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Santonian ammonite stratigraphy of the Münster Basin, NW Germany

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ABSTRACT:

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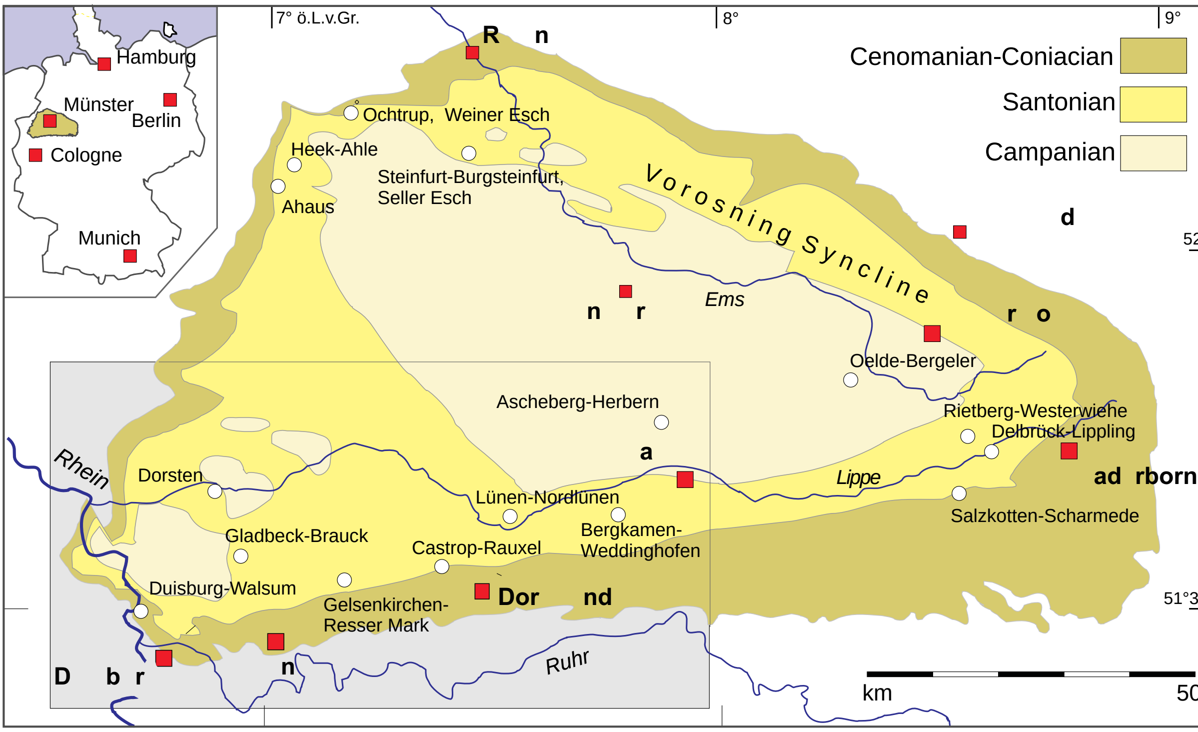
The upper Upper Coniacian and Santonian ammonite stratigraphy of the Münster Basin, Westphalia, NW Germany, is described in the context of regional litho-, inoceramid- and sequence stratigraphy. The *Sphenoceramus pachti* & *S. cardissoides* Zone, previously regarded as basal Santonian, is placed in the uppermost Coniacian. The Lower Santonian corresponds to the *Cladoceramus undulatoplicatus* Zone, the lower Middle Santonian to the *Cordiceramus cordiformis* Zone. The *Sphenoceramus pinniformis* Zone spans the upper Middle Santonian to the lower Upper Santonian. The succeeding *Sphenoceramus patootensiformis* Zone corresponds approximately to the *Marsupites testudinarius* crinoid zone of the upper Upper Santonian. Occurrences of the belemnite *Gonioteuthis* are discussed. The ammonite occurrences are documented in the context of inoceramid and, where possible, belemnite and crinoid stratigraphy. A *Texanites* (*Texanites*) *pseudotexanus* Zone extends from the uppermost *M. subquadratus* Zone to the Upper Coniacian/Lower Santonian boundary. The *Kitchinites emscheris* Zone comprises the Lower and Middle Santonian. The Upper Santonian corresponds to the *Boehmoceras arculus* Zone. The ammonite faunas are predominately endemic from the Upper Coniacian to the Middle Santonian. Only the Upper Santonian yields supraregional and even global ammonite taxa such as *Boehmoceras arculus* and *B. krekeleri,* which co-occur with the widespread crinoids *Uintacrinus socialis* and *Marsupites testudinarius*. Sequence boundaries, followed by transgressive pulses, are identified in the uppermost Coniacian, with a subordinate event in the Middle Santonian, the most significant event in the basal Upper Santonian and the last in the Lower Campanian. Ammonite occurrences are clearly related to the sequences recognized.

Key words: Upper Creteceous, Santonian, Stratigraphy, Ammonites, NW Germany, Münster Basin.

INTRODUCTION

The Santonian stage, introduced by COQUAND in 1857, was already recognized in north Germany by SCHLÜTER (1876), who treated it as a synonym of the Lower Senonian. SCHLÜTER (1874) had previously introduced the Emscherian Marl (= Emscher or Emscher-Mergel) for a unit underlying the Lower Senonian, and it has become firmly established as a lithostratigraphical term. The boundary between Emscherian and Lower Senonian has never been uniformly defined and is now of no more than historical interest. HEINZ (1934) contributed to a discussion with RIEDEL, and asserted that the widely held opinion that the Emscherian Marl was equivalent to the Coniacian was in error: he demonstrated that the Emscherian Marl covers considerable parts of the Santonian. It was only



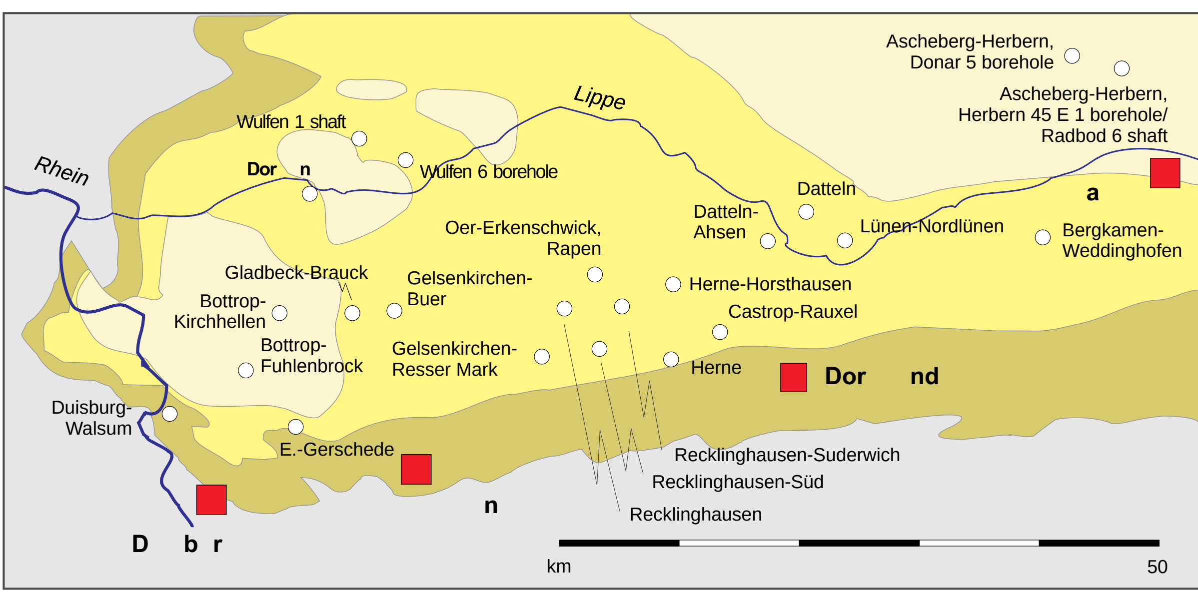


Fig. 1. Coniacian to Campanian outcrops in the Münster Basin, showing localities mentioned in text, *after* HISS (1995a)

with the work of SEITZ (1952) that the Santonian stage was accepted in the NW German Upper Cretaceous.

Rocks of Santonian age had considerable importance in regional mining geology, as they were cut by all boreholes and mine shafts in the northern Ruhr district. The highly variable facies development recognized in the subsurface is the expression of dynamic basin development, and gave rise to a major technical challenge for shaft construction. Shafts in the argillaceous, sandy-aquifers, and sometimes potentially mobile deposits of the western Münster Basin were usually constructed using refrigeration techniques, other shafts using flushing techniques. Both techniques regularely resulted in the destruction of most macrofossils; consequently only few macrofossils, among them ammonites, were collected from these at least partially fossil-rich shafts.

Surface quarries and pits, many now re-filled, were continuously collected, and suggest great richness in fossils. They exposed only short sections in relation to total thicknesses of in some cases several hundred metres, so their value in stratigraphical analysis is limited. Material from systematically collected shafts and cored boreholes of the southern and central Münster Basin compensate for these deficiencies. However, their ammonite faunas are usually badly preserved, partially undeterminable and relatively rare. For full biostratigraphic utilisation they must be linked to inoceramid and if possible to crinoid occurrences whenever possible.

These practical difficulties have hindered the establishment of an upper Upper Coniacian and Santonian ammonite stratigraphy for the Münster Basin, while it has been equally difficult to establish elsewhere an ammonite zonation that can be traced at least over western Europe (HANCOCK 1991). Against this background, the Santonian ammonite stratigraphy of the Münster Basin is revised and emended, building on the fundamental, and in its central aspects still relevant, publication of RIEDEL (1931). WIEDMANN's (1979) brief account of Upper Coniacian and Santonian ammonite distributions in NW Germany is based on the work of SCHLÜTER (1876). WIEDMANN failed to consider or reflect on the works of WEGNER (1905), RIEDEL (1931), and the bulk of stratigraphical details given by SEITZ (1961, 1965, 1967, 1970) and ARNOLD (1964a, b, c). His stratigraphical scheme is superfical, and in parts wrong. LOMMERZHEIM (1995) established a multistratigraphical stratigraphy for the Santonian of the Münster Basin, and combined it with an excessively elaborated ammonite stratigraphy. He based it on the limited and more or less badly preserved ammonite material of the Herbern 45 E 1 preparatory borehole, Radbod 6 shaft, Donar 5 borehole, Ascheberg-Herbern and the Wulfen 1 borehole (*see below*). The revision of his ammonite material showed that many of his determinations are questionable (KENNEDY *in* KENNEDY & KAPLAN *in prep*.).

