Ammonite biostratigraphy and correlation of Middle/Late Albian drilling cores in the Hannover area (northern Germany)

Jens Lehmann[1]

With 3 figures, 1 plate, and 1 table

Abstract. The ammonite biostratigraphy of the Middle/Late Albian boundary interval in northern Germany has been significantly improved in the past few years by the Hannover-Lahe and Hannover-Kirchrode borehole sections. Both sections show are monotonous claystone successions deposited in a deep sub-basin of the Lower Saxony Basin. Here ammonite data of the Hannover-Lahe core are revised and re-evaluated, placing the section into the latest Middle/early Late Albian and allowing a correlation with the neighbouring Hannover-Kirchrode succession as well as the standard section for ammonite biostratigraphy on the European shelf – the Folkestone section in the UK. It demonstrates that sedimentation rates in this sub-basin of the Lower Saxony Basin were extremely high during the earliest Late Albian *Dipoloceras cristatum* Zone and the *Hysteroceras orbignyi* Subzone of the *Hysteroceras varicosum* Zone compared to all other well-dated sections available. The succession in the *H. binum/choffati* Subzones, indicates a short period of distinctly reduced sediment accumulation, before the greatly increased sedimentation rate during the *Callihoplites auritus* Subzone of the *Mortoniceras inflatum* Zone.

Key words. Ammonites, Albian, Cores, Hannover area, northern Germany, Correlation

1. Introduction

Middle and Late Albian ammonite faunas of the Boreal Sea are characterized by fast evolutionary rates, particularly the endemic hoplitid ammonites and provide a high-resolution stratigraphic tool in this realm. Well-preserved ammonite successions in the Anglo-Paris Basin are the base for a well-elaborated and detailed zonal and subzonal scheme (e.g. Owen, 1984, 1999; Fig. 1 and 2) and range charts (Amédro and Destombes 1978, Amédro 1992). In many other European basins, the ammonite biostratigraphy of the Middle/Late Albian is poorly known in sharp contrast

to the area focused on here. Hitherto, in the Lower Saxony Basin, earlier contributions were limited in their results by the lack of continuous outcrop successions containing a reasonable number of ammonites (e.g. Ernst 1921, 1927; Althoff and Seitz 1934; Stolley 1937; Owen 1979). Outcrops are widely missing in the basinal claystone facies of the Lower Saxony Basin, but three borings were drilled in the 1990's provide a good data base: Hannover Kirchrode I and II and Hannover Lahe. Macrofossils in these borings conform with a main pre-condition, they contained sufficiently well-enough preserved and fairly numerous ammonite specimens. These ammonite faunas

