is important to note that the comparatively more distal section at Nettlingen yielded more calcispheres in time-equivalent strata than at Groß-Flöthe. At Salder, the corresponding strata of this thickening upwards cycle are characterized by thickly-bedded calcisphere-wackestones with a calcisphere content of approximately 25 % (ERNST & WOOD 1995).

Interpreting the microfacies data presented by KRÖGER (1996a, 1996b), JÖRDENS-MÜLLER (1996) and in this paper, a facies zonation from proximal [hardground, (bioclastic) wackestone] to distal (foraminiferal wackestones, *e.g.* the interval around the *Micraster* Event) can be inferred. The calcisphere-maximum (calcisphere wackestones) possibly reflects a medial position close to swell margins between the proximal (bioclastic) wackestones and the distal foraminiferal wackestones. A comparable observation was also reported by NEUWEILER & BOLLMANN (1991) from the Turonian of Westphalia. This indicates that the maximum occurrence of calcispheres is restricted to a distinct calcisphere facies belt. The comparatively higher accumulation rates within this calcisphere belt are reflected by a generally higher bed thickness. Within a sea-level change, the stacking pattern of the strata, *e.g.* a thickening upwards development, can, therefore, indicate either a shallowing development (facies change from distal foraminiferal wackestones to medial calcisphere wackestones) or a deepening development [facies change from proximal (bioclastic) wackestones to medial calcisphere wackestones].

Following WALTHER'S law of facies, an increase of calcispheres should, therefore, be expected during transgression in a position more proximal to the calcisphere belt, when it shifts up-swell. In fact, this can be observed at Nettlingen and Groß-Flöthe. Above the Sponge Bed (Nettlingen) and the hardground (Groß-Flöthe), respectively, a significant increase of calcispheres can be recognized, accompanied by an increase of bed thickness of the limestones (Text-figs 3-5). Higher up-section the thicknesses of individual limestone beds decrease and those of marl seams increase. This may be regarded as representing a transgressive development. The lithostratigraphic boundary between the Lower Limsestone Unit and the GWA, therefore, is purely arbitrary, representing only a moment within an overall transgressive trend.

Macrofauna

Above the *Micraster* Event, the fauna is increasingly dominated, amongst others, by *Echinocorys gravesi*, *Sternotaxis* sp., brachiopods and, to some extent, by *Micraster leskei* in both Nettlingen and Söhlde. These faunal elements are part of what ERNST & *al.* (1979) called the *Conulus* Facies. This term is derived from the old-fashioned "Galeriten-Pläner" (*e.g.* VON STROMBECK 1857), Galeritenschichten (*e.g.* LÖSCHER 1910) or "Galeriten-Fazies" (*e.g.* BÄRTLING 1913) of Westphalia, interpreting the holectypoid echinoid genus *Conulus* as *Galerites*, and was used to describe a significant occurrence of *Conulus subrotundus* (MANTELL). The *Conulus* Facies is indicative of shallower environments (LÖSCHER 1912) and it is, where it occurs within otherwise normally developed Pläner limestones, interpreted as a regressive event (ERNST & *al.* 1979). In other localities where the *Conulus* Facies is developed (*e.g.* Wüllen in Westphalia, ERNST 1967; Vienenburg in Lower Saxony, ERNST & WOOD 1995; Steinberg in Lower Saxony, ERNST & SCHMID 1984), *Echinocorys* is an invariable element of the facies. In the strongly condensed Wüllen section, *Conulus* occurs abundantly, *Echinocorys* is common, while *Micraster* is rare (ERNST 1967). In the Vienenburg section, where the GWA is condensed but without hardgrounds, *Echinocorys*, *Conulus* and *Sternotaxis* occur in approximately equal numbers, and *Micraster* is rare (ERNST & *al.* 1997). ERNST & WOOD (1995) showed that, beside the eponymous *Conulus* an assemblage of *Echinocorys gravesi*, *Sternotaxis* sp., *Orbirhynchia* and other brachiopods characterize this facies. Additionally, the hexactinellid sponge *Cystispongia bursa* is common in regressive phases, as observed in other localities in Lower Saxony. With or without *Conulus*, the association of *Echinocorys*, *Sternotaxis*, *Cystispongia* and brachiopods and the absence of *Micraster* ex. gr. *praecursor/cortestudinarium* fits the observations from other localities. In this paper, we apply the term "incipient *Conulus* Facies" to the latter faunal assemblage associated with lithologies suggestive of shallower environments and/or reduced accumulation rates.