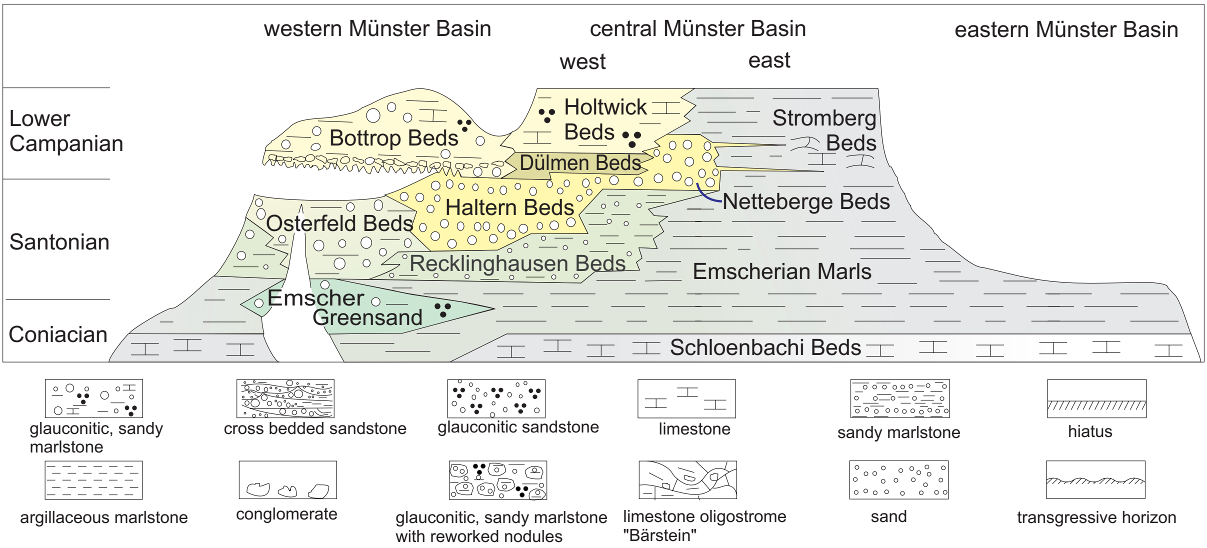


Fig. 2. Schematic diagram, to show the relationship of the lithostratigraphical units of the Münster Basin Coniacian to Lower Campanian (*after* HISS 1995a), and lithological symbols used in this paper

LOCALITY DETAILS

Stratigraphically relevant localities in the Münster Basin (Text-fig. 1) are listed below. For further localities, ammonite occurrences, repositories of collections and additional literature see KENNEDY & KAPLAN (1994) and KENNEDY & KAPLAN (1995; *in prep*.). There are only three still existing (1999) and accessible exposures of rocks of Santonian age in the Münster Basin: the abandoned Leßmöllmann claypit at Castrop-Rauxel (Ruhr district), the abandoned but conserved Weiner Esch quarry at Ochtrup (northern Münster Basin) and the Rehage claypit of the Wienerberger brickworks, Rietberg-Westerwiehe (eastern Münster Basin). A key to the lithological symbols are set out in Text-Fig. 2 (It should be noted that stratigraphical ranges of boreholes and shafts are only given as far as they are relevant for this paper).

AHAUS, excavations in northern building area, topographic sheet TK 25 Blatt 3908 Ahaus, R = 2568850, H = 5773350 (central value), Upper Santonian, *B. arculus* Zone.

ASCHEBERG-HERBERN, a) Herbern 45 E1 preparatory borehole and subsequent shaft Radbod 6 (Text-Fig. 3), topographic sheet TK 25 Blatt 4212 Drensteinfurt, R = 34 12709, H = 5734046, upper Coniacian to lower Campanian. b) Donar 5 borehole (Text-Fig. 3), topographic sheet TK 25 Blatt 4212 Drensteinfurt, R = 3411632, H = 5735459, upper Upper Coniacian to lower Campanian.

BERGKAMEN-WEDDINGHOFEN, Monopol coal mine, Grimberg 3/4 shaft work, shaft IV (Text-Fig. 4), topographic sheet TK 25 Blatt 4311 Lünen, R = 2611712, H = 5720786, upper Upper Coniacian to Middle Santonian.

BOTTROP-FUHLENBROCK, Franz Haniel coal mine, Franz Haniel 2 shaft (Text-Fig. 9), topographic sheet TK 25 Blatt 4407 Bottrop, R = 2561087, H = 5712662, upper Upper Coniacian to lower Campanian.

BOTTROP-KIRCHHELLEN, Kirchhausen, Lippermulde 1a borehole, topographic sheet TK 25 Blatt 4407 Bottrop, R = 2563894, H = 5720807, upper Upper Coniacian to upper Upper Santonian.

CASTROP-RAUXEL, OBERCASTROP, abandoned claypit of Leßmöllmann brickworks, a) old pit: topographic sheet TK 25 Blatt Herne R = 2591380, H = 5711790, upper Upper Coniacian, *S. pachti* and *S. cardissoides* Zone to lower Lower Santonian, *S. undulatoplicatus* Zone, b) new pit: topographic sheet TK 25 Blatt 4409 Herne, R = 2590940, H = 5711970, Lower Santonian, basal *S. undulatoplicatus* Zone.

DELBRÜCK-LIPPLING, trial pit north at Wilsmann farm, topographic sheet TK 25 Blatt 4117 Verl, R =

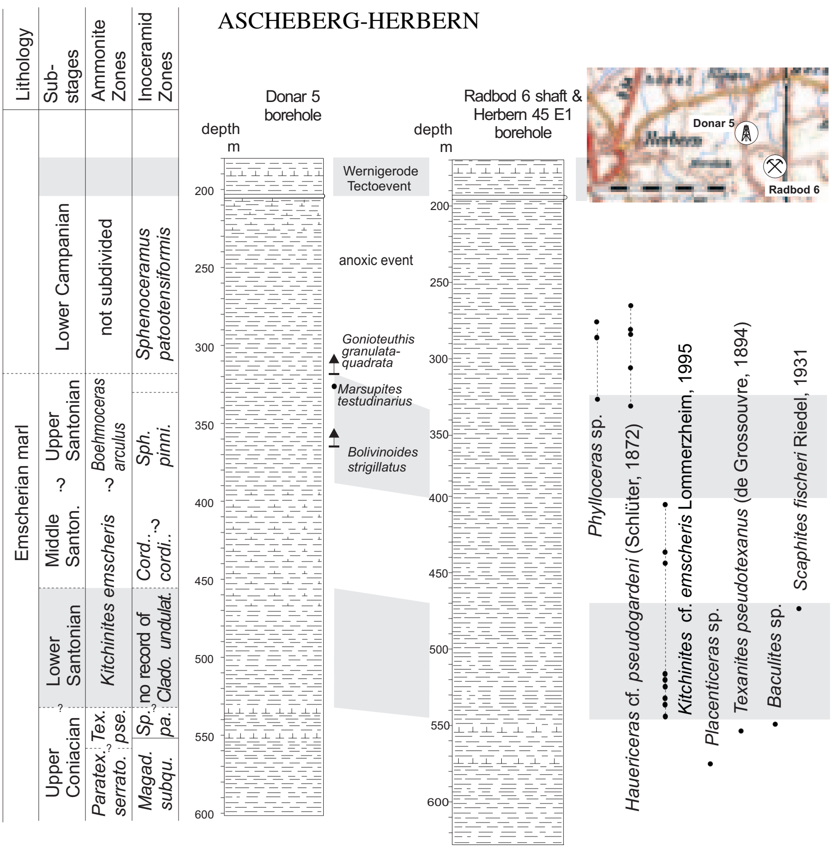


Fig. 3. Uppermost Coniacian-Santonian ammonite occurrences in the Donar 5 borehole and the nearby Herbern 45 E1 preparatory borehole/, Radbod 6 shaft. Ascheberg-Herbern. Lithology and inoceramid zones are modified after ARNOLD & WOLANSKY (1964), SEITZ (1970) and LOMMERZHEIM (1995). *Paratex. serrato.* = *Paratexanites serratomarginatus*; *Tex. pse.* = *Texanites pseudotexanus*; *Magad. subqu.* = *Magadiceramus subquadratus*; *Clado. undulat.* = *Cladoceramus undulatoplicatus*; *Cord. cordi.* = *Cordiceramus cordiformis*; *Sph. pinni.* = *Sphenoceramus pinniformis*

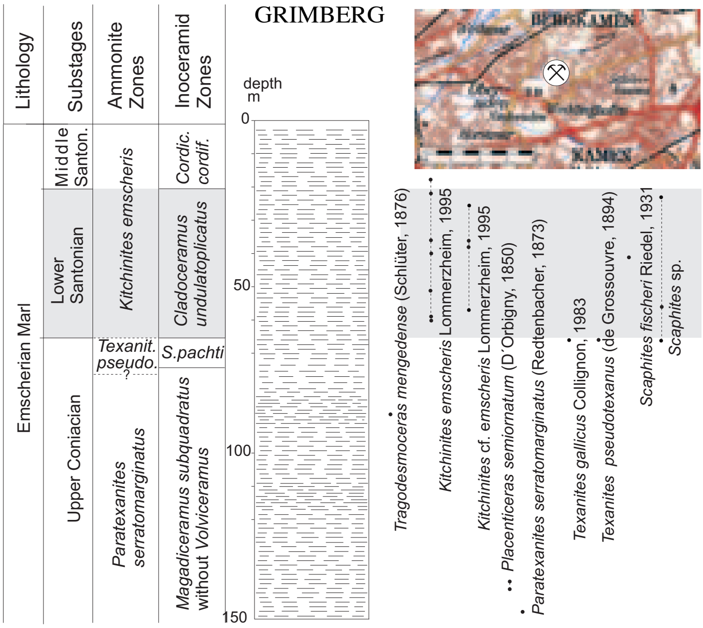


Fig. 4. Upper Coniacian-Santonian ammonite occurrences in the Grimberg coal mine, shaft IV, Bergkamen-Weddinghofen. Lithology after FALK (1935) and RIEDEL (1931); inoceramid zones after RIEDEL (1931) and TRÖGER (1974). Middle Santon. = Middle Santonian; *Texanit. pseudo.* = *Texanites pseudotexanus; S. pachti* = *Sphenoceramus pachti; Cordic. cordif.* = *Cordiceramus cordiformis*

3467615, H = 5741205, upper Middle Santonian, *C. cordiformis* Zone.

DORSTEN-WULFEN, a) Wulfener Heide, Wulfen 6 borehole, topographic sheet TK 25 Blatt 4208 Wulfen, R = 2571072, H = 5730222, upper Upper Coniacian to Upper Santonian. b) Wulfen 1 shaft, topographic sheet TK 25 Blatt 4208 Wulfen, R = 2573049, H = 5732228, upper Coniacian and Santonian.