Author's address:
[1] Faculty of Geosciences, University of Bremen, Klagenfurter Strasse, 28357 Bremen, Germany. E-Mail: jens.lehmann@uni-bremen.de
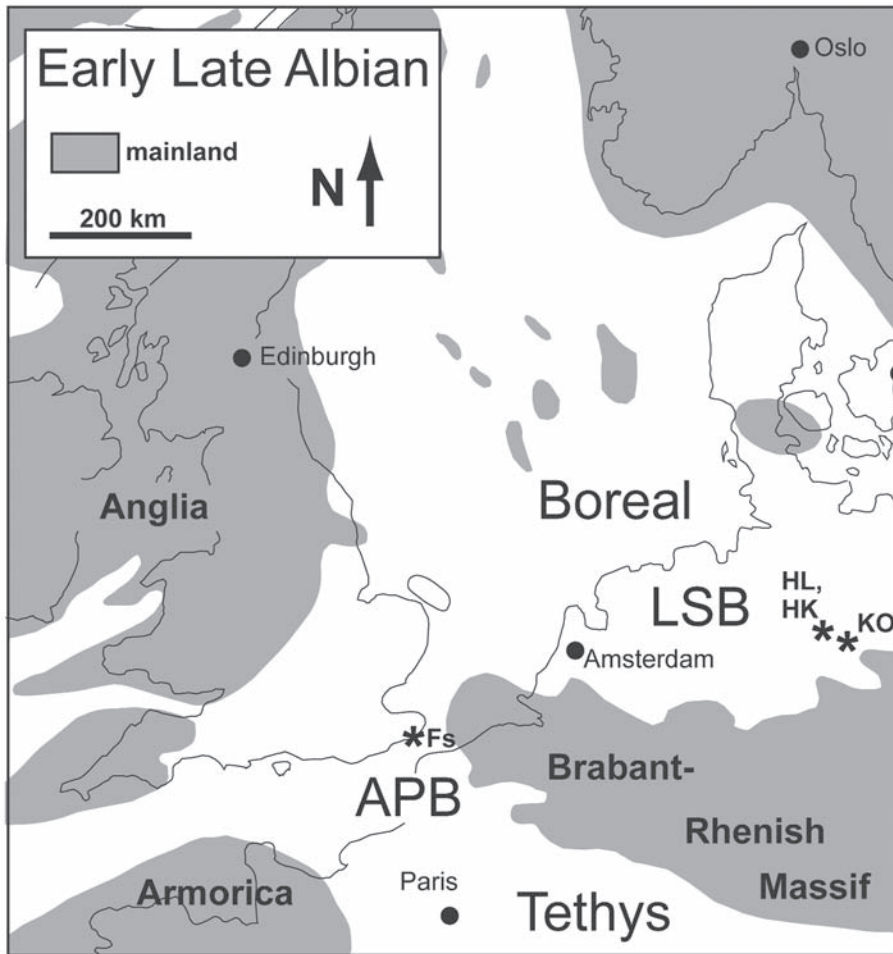
Fig. 1. Palaeogeography of the early Late Albian in northern Europe with localities and areas mentioned in the text. Localities: Fs = Folkestone, Kent; HL, HK = Drilling core Lahe and Kirchrode I and II at the city limits of Hannover, Lower Saxony. KO = Schacht Konrad 1 section. APB = Anglo-Paris Basin, LSB = Lower Saxony Basin. Map modified after Ziegler (1990).

have been described in greater detail (Wiedmann and Owen 2001; Owen 2007; Lehmann et al. 2007). The taxonomy is based mainly on the monograph by Spath (1923–1943) on the British Albian fauna. Although still the most comprehensive systematic paper on this subject, it contains much inadequacies that make identifications difficult without a study of a larger quantity of three-dimensional well preserved specimens. For this reason the present author decided to revise the taxonomy of the Hannover-Lahe core (Lehmann et al. 2007) by examining a large number of the relevant types and further reference material in the Natural History Museum in London. Determination of distorted and predominantly fragmentary ammonites is nevertheless challenging. The overall scarce knowledge on the ammonite fauna of the Middle/Late

Albian in the Lower Saxony Basin underlines that the more advanced analysis and revision of the taxonomy of the Hannover-Lahe fauna given in the present paper is relevant and a correlation of the biostratigraphical data is needed.

2.   Geological setting

All core sections referred to here have been obtained around the city of Hannover in northern Germany. During the Early Cretaceous this area has been the deepest part of the Lower Saxony Basin (Kemper 1979), called 'Harz foredeep' by Owen (1979). Halokinesis influenced large parts of northern Germany during the Mesozoic and Cenozoic (e. g. Jaritz 1973),

and Cretaceous sediments in the eastern city limits of Hannover were deposited in a subbasinal deep between the saltdomes of Benthe and Lehrte (e. g. Fenner et al. 1996; Fenner 2001b). Nevertheless, these sub-basins were in open connection to the Boreal Sea in the north and to the adjacent areas of the foredeep bordered on the south and west by the Harz and Brabant-Rhenish Massifs (e. g. Fenner 2001b, Fig. 1). A more comprehensive introduction with respect to the Hannover-Lahe boring focussed herein was given by Lehmann et al. (2007).