At Salder, no evidence for a *Conulus* Facies can be recognized at the investigated level, suggesting continuous sedimentation. However, brachiopods (*Naidinothyris* sp., *Gibbithyris* sp.), and inoceramids (C.J. WOOD, *pers. comm.*), including fragments of large specimen of *Inoceramus hercules*, occur commonly in an interval approximately 4 m above the *Micraster* Event. At Söhlde, the presence of *Conulus* 'nests' (locally developed, weak *Conulus* Facies) and sedimentary anomalies (ERNST & WOOD 1995), approx. 50 cm above the *Micraster* Event, indicates condensation and a possible hiatus and may be the expression of the regressive event observed in the investigated localities.

With the renewed transgression in the uppermost part of the Lower Limestone Unit, the incipient *Conulus* Facies dissappears, and the faunal content decreases significantly. The echinoid association changes towards an assemblage that is dominated by *Sternotaxis* cf. *placenta*, *Infulaster* sp. and *Micraster* ex. gr. *praecursor/cortestudinarium*, indicating the more distal settings suggested by the lithological development.

Further faunal support for relative bathymetric reconstructions may be provided by the ammonite fauna. In Westphalia, KAPLAN (1991) demonstrated a threefold subdivision of the *Hyphantoceras* Event into three distinct, successive ammonite associations. The basal association fauna is characterized by a collignoniceratid/allocrioceratid association. It is followed by a nostoceratid and a desmoceratid association. The latter fauna reflects already advanced transgression, and its presence in the working area can be demonstrated in the northern part of the Groß-Flöthe quarry. There, the desmoceratid association is characterized by the common occurrence of *Lewesiceras mantelli* together with *Hyphantoceras flexuosum* and *Neocrioceras* sp. The interval around the *Micraster* Event marks peak transgression (KRÖGER 1996a), and it is accompanied by a low-diversity fauna of sporadic *Sciponoceras bohemicum* and *Scaphites* sp. As these genera are ubiquitous in the Upper Turonian of northern Germany, it is the absence of any other significant ammonites, rather than the presence of these genera, that indicates a period of relative high sea-level.

Within the thickening-upwards development towards the incipient *Conulus* Facies in the upper Lower Limestone Unit, the macrofaunal content increases. Concomitantly with the observed regressive development, the ammonite fauna shifts back into a nostoceratid association, consisting of *Hyphantoceras flexuosum*, *Neocrioceras* sp. and *Eubostrychoceras saxonicum*. A similar fauna in the same stratigraphic position was described by HORNA & WIESE (1997) from Hoppenstedt (Saxony-Anhalt) and by KAPLAN (1991) from the Anneliese quarry at Bad Laer (Westphalia). The FAD of the collignoniceratid ammonite *Prionocyclus germari* is located in this interval at the latter locality. It should also be noted that at Groß-Flöthe (interpreted here, based on lithology and fauna, as the shallowest section of this interval in the working area) several fragments of *Subprionocyclus normalis* were collected (Pl. 2, Fig. 5). This fits the distribution of collignoniceratid ammonites in general (TANABE & *al.* 1978, TANABE 1979, WESTERMANN 1996) and is specifically reported from the Turonian of the Münsterland Cretaceous Basin, where *Subprionocyclus normalis* and *Subprionocyclus branneri* (ANDERSON) occur preferentially in proximal settings (KAPLAN 1988). Furthermore, no other section in Lower Saxony has so far yielded collignoniceratid ammonites in this interval with the exception of a single, loose fragment from the *scupini* Zone of Hoppenstedt in Saxony-Anhalt (HORNA & WIESE 1997). Therefore, it may well be possible that the finds from Groß-Flöthe can be interpreted as indicating a shallow environment, which agrees well with the data presented above.