DUISBURG-WALSUM, Walsum coal mine, a) shaft I = Wilhelm Roelen shaft (Text-Fig. 9), topographic sheet TK 25 Blatt 4406 Dinslaken, R = 2549669, H = 5710760, upper Upper Coniacian and Upper Santonian. b) shaft II = Franz Lenze shaft, topographic sheet TK 25 Blatt 4406 Dinslaken, R = 2549765, H = 5710790, upper Upper Coniacian and Upper Santonian.
ESSEN-GERSCHEDE, abandoned claypit of Reuenberg brickworks, also known as Ziegelei Dellwig = Dellwig brickworks in SEITZ (1967); ERNST (1964a), topographic sheet TK 25 Blatt 4507 Mülheim, R = 2565150, H = 5705960, Middle Santonian, lower *C. cordiformis* Zone, lower *G. westfalica* Zone.

ESSEN-VOGELHEIM, excavations for town harbour, = Essen-Stadthafen of ERNST (1964a) topographic sheet TK 25 Blatt 4407 Bottrop, R = 2567760, H = 5707930 (central value), Lower Santonian *C. undulatoplicatus* Zone/Middle Santonian *C. cordiformis* Zone.

GELSENKIRCHEN-BUER, Beckhausen, abandoned claypit of Beckhausen brickworks, also known as Buer Süd brickworks, topographic sheet TK 25 Blatt 4408 Gelsenkirchen, R = 2573000, H = 5714200, Upper Santonian, *B. arculus Zone*, *S. pinniformis* Zone, *G. westfalicagranulata* Zone.

GELSENKIRCHEN-BUER, motorway A 2 roadworks (1992-1995), topographic sheet TK 25 Blatt 4408 Gelsenkirchen, R = 2572175, H = 5714310, Middle Santonian Upper Santonian boundary.

GELSENKIRCHEN-RESSER MARK, Graf Bismarck coal mine, Graf Bismarck 10 central air shaft, renamed in Ewald coal mine, Ewald 1/2/7 shaft work, Emschermulde 1 shaft, topographic sheet TK 25 Blatt 4408 Gelsenkirchen, R = 2577232, H = 5713910, upper Coniacian to Middle Santonian.

GLADBECK-BRAUCK, a) Rosenhügel, canalization of Hahnenbach, topographic sheet TK 25 Blatt 4408 Gelsenkirchen, R = 2570270, H = 5713240 to R = 2570610, H = 5713630, upper Middle Santonian, *C. cordiformis* Zone. b) motorway A 2 roadworks (1992-1995) (Text-Fig. 5), topographic sheet TK 25 Blatt 4408 Gelsenkirchen, R = 2570615, H = 5714260 (central value), Upper Santonian, *S. pinniformis* Zone, *U. socialis* Zone.

HEEK-AHLE, Ahler Esch, topographic sheet TK 25 Blatt 3808 Heek, R = 2572400, H = 5775500 (central value), Upper Santonian, *M. testudinarius* Zone, *B. arculus* Zone.

HERTEN, Ewald coal mine, shaft work 1/2/7, Ewald 5 air shaft (Text-Fig. 6), topographic sheet TK 25 Blatt 4408 Gelsenkirchen, R = 2580810, H = 5717620, upper Upper Coniacian to Upper Santonian.

LÜNEN-NORDLÜNEN, abandoned claypit of Roberts brickworks, also known as Nordlünen brickworks, topographic sheet TK 25 Blatt 4311 Lünen, R = 3398770, H = 5723150, Upper Santonian, upper *U. socialis* Zone & *M. testudinarius* Zone, *B. arculus* Zone.

OCHTRUP, Weiner Esch, abandoned quarry and protected geological site, topographic sheet TK 25 Blatt 3809

Metelen, R = 2580590, H = 5784845, Upper Santonian, *U. socialis* Zone ?.

OELDE, Bauernschaft Bergeler, motorway A 2, excavations at Landhagen car park (Text-Fig. 9), topographic sheet TK 25 Blatt 4115 Rheda-Wiedenbrück, R = 5744870, H = 5743830, upper Upper Santonian to Lower Campanian.

OER-ERKENSCHWICK, Rapen, abandoned claypit of Rapen brickworks, also known as Deitermann brickworks, topographic sheet TK 25 Blatt 4309 Recklinghausen, R = 2589735, H = 5724402, Upper Santonian, *B. arculus* Zone.

RECKLINGHAUSEN-SÜD, Recklinghausen coal mine, Recklinghausen II shaft work, Recklinghausen III air shaft, nowadays Ewald coal mine, Ewald 1/2/7 shaft work, topographic sheet TK 25 Blatt 4309 Recklinghausen, R 2582190, H = 57116790, upper Upper Coniacian to Upper Santonian.

RECKLINGHAUSEN, General Blumenthal coal mine, General Blumenthal 7 shaft work, shaft 7, topographic sheet TK 25 Blatt 4309 Recklinghausen, R = 2580960, H =

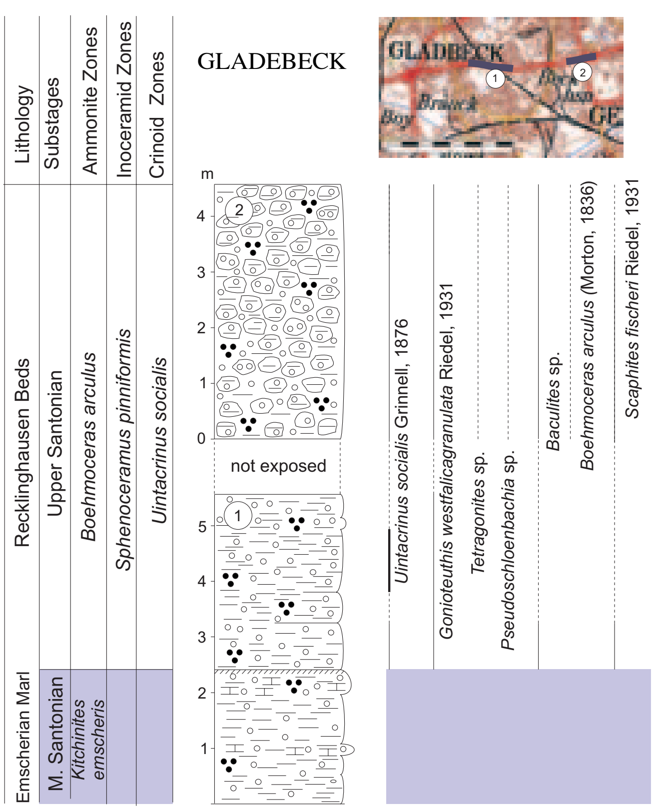


Fig. 5. Santonian-macrofossil occurrences in the Gladebeck-Brauck and Gelsenkirchen-Buer A 2 motorway excavations

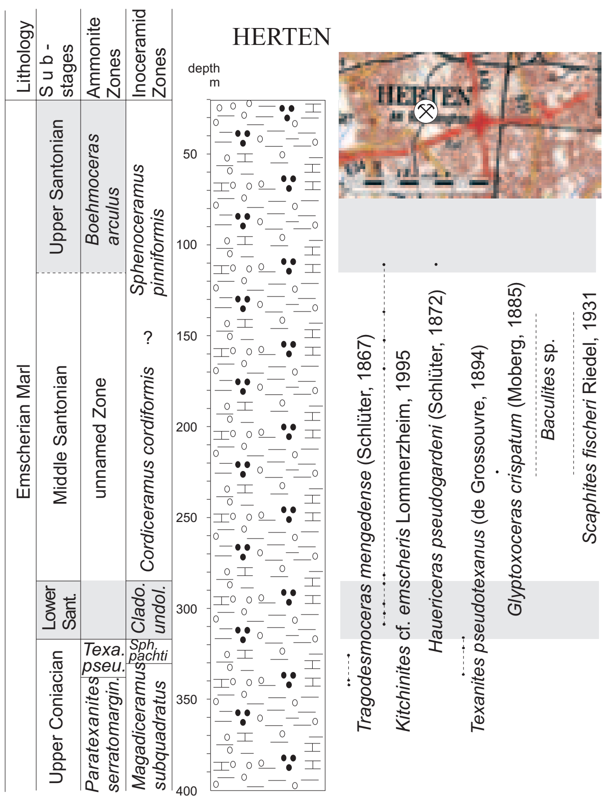


Fig. 6. Upper Coniacian and Santonian ammonite occurrences in the Ewald coal mine, shaft works 1/2/7, air shaft 5, Herten, *after* SEITZ (1961, 1965), where erroneously referred to as the Ewald-Fortsetzung coal mine, Oer-Erkenschwick - Rapen. *Texa. pseu.* = *Texanites pseudotexanus; Sph. pachti* = *Sphenoceramus pachti*

5721830, upper Upper Coniacian to lower Upper Santonian, *S. pinniformis* Zone.

RIETBERG-WESTERWIEHE, Rehage claypit of Wienerberger brickworks (Text-Fig. 7), topographic sheet TK 25 Blatt 4117 Verl, pit I: R = 3466690, H = 5742070 (refilled), pit II: R = 3466890, H = 5741990 (refilled), pit III: R = 3466760, H = 5742370 (in use 1998), Upper Santonian, upper *U. socialis* Zone and *M. testudinarius* Zone, *B. arculus* Zone.

STRATIGRAPHY

Lithostratigraphy

The facies development of the Upper Coniacian and Santonian of the Münster Basin has been described in numerous papers, many among them under the aspect of mining geology (*cf*. WEGNER

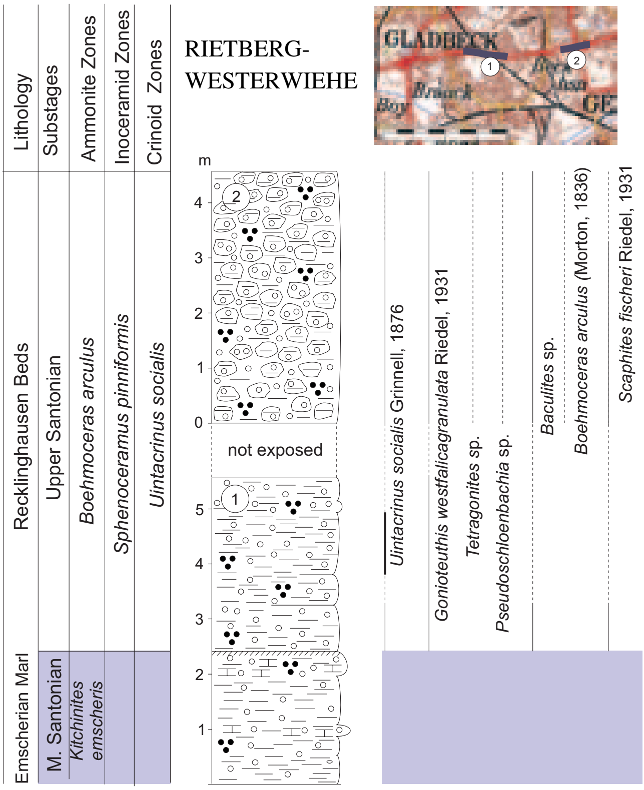


Fig. 7. Upper Santonian ammonite records from the Rehage claypit of the Wienerberger brickworks, Rietberg-Westerwiehe, after SCHÖNFELD (1985)

1905; BÄRTLING 1921; HEINE 1929; RIEDEL 1931, 1933; BEYENBURG 1934, 1941a, b; KUKUK 1938; ARNOLD 1957; WOLANSKY 1957; ARNOLD & WOLANSKY 1964; JORDAN & GASSE 1986; GASSE 1987; LOMMERZHEIM 1995). A recent summary was given by HISS (1995a), we confine ourselves to a short overview here (Text-Fig. 2).