3.   Locality and core section details, conventions

The Hannover-Lahe core (referred to as Lahe below) was drilled in 1996 in the northeastern city limits of Hannover. There are no ammonites recorded for the initial 15–30 m depth and other details about the exact location, core handling, sampling history, repository

and lithological succession are given in Lehmann et al. (2007). The ammonite biostratigraphy of Lahe revised in the present paper is based on 55 specimens that are sufficiently well preserved among a total number of 72 specimens obtained from the core.

Hannover-Kirchrode is located at the southeastern city limit of Hannover, only about 5 km S of the Lahe drilling site. Two cores were drilled in 1991 and 1994 (Kirchrode I and Kirchrode II respectively), less than 2 km apart; details can be obtained e. g. from Fenner et al. (1996) and Fenner (2001). The Hannover-Kirchrode sites are referred to as Kirchrode I and II in the following for simplicity. The ammonite data used here is based on the work of Wiedmann & Owen (2001) and Owen (2007). The latter paper furthermore figures a profile of the Schacht Konrad 1 section, referred to in chapter 5 below with respect to the lithostratigraphic subdivision. Basic information on the dating of Schacht Konrad 1 sediments are given by Owen (1979). 'BGR' is the acronym of the Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute
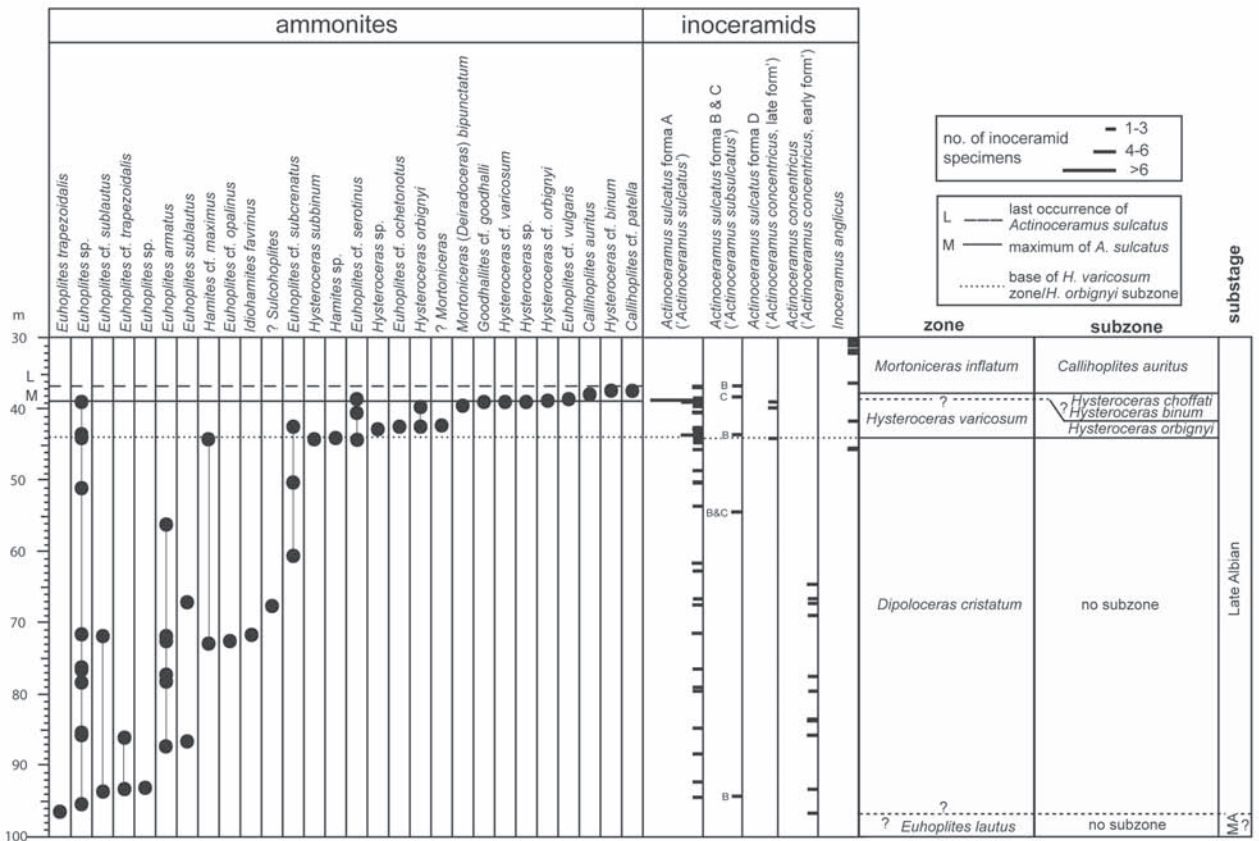