On the other hand, the sudden collapse of the nostoceratid ammonite assemblage and the occurrences of *Sciponoceras* sp. and *Scaphites* sp. in the uppermost Lower Limestone Unit and the GWA may indicate renewed transgression, with an ammonite assemblage similar to that around the *Micraster* Event. This interpretation is supported by the development of lithology and the other macrofauna.

Sequential interpretation

Bringing the lithological and macrofaunal data together, a statement on the change of the relative sea-level appears possible (Text-fig. 5). The short interval from the *Micraster* Event to the top of the thickening up cycle may well be interpreted as a late highstand systems tract (HST) *sensu* VAN WAGONER & *al.* (1988). As only a progradational development can be observed, no early, aggradational highstand is documented. The *Micraster* Event is inferred to reflect the maximum flooding zone as already proposed by KRÖGER (1996a). Based on data from HORNA & WIESE (1997) and VOIGT & HILBRECHT (1997), who show a major hiatus below the *Micraster* Event, and our own field data, it is suggested that the HST above the *Micraster* Event belongs to a sequence that is interpreted here to start within the *Hyphantoceras* Event, above the main *Hyphantoceras* occurrence. In order to avoid confusion by numbering individual sequences (as done *e.g.* by HORNA & WIESE 1997), this sequence is named here the "*flexuosum* Sequence", after the ammonite *Hyphantoceras flexuosum* that is characteristic of this interval. The *flexuosum* Sequence is terminated in the proximal section of Groß-Flöthe by a hardground that is taken as a third order cycle sequence boundary. Lithostratigraphic correlation with adjacent areas suggest an hiatus which is lithologically confirmed by the occurrence of reworking above the sequence boundary. Down-swell, the time-equivalent strata of the hiatus are characterized by an (incipient) *Conulus* Facies (Nettlingen, Söhlde) or even by an apparently continuous succession with a significant increase in faunal diversity that can be observed 4 m above the *Micraster* event at Salder. The latter interval at Salder, around the marl bed 9c of WOOD & ERNST (1997), however, is characterized by laminated and slightly convoluted bedding, suggesting minor sedifluction structures. This points to the possibility of a small hiatus, and might be interpreted as the expression of the sequence boundary in the distal setting of Salder. Within this context, it is interesting to note that, based on a comparison of the stable carbon isotope curve from Salder with that from northern Spain (WIESE, *in press*), the interval above marl bed 9c is inferred to be characterized by an expanded hiatus because part of the Spanish isotope curve is missing from the Salder. Based on this information, a detailed correlation of the lowermost part of the *Didymotis* Sequence is not possible.

The uppermost part of the Lower Limestone Unit exhibits a slow thinning upwards development, with an increase of marl beds, that grades continuously into the GWA. Both lithological and faunal parameters suggest a progressive deepening. This interval is, therefore, regarded as representing a TST of a third order cycle. Based on the literature, it appears that this sequence may extend up into the Lower Coniacian Upper Limestone Unit of ERNST & *al.* (1983). The latter shows a progradational stacking pattern and may, therefore, be regarded as a HST. As the sequence largely corresponds to the reported range of *Didymotis*, we suggest the name "*Didymotis* Sequence" for this sequence.