The eastern Vorosning syncline and the centre of the Münster Basin are dominated by marl - and claystones, which range from Middle Coniacian into the lower Upper Campanian (Text-Fig. 9). Milankovich cycles seem to be common (LOMMERZHEIM, 1992, 1995; KAPLAN *in* KENNEDY & KAPLAN *in prep*.). The Emscherian Marl extends to a thickness of about 1500 m in the Vorosning syncline at the north-eastern margin of the basin (ARNOLD 1964b). To the west its thickness decreases continuously and it passes into the Upper Coniacian glauconitic Emscherian Greensand and, higher up, into the Upper Santonian argillaceous Recklinghausen Beds. The Emscher Greensand extends into the Santonian at the western margin of the Münster Basin. It is overlain by the sandy deposits of the Osterfeld Beds and the Haltern Beds. These are overlain by the predominately Lower Campanian Bottrop Beds

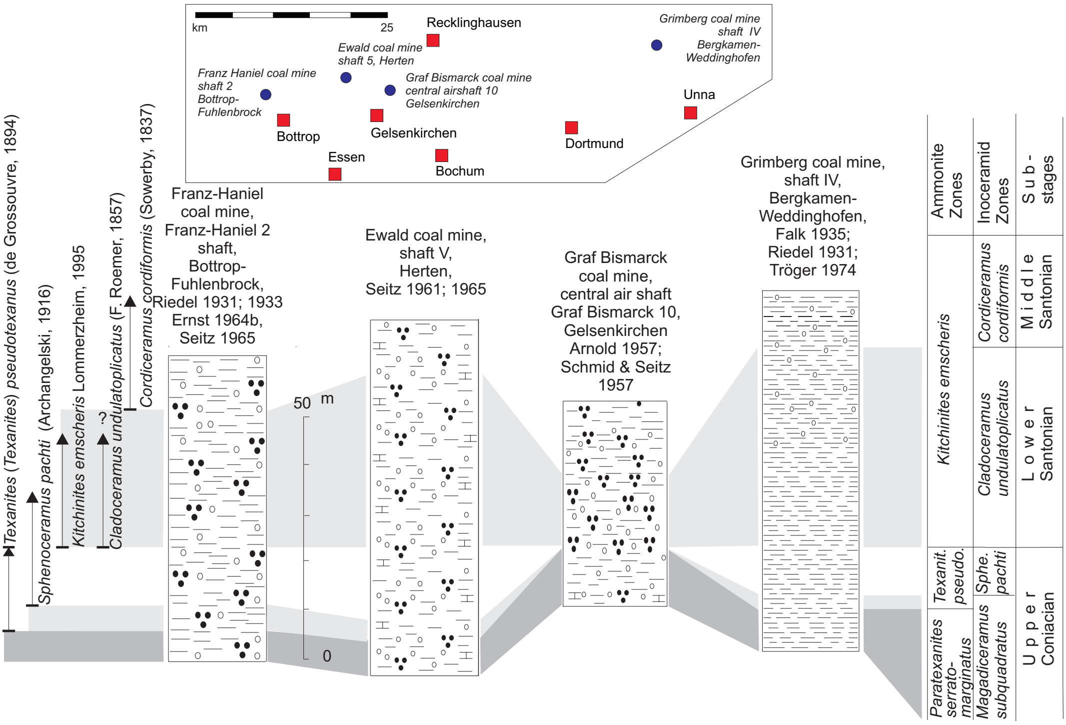


Fig. 8. Selected macrofossil records from the Coniacian-Santonian transition and the base of Middle Santonian in mine shafts of the Ruhr district, southern Münster Basin. Inoceramid zones after SEITZ (1961, 1965, 1967). *Texanit. pseudo.* = *Texanites pseudotexanus; Sphe. pachti* = *Sphenoceramus pachti*

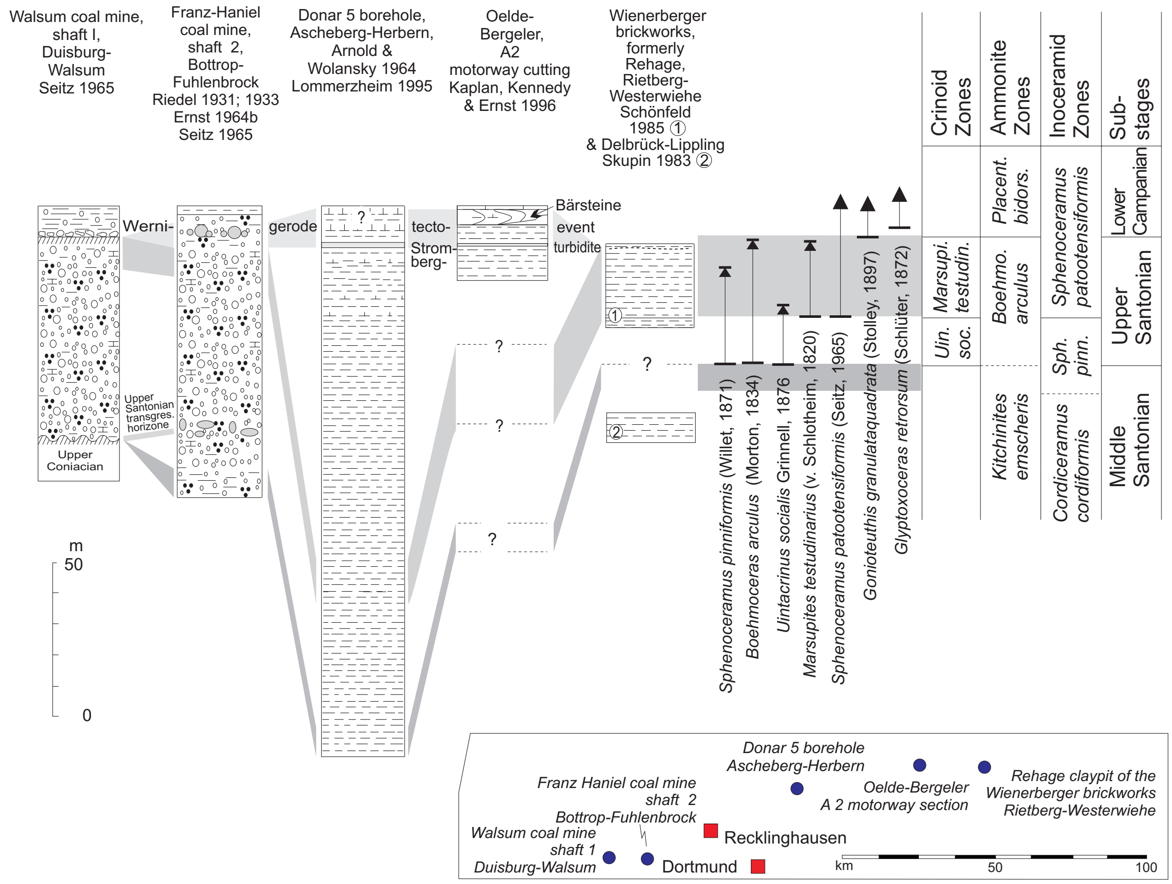


Fig. 9. Key macrofossil occurrences in the Upper Santonian and occurrences in the Santonian-Campanian transition (including the Wernigerode tectoevent) in the southern Münster Basin. Inoceramid zones after SEITZ (1961, 1965, 1967). *Uin. soc. = Uintacrinus socialis; Marsupi. testudin. = Marsupites testudinarius; Boehmo. arculus = Boehmoceras arculus; Placent. bidors. = Placenticeras bidorsatum; Sph. pinn. = Sphenoceramus pinniformis*

(ARNOLD 1964c). The northern Münster Basin is similarly differentially developed. Argillaceous and glauconitic deposits intercalate with marls and mudstones. HISS (1995b; 1997) describes the complicated facies relations. A special mention should be made of the bioclastic detrital rocks of Weiner Esch, Ochtrup and the Seller Esch, Steinfurt-Burgsteinfurt at the northern margin of the Münster Basin (WEGNER 1905, ARNOLD 1964b, HISS 1995b).

The monotonous clay - and marlstones of the Emscherian Marl show only few obvious lithological features. At the Coniacian/Santonian transition of the eastern basin, thinly bedded glauconitic argillaceous limestones with convolute bedding occur (SKUPIN 1983). Two layers of argillaceous limestones occur in the Coniacian/Santonian transition of the Radbod 6 shaft, and the similar Donar 5 borehole, Ascheberg-Herbern (Text-Fig. 3). A series of turbidites, usually some centimetres thick, are intercalated in the top of the Emscherian Marl in the central and eastern Münster Basin (ARNOLD & WOLANSKY 1964). LOMMERZHEIM (1995) demonstrated a organic carbon content of up to 3,3% for the beds below a prominent turbidite at a depth of 205 m in the Herbern 45 borhole at Ascheberg-Herbern. He inferred from this and the high content of pyrite, and the sparse benthos, the presence of an anoxic event.

In the western and northern Münster Basin argillaceous and glauconitic marlstones dominate. In the Prosper 4 preparatory borehole (ARNOLD & TASCH 1964) and in the Lippermulde 1a borehole (ARNOLD & WOLANSKY 1964), both Bottrop-Kirchellen, green sandy marlstones occur in the late Coniacian *S. pachti* & *S. cardissoides* Zone (indicated by ARNOLD & TASCH 1964 and ARNOLD & WOLANSKY 1964 as “Santon 1”). The appearance of reworked sediments in the Emscher Greensand and possible hiatuses in the Coniacian/Santonian transition in the western Ruhr district are mentioned by ARNOLD (1964b). There are some faunal indications of condensation in Graf Bismarck coal mine central air shaft 10.