Fig. 2. Significant ammonite occurrences in and biozonation of the Lahe core, Hannover, northern Germany. MA = Middle Albian.

for Geosciences and Natural Resources), Hannover, Germany. All numbers following the BGR abbreviation are inventory numbers of the BGR collection. FO means 'first occurrence' – the lowest stratigraphic occurrence of a taxon – and LO means 'last occurrence'.

4. Revision of ammonite ranges for the Lahe boring

4.1 General introduction

The revised ranges of ammonite taxa from Lahe are presented in Fig. 2. The zonal scheme used in Figs. 2 and 3 is founded on early work in the Anglo-Paris Basin (e. g. Spath 1923–1943). Owen (1979, 1984) adapted it to northern Germany and Lehmann et al. (2007) gave a full account on definitions and limits with respect to the Lower Saxony Basin. The chart (Table 1) here is different from that used by Lehmann (2007), following recent modifications by Owen (2007) and Owen in Lopez-Horgue et al. (2009).

4.2 Ammonite occurrences and taxonomic notes

In the following list of ammonite occurrences, revised identifications are given where applicable, the phrase 'former identification' each refers to Lehmann et al. (2007). Furthermore, critical features and important species discriminations are presented, particularly where details are difficult so see on the photos on Plate 1 or in Lehmann et al. (2007). Determinations are given as core depth, in ascending order from the base of the Lahe core to its top.

Ammonite identifications and revisions for those given in Lehmann et al. (2007) are as follows, given in borehole depth order.

Substage	Zone	Subzone
Upper Albian (pars)	*Mortoniceras inflatum* (pars)	*Callihoplites auritus*
	Hysteroceras varicosum	*Hysteroceras choffati*
		Hysteroceras binum
		Hysteroceras orbignyi
	Dipoloceras cristatum	no index
Middle Albian (pars)	*Euhoplites lautus*	*Anahoplites daviesi*
		Euhoplites nitidus

Table 1 Ammonite biozonal scheme for the Middle/Late Albian boundary interval applied herein. Further explanation see text.

96.50 m *Euhoplites trapezoidalis*; BGR 13941 (Lehmann et al. 2007: Fig. 9b). The expanded, smooth lower flank was the argument for the former determination as *Euhoplites nitidus*. However, one of the ventrolateral tubercles is preserved and this is a clavus as in *E. trapezoidalis* rather than a tubercle as in *E. nitidus*.

95.34 m *Euhoplites* sp.; BGR 13936. This specimen is a flattened ventral aspect fragment considered here to be indeterminable at species level; thus, the former identification as *Euhoplites* cf. *lautus* is changed.

93.66 m *Euhoplites* cf. *sublautus*; BGR 13931. The flexuous and generally fairly smooth ribbing requires the former identification as *Euhoplites nitidus* to be revised.

93.31 m *Euhoplites* cf. *trapezoidalis*; BGR 13930. The same arguments as given for BGR 13916 (86.12 m) is relevant to the change of the former identification of *Euhoplites* cf. *nitidus*.