Interbasinal correlation

The data presented in this paper show a third order sequence boundary (SB) to occur within the Late Turonian *Mytiloides scupini* Zone of Lower Saxony. Taking the faunal data into consideration, it appears that this SB is located in the lowermost *Prionocyclus germari* Zone. These data suggest this regressive event to be the same as the one that generated the facies change towards the shallow water greensand facies in the lowermost *germari* Zone of the Münsterland Cretaceous Basin. It must be concluded that this SB, therefore, is not a local phenomenon but can be recognized at least in Westphalia, Lower Saxony and Saxony-Anhalt. Cycle charts from other regions (Saxony: TRÖGER & VOIGT 1995; England: GALE 1996; northern Spain: GRÄFE 1994; Tunisia: ROBASZYNSKI & *al.* 1990) or at the "global" cycle chart of HAQ & *al.* (1988), do not recognize a SB in this stratigraphic position.

In the North Cantabrian Basin (northern Spain), however, WIESE & WILMSEN (*in press*) report a SB in the lower part of their late Turonian *Mytiloides scupini/Prionocyclus germari* Assemblage Zone that equates with the *scupini* Zone as recognized in northern Germany.

Therefore, this SB is inferred to correlate with that observed in the working area.

In the Úpohlavy section in the Bohemian Cretaceous Basin (Czech Republic), a sequence boundary can be recognized in the Late Turonian, indicated by channels that incise deeply into the underlying strata (ČECH & *al.* 1996). Based on the stratigraphic data, this SB lies within the Teplice Formation, which falls within a *Mytiloides striatoconcentricus* Zone. In Bohemia, this zone spans roughly the interval from the equivalent of the German *Hyphantoceras* event to the base of the Lower Coniacian. As this SB still lies well below the *Didymotis* I Event in the litho unit Xb (ČECH 1989), it is highly possible that it can be correlated with the *scupini* Zone SB discussed in this paper. Biostratigraphic data from boreholes and exposures elsewhere in the Bohemian Cretaceous Basin are also relevant to the discussion. ČECH (1989) could demonstrate that the top of litho-unit Xb ranged almost to the base of the *germari* Zone, which likewise marks the base of the succeeding litho-unit Xc. The channel fill is interpreted as belonging still to litho-unit Xb by ČECH & *al.* (1996), without giving any biostratigraphic or lithostratigraphic reasons. It therefore may be worth discussing, whether the channel cuts down from the unit Xc into the underlying strata of Xb. If this were the case, the SB recognized in the Úpohlavy section would also fall into the basal *germari* Zone and would, therefore, equate exactly with the position of the SB recognized in Westphalia and Lower Saxony.

In southern England (Lewes), the *Micraster* Event cannot be recognized. A thick marl with abundant large *Micraster leskei*, the Lewes Marl, however, may be a correlative event of either the tuff T_F or the marl bed M_F (Text-fig. 2, *see* WRAY & *al.* 1996). Based on a bio- and event stratigraphic correlation between northern Spain, northern Germany and southern England, WIESE (1997) discussed whether the Lewes Marl may equate the tuff T_F [investigations on the origin (detrital *versus* volcanic) of Turonian marl beds are currently being carried out by D. WRAY; University of Greenwich]. In any case, the FAD of the "modern" *Micraster* ex gr. *praecursor/cortestudinarium* immediately above the Lewes Marl indicates that this interval equates with the base of the strata investigated in this paper. Above the Lewes Marl, a progressive development towards nodular chalks (Lewes Nodular Chalk), locally flinty chalk (Upper Lewes Flints) and cemented surfaces (Lewes Hardground) can be observed (MORTIMORE 1986, MORTIMORE 1987, MORTIMORE 1997). Based on HANCOCK (1989) and ERNST & *al.* (1996), this is inferred to indicate a shallowing development. Above the Lewes Nodular Chalk, the facies changes rapidly towards a soft white chalk (Cuilfail Bänderkreide/*Zoophycos* beds). It correlates positively with a turnover in the ichnofacies from a *Thalassinoides/Spongeliomorpha* association in the Lewes Nodular Chalk towards a *Zoophycos/Chondrites* association in the Cuilfail Bänderkreide. Following ichnofacies models of *e.g.* EKDALE & BROMLEY (1984), FREY & PEMBERTON (1984) and SAVRDA & *al.* (1991), this turnover can be interpreted as indicating a deepening and, therefore, as a transgressive development (MORTIMORE & POMEROL 1991). Based on these data, it can be shown that a regressive/transgressive event can be observed in southern England in a stratigraphic position that demands a correlation with that observed in northern Germany.