RIEDEL (1931) recognised the great importance of two conglomeratic horizons in the Franz Haniel shaft 2, Dorsten-Fuhlenbrock. The lower one, dated as lower but not basal Upper Santonian (depth 109.5 m), was known from several sites (ARNOLD 1964a; RIEDEL 1931). Both LÖSCHER (1928) and RIEDEL (1931) interpreted it as a transgressive horizon. It corresponds to the Upper Santonian transgressive horizon in the Walsum shafts (SEITZ 1965, JANSEN 1995) (Text-Fig. 9), Duisburg-Walsum, 13,7 km to the west, which terminated a hiatus beginning in Upper Coniacian (SEITZ 1965). During roadworks at the motorway A 2, Gladbeck-Brauck (Text-Fig. 5) an omission surface overlain by a horizon with small reworked phosphate nodules was exposed (WITTER & *al*. 1999). This horizon is situated in the basal *U. socialis* Zone, upper *S. pinniformis* Zone. The correlation with the transgressive horizon of the Walsum shafts and Franz-Haniel 2 shaft is obvious (Text-Fig. 9). Lower but not basal Upper Santonian transgresses on Lower Santonian or even older strata in the northern Münster Basin (WEGNER 1905; HISS 1995b, 1997) without a specific transgressive horizon being proved.

The upper approximately 8 m thick conglomeratic horizon of the Franz Haniel 2 shaft, Dorsten-Fuhlenbrock (depth 42 - 50 m) was placed into the basal Bottrop Beds by RIEDEL (1931, 1933). This horizon was also proved in the Heiermann and Ridderbusch claypits (ARNOLD 1964a), the new Lippe riverbed, Dorsten (RIEDEL 1931), and the Walsum shafts 1 and 2, Duisburg-Walsum (SEITZ 1965) (Text-Fig. 9).

Biostratigraphy

The stage and substage defintions used here are those provisionally adopted at the Symposium on Cretaceous Stage boundaries held in Brussels, September 1995 (LAMOLDA & HANCOCK 1996) with the exception of that of the Middle Santonian. Ammonite occurrences are set out in Text-Fig. 10. The base of the Santonian was defined by the first occurrence of *Cladoceramus undulatoplicatus*. In the Münster Basin it is accompanied by *Platyceramus cycloides*, *P. rhomboides* and *Cordiceramus cordiinitialis* (see SEITZ 1961). That of the Middle Santonian was defined by the extinction of *C. undulatoplicatus* (LAMOLDA & HANCOCK 1996). But as already SEITZ (1961, p. 14) stated "kommt *I. undulatoplicatus* F. RÖMER zu selten vor, um allein als brauchbares Zonen-Fossil angewandt werden zu können". So we follow a proposal of KENNEDY (1995) and define the base of Middle Santonian by the first occurrence of *Cordiceramus cordiformis*, that of the Upper Santonian by the first occurrence of *Uintacrinus socialis* and base of the Campanian by the last occurrence of *Marsupites testudinarius* (GALE & *al*. 1995, HANCOCK & GALE 1996), all at localities to be agreed subsequently.

The biostratigraphical subdivisions of the upper Upper Coniacian and Santonian of the Münster Basin are best-defined using inoceramid bivalves. Other fossil groups, among them ammonites, are relatively rare and less diverse. Moreover, the inoceramid faunas and especially those from shafts were systematically and biostratigraphically described by SEITZ (1961, 1965, 1967, 1970). Belemnites, which allow a detailed subdivision of the North German Chalk (ERNST & SCHULZ 1974) and on Bornholm (CHRISTENSEN & SCHULZ 1997), occur only sporadically in the Münster Basin. However the excavation of the Essen town harbour, the Reuenberg claypits, Essen-Gerschede, Mülheim-Kellermannshof, and parts of the Bottrop Beds yielded enough material for a belemnite-based stratigraphical classification (ERNST 1964a, b).

Upper Upper Coniacian and the Coniacian/Santonian transition

The base of the Santonian was formerly defined in NW Germany by the first occurrence of *Sphenoceramus pachti* and *S. cardissoides* (SEITZ 1956, 1961; TRÖGER 1989). The use of the entry of the genus *Texanites* (*Texanites*), corresponding to the entry of the species *T.* (*T.*) *pseudotexanus* as an ammonite marker (KENNEDY 1984) in the Münster Basin, seems to be no more practicable. *Texanites* (*Texanites*) *pseudotexanus* occurs already in the upper Upper Coniacian *Magadiceramus subquadratus* Zone in the present study area, as in other regions (Text-Fig. 6; LAMOLDA & HANCOCK 1996) and is widely distributed in the uppermost Coniacian up to the entry of *C. undulatoplicatus*.

These four species usually enter in a narrow stratigraphic interval, beginning with rare *T.* (*T.*) *pseudotexanus* in the uppermost *M. subquadratus* Zone, followed by *S. pachti* and *S. cardissoides*. The main occurrence of *T.* (*T.*) *pseudotexanus* is situated in the S. *pachti* & S. *cardissoides* Zone. *C. undulatoplicatus* enters last (Text-Fig. 8). The inoceramids extend up into the Middle Santonian. However *C. undulatoplicatus* could not be proved in some sections *e.g.* the Donar 5 borehole and the closely similar Radbod 6 shaft, Ascheberg-Herbern (Text-Fig. 3) as well as in the Wulfen 6 borehole, Dorsten-Wulfen (LOMMERZHEIM 1995). On the other hand *S. pachti* and *S. cardissoides* are missing in the Franz Haniel 2 shaft, Bottrop-Fuhlenbrock (RIEDEL 1931, SEITZ 1961). *C. undulatoplicatus, S. pachti* and *S. cardissoides* are said to enter at the same level in the Graf Bismarck 10 central airshaft, Gelsenkirchen-Resser Mark (SCHMID & SEITZ 1957), indicating condensation.

The narrowly defined main occurrence of *Texanites* (*Texanites*) *pseudotexanus* is a striking feature of the sequence; it is some way above the base of the *S. pachti* & *S. cardissoides* Zone. It was found not only in surface excavations (*e.g.* abandoned and refilled old Leßmöllmann claypit, and excavations in Castrop-Rauxel, Dortmund-Holthausen, Herne) but was widely encountered in cored boreholes and shafts (*e.g.* Ascheberg-Herbern, Radbod 6 shaft (Text-Fig. 3), Bergkamen-Weddinghofen, Grimberg IV shaft (Text-Fig. 4), Bottrop-Fuhlenbrock, Franz Haniel 2 shaft (Text-Fig. 9), Bottrop-Kirchhellen, Lippermulde 1a borehole and Prosper 4 preparatory borehole (ARNOLD & WOLANSKY 1964), Dorsten-Wulfen, Wulfen 6 borehole (LOMMERZHEIM 1995), Gelsenkirchen-Resser Mark, Graf Bismarck 10 central air shaft, Herten, Ewald coal mine shaft V (Text-Fig. 6). *T.* (*T.*) *pseudotexanus* occurs in the clay and marlstones of the basin centre as well as in the glauconitic and argillaceous marls of the western parts of the basin. Its vertical extent can only be determined from occurrences in the Ewald shaft V (Text-Fig. 6). One specimen of *T.* (*T.*) *pseudotexanus* is labelled with a depth of 339 m, occurs together with *M. subquadratus,* and is to be placed in the equivalent Upper Coniacian zone (*cf.* SEITZ 1965). Two specimens were collected at depths of 318 m and 322 m, which agrees well with the *S. pachti* & *S. cardissoides* Zone and the base of the *C. undulatoplicatus* Zone. If there was no collecting and/or labelling error, it is probable that *T.* (*T.*) *pseudotexanus* extends from the Upper Coniacian upper *M. subquadratus* Zone to the base of the *C. undulatoplicatus* Zone. RIEDEL (1933) listed for the Auguste Victoria coal mine

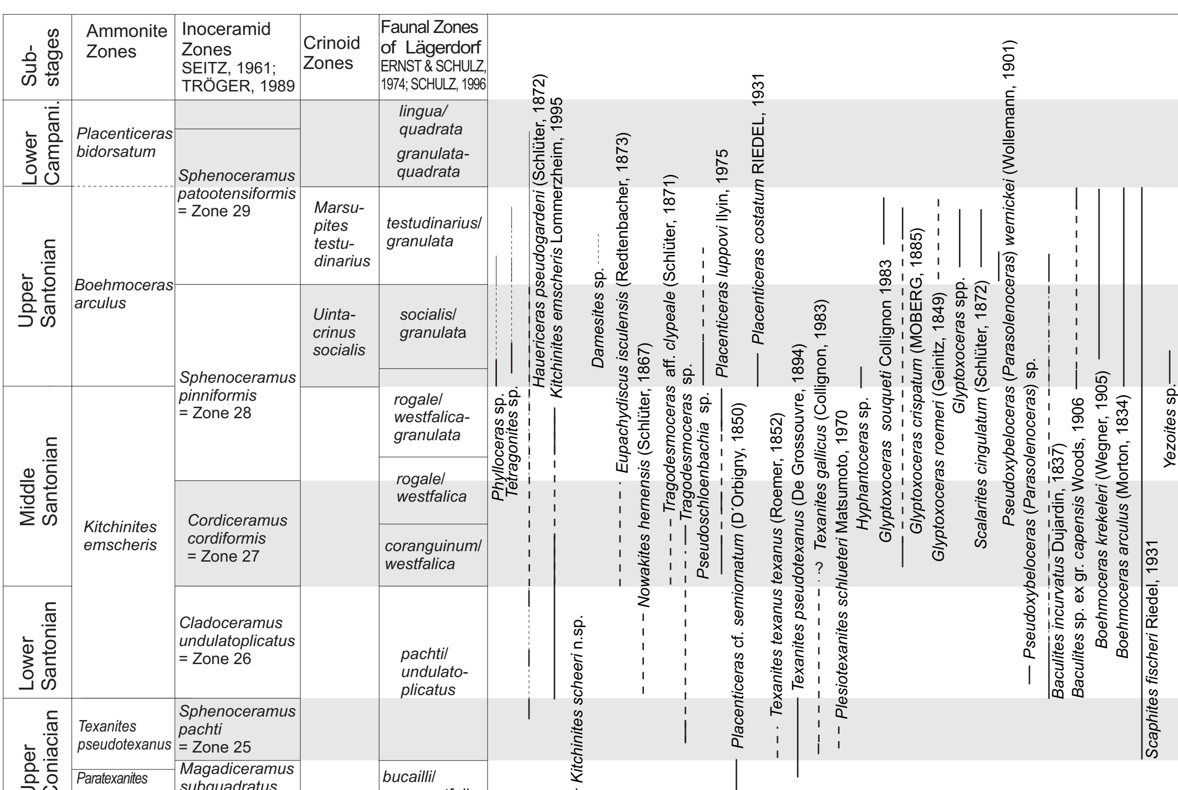


Fig. 10. Santonian ammonite distributions in the Münster Basin

shaft 5, Marl-Hüls, *Mortoniceras texanum* [= *T.* (*T.*) *pseudotexanus*] at a depth range from 230 m to 240 m. The contemporary *S. pachti* and *S. cardissoides* indicate upper Upper Coniacian. RIEDEL (1931) further mentioned *Mortoniceras texanum* [= *T.* (*T.*) *pseudotexanus*] *S. pachti, S. cardissoides* and *M. subquadratus* at a depth range from 240 m to 270 m. We could not trace the material. If RIEDEL's specifications and determinations are correct, it cannot be excluded that *T.* (*T.*) *pseudotexanus* enters already in the *M. subquadratus* Zone. Beside the frequent *T.* (*T.*) *pseudotexanus,* one specimen of *T.* (*T.*) *gallicus* was collected from the Grimberg IV shaft, Bergkamen-Weddinghofen (Text-Fig. 4). There is also a single specimen of *T.* (*T.*) *texanus* in the collections of the University of Bonn that was collected by CLEMENS SCHLÜTER from one of the shafts of the Ewald coal mine near Gelsenkirchen-Buer. Its precise locality and horizon remains unclear.