93.09 m *Euhoplites* sp.; BGR 13927 (Lehmann et al. 2007: Fig. 9e). A re-evaluation of the features shown by this specimen indicate that these are insufficient for a determination at species level, thus the former identification as *Euhoplites nitidus* is revised herein.

91.74 m *Euhoplites armatus*; BGR 13925 (Lehmann et al. 2007: Fig. 9c).

87.40 m *Euhoplites armatus*; BGR 13918 (Lehmann et al. 2007: Fig. 9h).

86.57 m *Euhoplites sublautus*, BGR 13917. The former identification as *Euhoplites* sp. was careful, but this fairly well-preserved specimen shows a good resemblance with the type of *E. sublautus* (Spath 1930: Pl. 30, Fig. 11b).

86.12 m *Euhoplites* cf. *trapezoidalis*, BGR 13916. This specimen shows a smooth lower flank and a mid-lateral tubercles, a main argument for its former identification as *Euhoplites* cf. *nitidus*. However, BGR 13916 differs by possessing lautiform rib endings at the ventrolateral margin that appear to end in a clavus rather than in clavate tubercles typical of the Middle Albian subzonal index species *E. nitidus*. The smooth lower flank mentioned is unique among the Late Albian representatives of the *Euhoplites opalinus*/*E. trapezoidalis* clade. This morphology was described by Spath (1930: p. 285) as *Euhoplites trapezoidalis* var. *formosa*. Spath (1930) noted continuous transitions
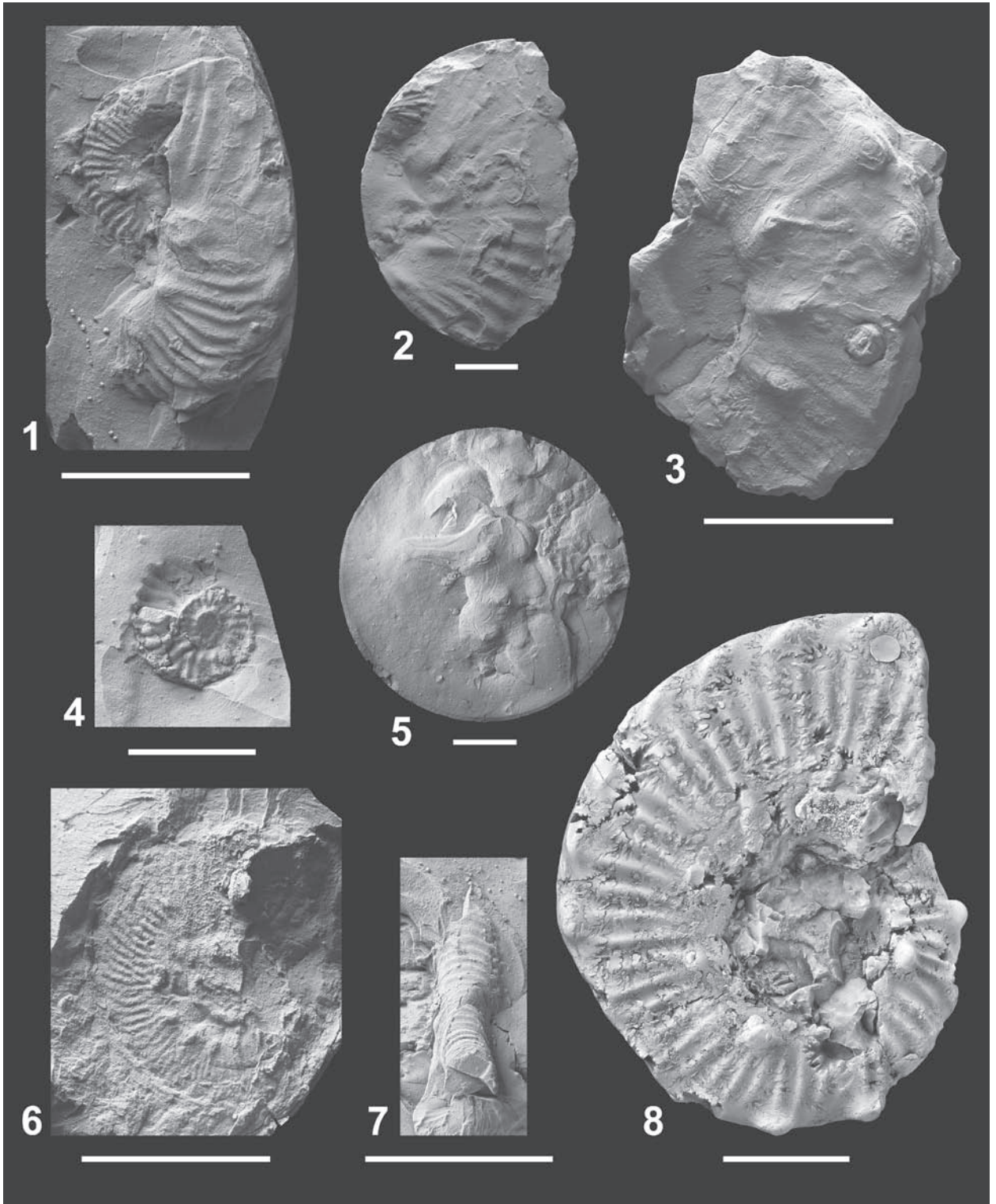
Plate 1. Late Albian ammonites. **1.** *Euhoplites* cf. *sublautus*, BGR 13879a (71.64 m). **2.** *Euhoplites* cf. *subcrenatus*, BGR 13811 (42.20 m). **3.** *Euhoplites sublautus*, BGR 13917 (86.57 m). **4.** *Hysteroceras* cf. *varicosum*, BGR 13795 (38.78 m). **5.** *Euhoplites armatus*, BGR 13881 (72.50 m). **6.** *Callihoplites* cf. *patella*, 13783b (37.11 m). **7.** *Hamites* cf. *maximus*, BGR 13883 (72.67 m). **1.–7.** All from the Lahe core, with core depth given in brackets. **8.** *Euhoplites serotinus*, NHM C35150, the holotype of Spath (1930: p. 286; Pl. 26, fig. 6) from the *D. cristatum* Zone of Folkestone, Great Britain.