In the Upper Turonian *Mytiloides incertus* Zone [which spans the interval from the north German *Mytiloides incertus* Event (Text-fig. 2) to the Turonian/Coniacian boundary interval, WALASZCZYK 1992] of the Folwark quarry (Opole Trough, Poland), passively back-filled, synsedimentary depressions were observed during field work of the working group G. ERNST (Berlin). These are located well above the top of the *Hyphantoceras* Event and significantly below the Turonian/Coniacian boundary. Stratigraphically, these features equate the position of the SB terminating the *flexuosum* sequence.

CONCLUSION

The investigation of the abandoned limestone quarries of Nettlingen and Groß-Flöthe shows that, based on fauna and lithology, the lower part of the upper Lower Limestone Unit (*Mytiloides scupini* Zone, Upper Turonian) above the *Micraster* Event exhibits a progradational and, therefore, a shallowing development. These strata are interpreted as a HST. The *Micraster* Event marks the maximum flooding Zone. Based on the data obtained from literature, it is assumed that the strata treated here are part of a third order cycle that starts above the *Hyphantoceras* Event. For this sequence the name *flexuosum* Sequence is proposed.

The succeeding sequence boundary is located in the lower part of the *Prionocyclus germari* Zone. In Groß-Flöthe, it is characterized by a hardground and reworking. Based on lithostratigraphic correlation within a bio/event stratigraphic framework it can be shown that the Groß--Flöthe section is the shallowest known section exhibiting this stratigraphic interval in Lower Saxony. In Nettlingen and Söhlde, the interval around the SB is characterized by an (incipient) *Conulus* Facies. This development can be tentatively recognized at Salder by an abundance and diversity peak of the macrofauna.

The following succession (uppermost Lower Limestone Unit and Grey and White Alternation) exhibits a retrogradational development. It is, therefore, interpreted as a TST. For this sequence, which presumably terminates in the Upper Limestone Unit, the name *Didymotis* Sequence is proposed.

Interbasinal correlation shows that the SB recognized here equates with that below the Westphalian greensand occurrence. Further evidence for a sequence boundary in the high Turonian can be recognized in Spain, southern England, Poland and the Czech Republic. It therefore seems that this event can be recognized over a wide area and that it may be of importance, at least in Europe, for a reconstruction of a relative sea-level curve.

Acknowledgements

The authors are indebted to C.J. WOOD (Croydon) for valuable discussion and for correcting the English. G. ERNST (Berlin) and U. REHFELD (Berlin) kindly provided material that was collected during a field trip to Groß-Flöthe in 1997. T. JÖRDENS-MÜLLER (Berlin) and A. CZAJA (Berlin) contributed material and information from their diploma-theses. M. WILMSEN (Berlin) gave helpful comments during the final phase of this paper. WIESE is especially indebted to Dr. S. VOIGT, TU BA Freiberg, for long and fruitful discussions.

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PLATES 1 – 2

PLATE 1

1 – Weakly bioclastic (calcisphere) wackestone (bed 1 at Nettlingen, HST of the *Hyphantoceras* Sequence) with calcispheres, spicules and debris of heterohelicid and hedbergellid planktonic foraminifera Based upon the above presented facies interpretation, the comparatively high calcisphere content suggests a more distal setting close to or within the calcisphere belt (width of picture: 2,1 cm)