Lower Santonian

S. pachti and *S. cardissoides* continue alongside the index species *C. undulatoplicatus*. The ammonite faunas show a remarkable change from the layer dominated by the acanthoceratid *T.* (*T.*) *pseudotexanus* in the *S. pachti* & *S. cardissoides* Zone to a fauna dominated by the desmoceratid *Kitchinites emscheris*. *Hauericeras* sp., *Baculites incurvatus*, and *Scaphites fischeri* are significant but rarer components (*cf.* Text-Figs 4, 5). This dominance of *K. emscheris* was confirmed by mapping in the south-eastern basin (SKUPIN 1983; 1995). Rare findings are (?) *Tragodesmoceras* sp., *Placenticeras* sp. and *Parasolenoceras* sp.

Belemnites are generally rare in the Münster Basin Lower Santonian as already stated by RIEDEL (1931). ARNOLD & WOLANSKY (1964) mentioned *Gonioteuthis* cf. *westfalica* from Santon 1 (= *S. pachti* & *cardissoides* Zone) of the Donar 5 borehole (Text-Fig. 3). SKUPIN (1995) mentioned *Gonioteuthis praewestfalica* and *G. westfalica* occurring together with *C. undulatoplicatus*, *C. pachti*, and *C. cardissoides* from two closely related sites near Lippstadt, south-eastern Münster Basin. SCHLÜTER (1876, Pl. 53, Figs 12 a, b; 19) figured *Actinocamax westfalicus* [= *Gonioteuthis westfalica*] from the Emscherian Marl between Paderborn and Salzkotten. The sole exception is the mass occurrence of *G. westphalica* in the excavations of the Essen-Vogelheim town harbour, which lay in the *C. undulatoplicatus* Zone/*C. cordiformis* Zone transition.

Middle Santonian

ERNST (1964a) placed the abandoned and refilled Reuenberg claypit, Essen-Gerschede (cited by SEITZ 1965, 1967 and ERNST 1964a as Ziegelei Dellwig = Dellwig brickworks) in the lower Middle Santonian *C. cordiformis* Zone/*Gonioteuthis westfalica* Zone. He used unhorizoned *Gonioteuthis westfalica,* which were however collected from a narrow stratigraphic range. SEITZ (1967) placed the pit less precisely into Lower to Middle Santonian. The Reuenberg claypit is the only Middle Santonian site to yield a diversive ammonite fauna. Here a single specimen of *Texanites gallicus* was collected, plus several *K. emscheris,* and *Placenticeras luppovi*, the last originally described from the Santonian of the Gissar Range, Tadzhikistan (ILYIN 1975). Further ammonites are *Baculites incurvatus* and *Scaphites fischeri*.

A few specimens of *Tragodesmoceras* aff. *clypeale* and *Scaphites fischeri* were found in the upper *C. cordiformis* Zone during the Hahnenbach canalization in Gladbeck-Brauck, Rosenhügel (*cf.* SEITZ 1961; 1965; 1967). *Tragodesmoceras* aff. *clypeale* was collected from the same biostratigraphic level in excavations for the Rhein-Herne canal lock, Recklinghausen-Suderwich.

Kitchinites emscheris is the dominating ammonite in shafts and borehole sections (*cf.* Text-Figs 4, 5). *Scaphites fischeri* is found in the lower Middle Santonian of the Grimberg shaft IV (Text-Fig. 4) and the Radbod shaft 6, Ascheberg-Herbern (Text-Fig. 3) and in Franz Haniel shaft 2, Bottrop-Fuhlenbrock (Text-Fig. 9). *Baculites incurvatus* is relatively rare there and in the Graf Bismarck central airshaft 10, Gelsenkirchen-Resser Mark. A specimen of *Glyptoxoceras crispatum* was collected from the middle Middle Santonian of the Ewald V shaft, Herten, depth 238-240 m (Text-Fig. 6), one of *Texanites gallicus* from the Middle Santonian of Ewald coal mine, airshaft III, Recklinghausen-Süd, depth 60 m.

ERNST (1964a) described a population of *G. westfalica* from Mülheim-Kellermannshof as well as from Essen-Gerschede, which he placed in the middle *C. cordiformis* Zone, in the transition between his lower and upper *G. westfalica* Zone. We have seen no ammonites from this site.

Upper Santonian
(Text-Fig. 9)

The definition of the base of the Upper Santonian by the first occurrence of *Uintacrinus socialis*

(KENNEDY *in* LAMOLDA & HANCOCK 1996) is not easily applicable to the Münster Basin. *U. socialis* has up to now not been documented in most shafts and boreholes. It has also not been recorded from most of the other Upper Santonian localities. A few unhorizoned specimens were collected from the abandoned Roberts claypit in Lünen-Nordlünen. SCHÖNFELD (1985) precisely located its occurrence in the Rehage claypit, Rietberg-Westerwiehe (Text-Fig. 7), but his section spans only the uppermost 3 m of the *U. socialis* Zone. WEGNER (1905) listed some sites with *Uintacrinus westfalicus* [= *socialis*], which cannot be exactly localized: Emscher Lippe coal mine, Datteln; Blumenthal coal mine, a railway cutting near Recklinghausen, and the Seller Esch, Steinfurt-Burgsteinfurt.

The sites in the Münster basin, where the entry of *U. socialis* and occurrences of belemnites and ammonites are accurately documented, are the neighbouring motorway A 2 excavations of Gladebeck-Brauck and Gelsenkirchen-Buer (WITTLER & *al.*, in press) (Text-Fig. 5). *U. socialis* enters immediately above an omission surface, which can be correlated with the base of the Upper Santonian transgression. *Goniotheuthis westfalica-granulata* occurs from the omission surface up to the top of the section. *Boehmoceras arculus* enters approximately 5 m higher up. *Sphenoceramamus pinniformis* occurs both below and above the omission surface. The Upper Santonian transgression is marked by a significant change from the predominately endemic Middle Santonian ammonite fauna to cosmopolitan Upper Santonian one, as the entry of *Tetragonites* sp., and *Pseudoschloenbachia* sp. in the Gelsenkirchen-Buer motorway excavations and that of *Hyphantoceras* sp. in the nearby former Gelsenkirchen-Beckhausen claypit indicate.

Placenticeras costatum was collected from the upper *S. pinniformis* Zone of General Blumenthal coal mine shaft 7, Recklinghausen (*cf.* SEITZ 1961, 1965, 1967). There are no determinable ammonites from the *S. pinniformis* Zone of Radbod 6 shaft and Donar 5 borehole, Ascheberg-Herbern (Text-Fig. 3). *Hauericeras pseudogardeni* was found in the uppermost *S. pinniformis* Zone/*U. socialis* Zone of the Rehage claypit, Rietberg-Westerwiehe (Text-Fig. 7).

The Rehage claypit (Text-Fig. 7) is the single Upper Santonian site in the Münster Basin, that was systematically collected bed by bed (SCHÖNFELD 1985). The index inoceramid *S. patootensiformis* and the index crinoid *Marsupites testudinarius* enter almost contemporaneously. The few belemnites are identified as *Gonioteuthis granulata* by SCHÖNFELD (1985). *Hauericeras pseudogardeni* is accompanied by heteromorphs exclusively: *Pseudoxybeloceras* (*Parasolenoceras*) *wernickei*, *Glyptoxoceras* sp., *Baculites* sp., *Boehmoceras krekeleri*, *B. arculus* and *Scaphites* sp. A similar fauna was found in the Roberts claypit, Lünen-Nordlünen: *Hauericeras pseudogardeni*, *Glyptoxoceras* sp., *B. arculus* and *B. krekeleri*. *Phylloceras* sp. and *Hauericeras pseudogardeni* were found in the *S. patootensiformis* Zone of Radbod 6 shaft and Donar 5 borehole (Text-Fig. 3). Two badly preserved ammonites, *Hauericeras* sp. and *Baculites* sp. cf. *capensis*, were collected from the highest Santonian *sensu* KAPLAN & *al.* (1996) of the motorway A 2 cutting near Oelde-Bergeler, where ERNST *in* KAPLAN & *al.* (1996) determined rare belemnites as *G. granulataquadrata* and *G. quadrata*.

There are a few more, and in most cases unhorizoned ammonite occurrences in the *S. patootensiformis* Zone of the Münster Basin: *Scaphites fischeri* from the Lippe canal, Datteln-Ahsen; *Glyptoxoceras* sp. from Datteln; *Tetragonites* (*Tetragonites*) sp. and *Placenticeras costatum* from the Ahler Esch, Heek-Ahle; *Parasolenoceras* sp. from the excavations of lock VII, Rhein-Herne canal, Herne-Horsthausen; *Glyptoxoceras* cf. *souqueti*, *B. arculus* and *B. krekeleri* from excavations in the northern building area of Ahaus, and *Tetragonites* (*Tetragonites*) sp., *Hauericeras pseudogardeni* and *Scaphites fischeri* from the Olfen borehole.