between *E. opalinus* and *E. trapezoidalis*, thus there are no arguments for the discrimination of *formosa* as a separate species and maybe, not even for the separation of *E. trapezoidalis* from *E. opalinus*. However, for purpose of the present study the species concept of Spath is followed and the fragmentary nature of the specimen permits only a comparison with *E. trapezoidalis*.

85.87 m *Euhoplites* sp.; BGR 13915. A re-evaluation of features weakens arguments for the former identification as *Euhoplites truncatus* because of its poor preservation.

85.40 m *Euhoplites* sp.; BGR 13914.

78.36 m *Euhoplites armatus*; BGR 13902.

78.30 m *Euhoplites* sp.; BGR 13901a. The former identification was *Euhoplites* cf. *lautus*, but the poor preservation of this specimen makes a specific identification doubtful.

77.35 m *Euhoplites armatus*; BGR 13898a.

76.60 m *Euhoplites* sp.; BGR 13895. Former identification was *Euhoplites* cf. *trunctatus*, but the poor preservation of this specimen makes a specific identification doubtful.

76.25 m *Euhoplites* sp.; BGR 13892. The former identification was *Anahoplites* sp., the same arguments for the revised determination as in BGR 13882b (72.54 m) apply.

72.67 m *Hamites* cf. *maximus*; BGR (Pl. 1, fig. 7): The former identification is *Hamites* sp., but there are dense, fine, regular non-tuberculate ribs, about as broad as interspaces, very similar to that in *H. maximus*. The rib density permits a distinction from *Hamites intermedius*.

72.54 m *Euhoplites*?; BGR 13882b. The former identification as *Anahoplites* sp. is changed because the lack of any ornament (particularly no umbilical and ventrolateral tubercles) might rather place it to a smoothly ornamented *Euhoplites* spp. of the Late Albian.