2 – Weakly bioclastic wackestone (bed 5 at Groß-Flöthe) with fragments of heterohelicid and hedbergellid planktonic foraminifera, lateral equivalent of bed 1 at Nettlingen (Pl. 1, Fig. 1). In context with the above presented facies model, this microfacies is inferred to reflect more proximal environments as the calcisphere wackestones (HST of the *Hyphantoceras* Sequence) (width of picture: 2.7 cm)

3 – Borings grade from the cemented hardground (3rd order cycles sequence boundary) into bed 5 at Groß-Flöthe. The open cavities are infilled with calcareous muds. The infill exhibits sometimes (left side of the picture) graded bedding (width of picture: 6.5 cm)

4 – Contact between the hardground (wackestone of the uppermost *flexuosum* Sequence) and the overlying debrite/conglomerate complex (bioclastic wacke/packstone of the basal *Didymotis* Sequence) at Groß-Flöthe (width of picture: 2.7 cm)

5 – Conglomeratic layer at Groß-Flöthe (bioclastic wackestone), consisting of echinoderm debris, planktonic and benthonic foraminifera, calcispheres and spicules (width of picture: 2.7 cm)

6 – Same as Fig. 5, here with calcispheres, 1) spines or regular echinoids, 2) asteroid ossicles, 3) heterohelicids, 4) hedbergellids, 5) spicules (width of picture: 4.1 cm)

7 – Echinoderm debris at Groß-Flöthe (bioclastic wackestone) with abundant echinoderm fragments [spines of regular echinoids, thick-shelled echinoderm debris of *Echinocorys* (?), thin shelled debris of irregular echinoids (*Sternotaxis*?), asteroid ossicles], inoceramid-debris, shells of *Spondylus* sp. (1), *Lenticulina* sp., biserial textulariid foraminifera, planktonic foraminifera, calcispheres and spicules. of subordinate importance Ostracodes (width of picture: 7 cm)

8 – Bioclastic calcisphere wackestone above the echinoderm debrite at Groß-Flöthe (bed 8), indicating renewed authochthonous sedimentation (TST of the *Didymotis* Sequence) (width of picture: 4.9 cm)