Santonian/Campanian transition

The base of the Campanian is defined by the last occurrence of *Marsupites testudinarius* (ERNST 1963, GALE & *al.* 1995, HANCOCK & GALE 1996), which is contemporaneous with the first occurrence of *Gonioteuthis granulataquadrata* (SCHULZ & *al.*, 1984) (Text-Fig. 9). The relationship of this datum to the entry of *Placenticeras bidorsatum* as index ammonite of the basal Campanian has not been clarified in the Münster Basin up to now. Definition using planktonic and benthonic foraminifera still presents problems (*cf.* KOCH & HILTERMANN *in* ARNOLD & WOLANSKY 1964, RESCHER 1991).

The most western occurrence of the Santonian/Campanian transition in the present study area is found in the Walsum I and II shafts, Duisburg-Walsum (Text-Fig. 9). Lower Campanian with *G. quadrata* transgresses over lower Upper Santonian, upper *S. pinniformis* Zone with *G. westfalicagranulata* according to SEITZ (1965). There are no ammonites. ERNST (1964b) proved *Gonioteuthis granulataquadrata* populations and therefore Lower Campanian in the upper conglomeratic horizon of the Franz Haniel 2 shaft, Dorsten-Fuhlenbrock (depth 42 - 50 m). The Ridderbusch brickworks claypit, W Bottrop exposed autochthonous and as well strongly reworked sediments which contain both typical late Middle and Upper Santonian faunal elements such as *Marsupites testudinarius*, *G. westfalicagranulata, G. granulata,* and Lower Campanian forms including *Placenticeras bidorsatum* and *G. granulataquadrata* (ARNOLD 1964a). *M. testudinarius* was found in the basal Bottrop Beds of the Wulfen 1 shaft, Dorsten-Wulfen (KALTERHERBERG 1964). The Santonian/Campanian transition of the western Münster Basin is thus characterized by hiatuses and reworking. *P. bidorsatum* occurs in the lower Lower Campanian Dülmen beds (SCHLÜTER 1876, KENNEDY & KAPLAN 1995), the Haltern beds (BEYENBURG 1941a) and Netteberge beds (BEYENBURG 1941b). Its entry in relation to the occurrence of other index species remains unclear.

In the south-eastern Münster Basin the Santonian/Campanian transition has been accessible in temporary excavations only. KAPLAN & *al.* (1996) proposed the Stromberg turbidite (Text-Fig. 9) as the provisional boundary because it corresponded approximately to the first occurrence of *G. granulataquadrata*. *Glyptoxoceras retrorsum* occurs 6 m above the Stromberg turbidite and is the first typical Lower Campanian ammonite in the sequence. But recently collected Lower Campanian *G. quadrata quadrata* (HISS, *pers. comm.*) indicate, that the boundary should be placed lower.

The interpretation of the Santonian/Campanian boundary of the Radbod 6 shaft and the closely related Donar 5 borehole, Ascheberg-Herbern in the central Münster Basin (Text-Figs 3 and 9) still presents some problems: the macrofossils present do not allow a clear definition of the boundary. LOMMERZHEIM (1995) recorded the occurrence of *Placenticeras bidorsatum* in the Herbern 45 E borehole at a depth of 289.2 m. This specimen is badly preserved and indeterminate (KENNEDY *in* KENNEDY & KAPLAN *in prep.*). Unequivocal Upper Santonian is proven by *M. testudinarius* at a depth of 329 m, and Lower Campanian by *Gonioteuthis granulataquadrata* at 317 m and *G. quadrata* at a depth of 215 m in the Donar 5 borehole (*cf.* LOMMERZHEIM 1995, p. 18). HILTERMANN & KOCH *in* ARNOLD & WOLANSKY (1964) placed the Santonian/Campanian transition interval between depths 250 - 278 m based on foraminifers.

Ammonite Stratigraphy

The stratigraphical distribution of the upper Upper Coniacian and Santonian ammonites of the Münster Basin is shown in Text-Fig. 10. The ammonite faunas can be interpreted in biostratigraphic terms as follows:

T. (*T.*) *pseudotexanus* is frequent in the upper Upper Coniacian *S. pachti* & *S. cardissoides* Zone. It enters in the uppermost *M. subquadratus* Zone without *Volviceramus*, ranges to the base of the *C. undulatoplicatus* Zone and defines a *T. pseudotexanus* total range zone.

The Lower and Middle Santonian ammonite faunas are dominated by *Kitchinites emscheris*. It enters and seemingly occurs in abundance at the base of the Lower Santonian. This abundance might help to identify the base of the Lower Santonian in sections where the index inoceramid *C. undulatoplicatus* is missing, *e.g.* Donar 5 borehole and Radbod 6 shaft, Ascheberg-Herbern (Text-Fig. 3) and Wulfen 6 borehole, Dorsten-Wulfen. The *Kitchinites emscheris* Zone is a total range zone that spans the Lower and Middle Santonian of the Münster Basin. *Scaphites fischeri,* which RIEDEL (1931) treated as zonal index of the Middle Santonian, enters in the uppermost Upper Coniacian and ranges throughout the Santonian. It belongs to an evolutionary lineage which makes it difficult to separate it from its Coniacian predecessor *S. kieslingswaldensis kieslingswaldensis* and its Lower Campanian successor *S. binodosus* in transitional intervals. There are two specimens of *Texanites gallicus,* from the lower *C. cordiformis* Zone and from the *S. pachti* & *S. cardissoides* Zone.

We have not seen the types of *Tragodesmoceras clypeale*, and remain uncertain as to its stratigraphical distribution. RIEDEL (1931) proposed *T. clypeale* as zonal index of the Middle Santonian in our sense. Thus it should not occur below *C. cordiformis,* the Middle Santonian inoceramid index. In his paper on the Salzberg Marl in the Subhercynian Basin near Quedlinburg RIEDEL (1938) recorded *T. clypeale* in and even below the *S. pachti* & *S. cardissoides* Zone as used herein, and so well below the base of the

Middle Santonian *C. cordiformis* Zone. If his determinations are correct, *T. clypeale* would occur significantly earlier than he stated for the Münster Basin. But RIEDEL (1931) himself emphasized the unsolved relationship between *'Hauericeras' clypeale* and *'Puzosia' mengedensis* (= *Tragodesmoceras mengedense*). Nevertheless, most specimens we have seen, which RIEDEL and other authors (*e.g.* SEITZ 1961, 1965, 1967 and ARNOLD & WOLANSKY 1964) determined as *T. clypeale* in routine determinations, are *Kitchinites emscheris* (KENNEDY *in* KENNEDY & KAPLAN *in prep.*). We have seen only two specimens, which we identify *H.* aff. *clypeale,* from the upper Middle Santonian of the Münster Basin.

There is a significant change in ammonite faunas at the base of the Upper Santonian. *Boehmoceras arculus* enters closely above the boundary in the glauconitic argillaceous marlstone facies of the western parts of the basin as well as in the clay and marlstone facies of the central and eastern parts of the basin. RIEDEL (1931) treated it as zonal index. The *B. arculus* Zone as here defined extends from the base of the *U. socialis* Zone to the Santonian/Campanian boundary. It can only be tentatively defined as a total range zone, because *B. arculus* and *B. krekeleri* extend into the uppermost Santonian only in the Rehage claypit, Rietberg-Westerwiehe (SCHÖNFELD 1985) (Text-Fig. 7) and could conceivably disappear earlier in other sections on the basis of our present limited data.

The lower part of the *B. arculus* Zone, which correlates with the upper part of the *S. pinniformis* Zone and the *U. socialis* Zone, yields seemingly more or less abundant and predominantly non-heteromorph ammonites in its lower part only. In contrast the lower part of the upper *B. arculus* Zone, which is coincident with the *M. testudinarius* Zone/lower *S. patootensiformis* Zone, is dominated by heteromorphs: *Scalarites serta*, *Glyptoxoceras* cf. *souqueti, B. arculus* and *B. krekeleri*. *Placenticeras costatum* occur rarely in the *S. pinniformis* Zone and in the *S. patootensiformis* Zone.

H. pseudogardeni is the single ammonite species that straddles the Santonian/Campanian boundary. As discussed below it remains unclear at which precise level *Placenticeras bidorsatum* first occurs. In the Subhercynian Basin *P. bidorsatum* enters in the upper part of the *G. granulataquadrata* Zone (ULBRICH 1971). The Santonian/Campanian boundary thus cannot at this time be defined in ammonite terms in the Münster Basin.

REMARKS ON SEQUENCE STRATIGRAPHY AND AMMONITE FAUNAS

An extensive event and sequence stratigraphical analysis of the Santonian of the Münster Basin is not possible from our present limited data. HISS (1995, Fig. 11) illustrated only a generalised tendency of sea-level changes. From early Coniacian to early Santonian there is a slight regressive trend, followed by a slight Middle Santonian transgressive trend. The upper part of the Santonian is marked by a marked regression and a subsequent transgression. LOMMERZHEIM (1995, Figs 7, 8) briefly discussed the sequence stratigraphy of the Herbern 45 borehole Upper Santonian and Campanian. He saw a sequence boundary in and not at the base of the Upper Santonian followed by a transgressive trend up the base of the Campanian.

We can add only a few of our own observations (Text-Fig. 11). In the upper Upper Coniacian *S. pachti* & *S. cardissoides* Zone thinly bedded glauconitic argillaceous limestones with convolute bedding in the south-eastern basin, intercalated limestone horizons in the central claystone facies, condensation, local hiatuses and greensand horizons in the western parts of the basin indicate the presence of a sequence boundary. To what extent the underlying regressive system tract correlates with the subhercynian *V. koeneni* regression (ERNST & SCHMID 1979) has to be proved. In this context it is important to note that, beginning in the upper Middle and Upper Coniacian, there is a tendency to increasing endemism in the Münster Basin ammonite faunas.

The *T.* (*T.*) *pseudotexanus*-Event is widespread in the Münster Basin and indicates initial transgression. The succeeding abundance of *K. emscheris* marks the change from an acanthoceratid to a desmoceratid-dominated ammonite fauna. Such faunal changes characterise other Upper Cretaceous transgressive pulses (KENNEDY & KAPLAN 1996; KAPLAN & *al.* 1996, 1998). The abundant *T.* (*T.*) *pseudotexanus* and *K. emscheris* are endemic and seemingly restricted to the Münster Basin. Widespread ammonite species such as *T.* (*T.*) *gallicus, P. luppovi* and *Glyptoxoceras* sp. occur only sporadically. It is likely that the transgression allowed only limited supraregional faunal exchange.

An unique mass occurrence of *G. westfalica* was observed in the excavations of Essen-Vogelheim town harbour (western basin), in the *C. undulatoplicatus* Zone/*C. cordiformis* Zone transition. Its sequence stratigraphical interpretation is difficult. As mass occurrences of belemnites can characterize transgressive horizons (*e.g.* mass occurrences of *Gonioteuthis* in the Upper Santonian transgression of Hannover-Misburg: ERNST 1975), it seems likely that the *Gonioteuthis* mass occurrence of Essen-Vogelheim could represent a transgressive horizon. But a specific transgressive horizon has never been mentioned and a correlatable transgressive horizon has never been seen in contemporaneous shaft and borehole sections in the study area and especially not in the immediate neighbourhood. In contrast the regional faunal change discussed above is a feature indicating a rise in sea-level. This isolated mass occurrence of *G. westfalica* can probably be related to an upthrust and subsequently flooded block creating an ecological niche for these belemnites.

The Lower and Middle Santonian of the Münster Basin are characterized by general subsidence in the Vorosning syncline in the north-eastern part of the basin, upthrust on the northern margin, and upthrust as well as subsidence in the western part. At the northern margin the movements are concentrated in the Middle Santonian as is indicated by the transgression of Upper Santonian over eroded Lower Santonian. But local hiatuses can extend from Upper Coniacian to basal Upper Santonian (HISS 1995b; 1997). At the western margin the hiatuses span upper Upper Coniacian to basal Upper Santonian (*cf.* Text-figs 8, 10).

Onlapping transgressive Upper Santonian is widespread in the western and northern Münster Basin. It can be dated as basal *U. socialis* Zone, as biostratigraphical data from the A 2 motorway cutting at Gladbeck-Brauck indicate (Text-Fig. 5). A change from an endemic Middle Santonian fauna to a more cosmopolitan fauna is a reliable indicator for Upper Santonian transgressive pulses in those parts of the basin where no transgressive sediments are proven. An Upper Santonian to Lower Campanian anoxic event in the central basin (LOMMERZHEIM 1995) and contemporaneous Milankovich cycles might indicate a highstand system tract (LOMMERZHEIM 1995, KAPLAN & *al.* 1996).

Conspicuous tectonically induced sedimentation analomies appear in the lower Lower Campanian.

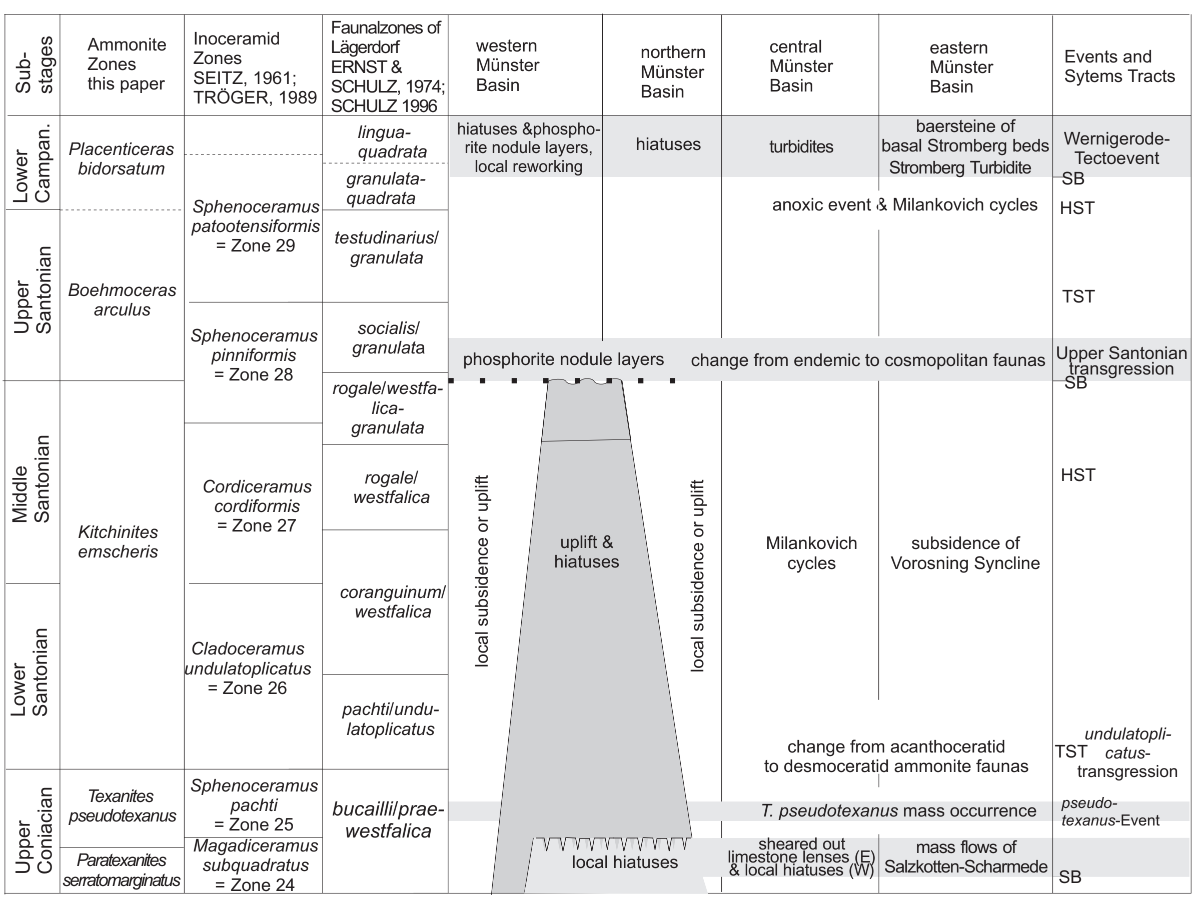


Fig. 11. Bio-, Event- and Sequence stratigraphy of the Münster Basin Santonian

Already RIEDEL (1931) discussed them in the context of the Wernigerode phase (= Wernigeröder Phase, STILLE 1924). Conglomeratic horizons in the western parts of the basin correlate with turbidite intercalations in the uppermost Emscherian Marl and oligostromes (locally called Bärsteine = bear-stones, GIERS 1958) of the lower Stromberg Beds in the south-eastern part of the basin (Text-Fig. 9). For the discussion of a sequence boundary in the transition from the Emscherian Marl clays and marlstones to the argillaceous limestones of the lower Stromberg beds see KAPLAN & *al.* 1996.

CORRELATION

The predominately endemic composition of the Upper Coniacian to Middle Santonian ammonite faunas of the Münster Basin makes direct correlation difficult, even with adjacent basins such as the Subhercynian Syncline and the Lower Saxony Block (*cf.* RIEDEL 1938; ULBRICH 1971; NIEBUHR & *al.* 1999). Correlation here, and with the North German chalk, is based on inoceramids, belemnites, and in the Upper Santonian, the crinoids *U. socialis* and *M. testudinarius*, which have a more-or-less cosmopolitan distribution (SIEVERTS 1927, MILSON & *al.* 1994). Only *Scaphites fischeri* is widespread, occurring in Belgium (JAGT & *al.* 1996), the Subhercynian Basin, N Germany (ULBRICH 1971), Bornholm, Denmark (KENNEDY & CHRISTENSEN 1991) and southern Sweden (KENNEDY & CHRISTENSEN 1993).

The first occurrence of the species *Texanites* (*Texanites*) *pseudotexanus* in the upper Upper Coniacian uppermost *M. subquadratus* Zone, is coincident with the first occurrence of the genus *Texanites* below the *S. pachti* & *S. cardissoides* Zone in Texas and northern Spain. Abundance of *Texanites* (*Texanites*) in the uppermost Coniacian *S. pachti* & *S. cardissoides* Zone is observed in other regions as well (*cf.* LAMOLDA & HANCOCK 1996). *Texanites* (*Texanites*) seems to be absent from the Subhercynian Basin (*cf.* RIEDEL 1938). According to LAMOLDA & HANCOCK (1996), *C. undulatoplicatus* has an almost a world-wide distribution; our present data demonstrate that *S. undulatoplicatus* is missing in some Münster Basin sections.

Single specimens of *T.* (*T.*) *gallicus* were found in the Upper Coniacian *S. pachti* & *S. cardissoides* Zone and at the base of the Middle Santonian *C. cordiformis* Zone. This species occurs in the Middle and Upper Santonian of the NE Pyrénées (southern France), northern Spain, Bulgaria, Italy, Venezuela, Zululand (South Africa), and Madagascar (KENNEDY *in* KENNEDY & *al.* 1995).

The change from predominately endemic upper Upper Coniacian-Middle Santonian faunas to more cosmopolitan Upper Santonian faunas makes wider correlations possible. *Boehmoceras* enters within the *G. westfalicagranulata* Zone in the Münster Basin, as in the subhercynian Basin (ULRICH 1971). Further occurrences are in western and southern France (KENNEDY *in* KENNEDY & *al.* 1995), southern Sweden (KENNEDY & CHRISTENSEN 1993; 1997), in the Austrian Gosau Group (SUMMESBERGER 1985), and in Alabama, Mississippi and Texas, USA (KENNEDY & COBBAN 1991). Other more widely occurring ammonites associated with the faunal change are *Pseudoschloenbachia* sp., a genus known from the Lower Santonian to Lower Campanian of the Tethyan Realm (KENNEDY *in* KENNEDY & *al* 1995; WRIGHT 1996), *Glyptoxoceras souqueti* in the *M. testudinarius*/*S. patootensiformis* Zone, and also known from the Corbières (France). There are *Hauericeras pseudogardeni* in the Upper Santonian of the Subhercynian Basin (MÜLLER & WOLLEMANN 1906; ULBRICH 1971) Yorkshire, England, and southern Sweden (KENNEDY & CHRISTENSEN 1993; 1997). Yet other species *e.g. Placenticeras costatum* remain restricted to the study area.

CONCLUSIONS

Only the abundance of *Texanites* (*Texanites*) in the upper Upper Coniacian and the wide distribution of *Hauericeras pseudogardeni*, *Boehmoceras arculus* and *B. krekeleri* in the Upper Santonian provide reliable interbasinal biostratigraphical markers that can be correlated with areas outside the Münster Basin. The occurrence and distribution of these taxa appear to be linked to transgressive pulses. The sequence stratigraphical succession in the Münster Basin corresponds to that of western European (HANCOCK 1989), and the global model (HAQ & *al.* 1988). HAQ & *al.* (1988) identified a sequence boundary in the Coniacian/Santonian transition, a second one at the base of the *U. socialis* Zone, and a third in the lower Lower Campanian, which would correspond to the basal Wernigerode tectoevent. HANCOCK`s (1989) sea-level curve suggests a minimal fall around the Coniacian/Santonian transition followed by a rise. In Hannover-Misburg, in the Lower Saxonian Basin, ERNST (1975) dates the

Upper Santonian transgression as lower Upper Santonian. The regressive event around the Santonian/Campanian transition of the Münster Basin can be recognized widely (ERNST 1975, HAQ & *al*. 1986, HANCOCK 1989).

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