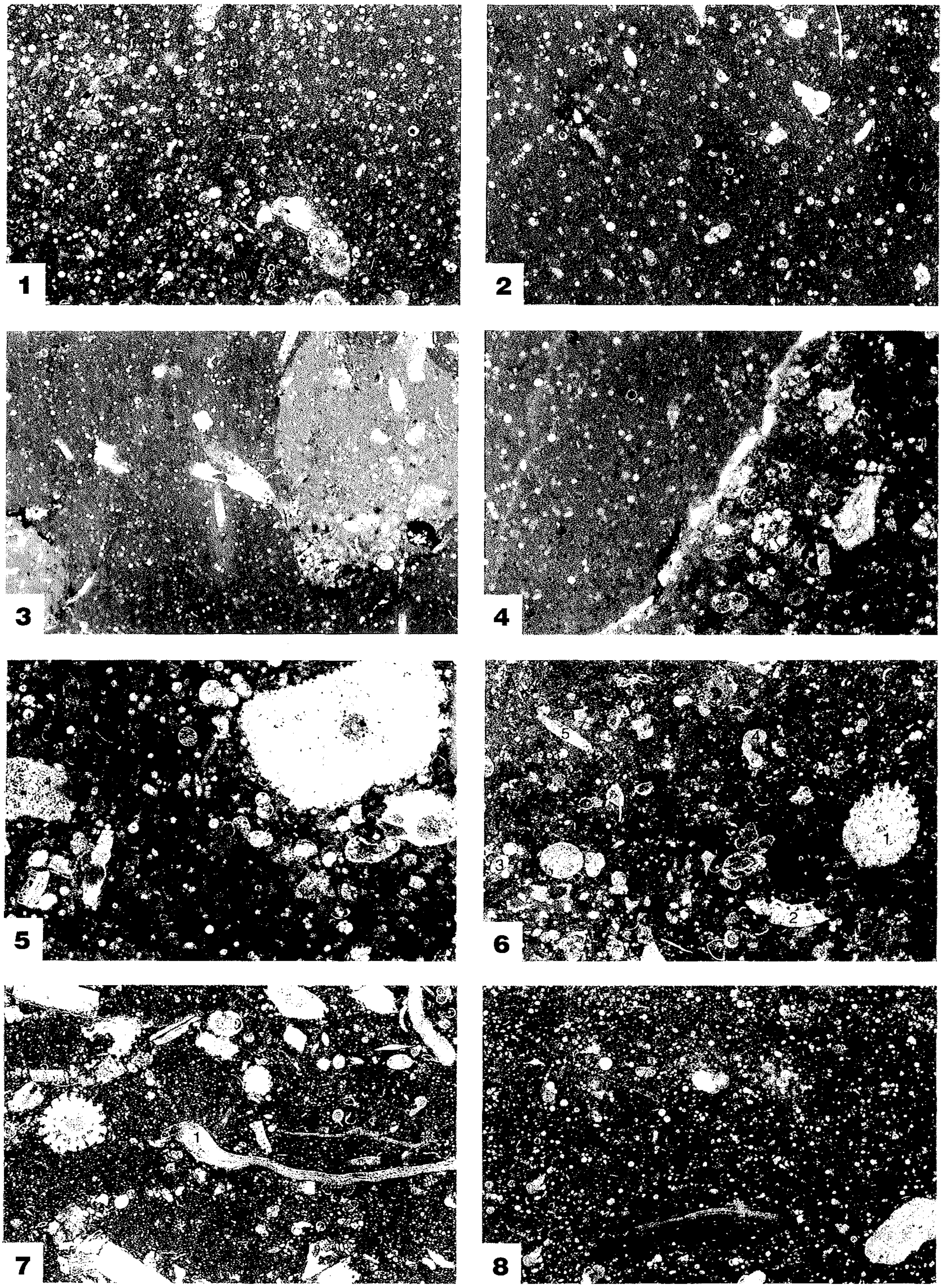


PLATE 2

1 – Limonitized sponge from the Sponge Bed of Nettlingen, late HST of the *Hyphantoceras* Sequence (× 1).

2 – *Cystispongia bursa* (QUENSTEDT), Heteromorph Beds of Groß-Flöthe (bed 5), HST of the *flexuosum* Sequence (× 1).

3 – Associated ossicles of *Metopaster* sp. (?), Heteromorph Beds at Groß-Flöthe (bed 5), HST of the *flexuosum* Sequence (× 1)

4 – *Hirudocidaris* sp., bed 5 at Nettlingen, TST of the *Didymotis* Sequence (× 1)

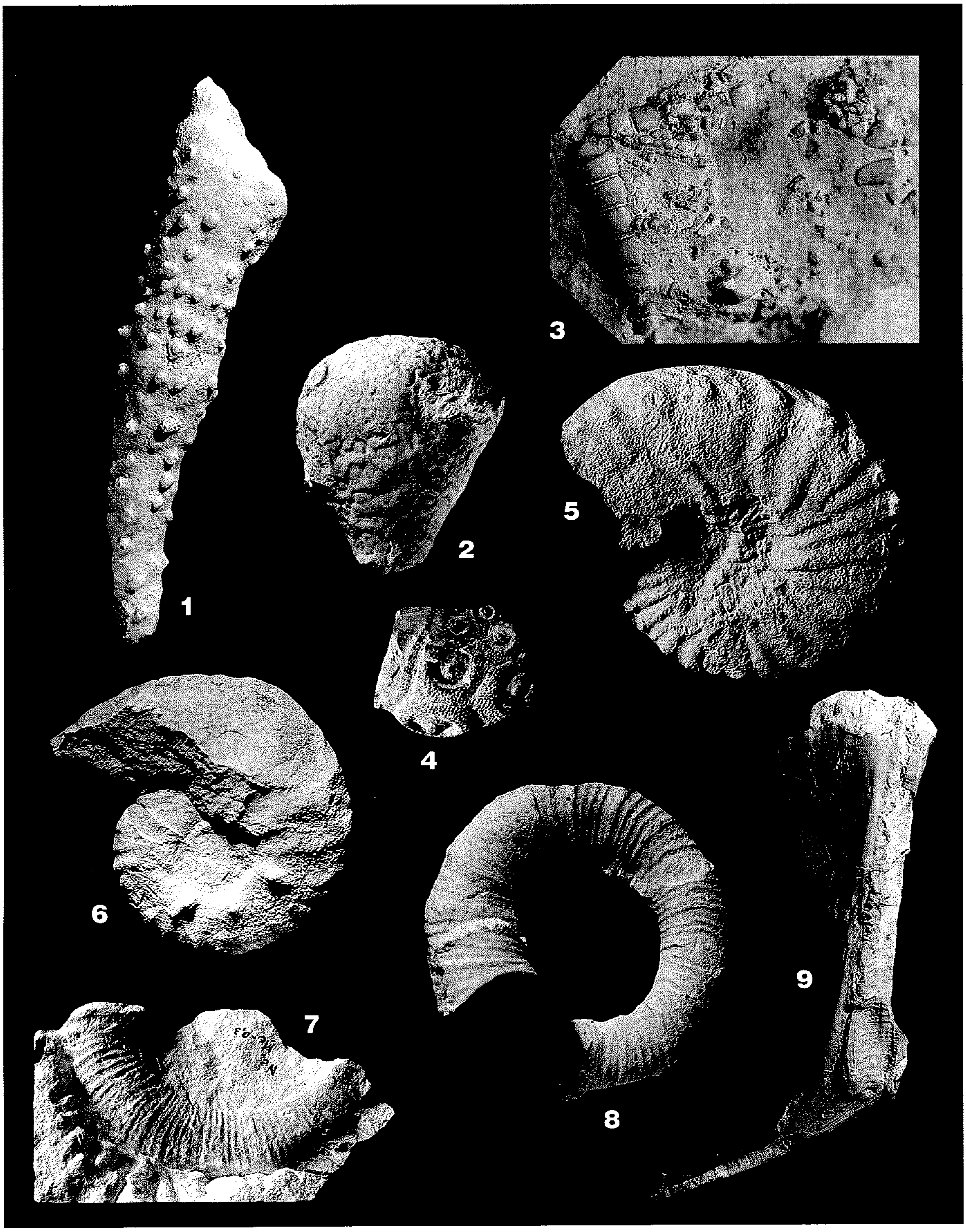
5 – *Subprionocyclus normalis* (ANDERSON), loose from the lower Heteromorph Beds (approximately base of bed 5) at Groß-Flöthe, HST of the *flexuosum* Sequence (× 1)

6 – *Lewesiceras mantelli* WRIGHT & WRIGHT, base of the exposed strata at Groß-Flöthe. It belongs to the desmoceratid ammonite assemblage of the *Hyphantoceras* Event *sensu* KAPLAN (1991), TST of the *flexuosum* Sequence (× 1)

7 – *Neocrioceras* sp. aff. *paderbornense* (SCHLÜTER), Heteromorph Beds (bed 1) at Nettlingen, uppermost *flexuosum* Sequence (× 1)

8 – *Hyphantoceras flexuosum* (SCHLÜTER), base of the exposed strata at Groß-Flöthe. It occurs together with *Lewesiceras mantelli* in the desmoceratid ammonite assemblage of the *Hyphantoceras* Event *sensu* KAPLAN (1991), TST of the *flexuosum* Sequence (× 1)

9 – Large hinge of *Inoceramus hercules* HEINZ from the Heteromorph Beds (bed 5) at Groß-Flöthe, uppermost *flexuosum* Sequence. Original size: 20 × 9 cm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