72.54 m *Euhoplites* cf. *opalinus*; BGR 13882a (Lehmann et al. 2007: Fig. 9a). The specimen shows lautiform rib endings at the ventrolateral margin. A similar morphology is shown in a non-typical example of *Euhoplites nitidus* Spath, 1925, figured by Spath (1930: Pl. 27, Fig. 10) and for this reason, the former identification as *Euhoplites nitidus*

was made. The typical *E. nitidus* is a micromorph species with relatively simple non-lautiform ribbing. However, BGR 13882a shows a stronger development of this lautiform rib pattern at the ventrolateral shoulder and is therefore better placed close to *E. opalinus*.

72.50 m *Euhoplites armatus*; BGR 13881 (Pl. 1, fig. 5): This is an example of the most common ammonite species identified from the Lahe core, to illustrate variability in addition to Lehmann et al. (2007: Fig. 9c, f, g). BGR 13881 lacks ribs, has a fairly large whorl height (maximum 27 mm absolute), large ventrolateral clavi and distinct and large umbilical tubercles and thus can be positively identified despite its fragmentary nature.

71.74 m *Euhoplites armatus*; BGR 13880.

71.64–71.69 m *Euhoplites* cf. *sublautus*, BGR 13879a (Pl. 1, fig. 1). The specimen shows a fairly dense and prominent ribbing, stemming from distinct umbilical bullae at the umbilical edge; there are prominent ventrolateral clavi at the ventrolateral shoulder; in these aspects the specimen resembles the holotype of *Euhoplites sublautus*. This species differs from juvenile *E. solenotus* by a more compressed whorl section and a less robust ornamentation according to Spath (1930, p. 287). Since no small-size specimens of *E. solenotus* are figured, it is impossible to make a distinction based on these features founded by data in the literature. According to material in various British collections the rib pattern is transitional between *E. solenotus* and *E. sublautus* in terms of the umbilical tubercle relation to ribs (H. G. Owen, pers. commun. 2010). BGR 13879a shows less distinct ventrolateral tubercles than *E. truncatus*, the umbilical tubercles are closer and more distant from the umbilical rim and thus the former identification as *Euhoplites* cf. *truncatus* is changed herein.

67.59 m? *Sulcohoplites*, BGR 13868 (Lehmann et al. 2007: Fig. 10e). A re-evaluation of the ventral aspect modifies the former identification as *Anahoplites* sp. This specimen is a completely smooth, large body chamber with a sulcate venter. The smooth, narrow venter with sharp edges might suggest a relation to *Sulcohoplites* described by Mikhailova and Savel'ev (1994) from Mangyshlak, Kazakhstan. However, representatives of this genus retain at least a faint ribbing at that ontogenetic stage and show a tuberculation. BGR 13868 is different from *Sulcohoplites* and *Anahoplites* (widely distributed in Middle/Late Albian sediments in Europe), by the ribbing and tuberculation

and the latter differs also by a much less distinct sulcate venter.

71.55 m *Idiohamites favrinus*, BGR 13878b (Lehmann et al. 2007: Fig. 11d).

71.55 m *Euhoplites* sp., BGR 13878a. The indistinct ornament and the ventrolateral aspect, argue for an identification of a *Euhoplites* of the *E. sublautus* or *E. ochetonotus* group, in contrast to the former identification as *Euhoplites* cf. *lautus*.

66.92 m *Euhoplites sublautus*, BGR 13863. The ornament is feeble in general, with delicate ribs and less distinct ventrolateral tubercles at a larger diameter (reconstructed maximum diameter of the fragment is larger than 50 mm), but with distinct clavate umbilical bullae. In this respect BGR 13863 resembles Spath's (1930) variety *monacantha* of *E. sublautus*. The former identification as *Euhoplites truncatus* (Lehmann et al. 2007: Fig. 9i) is, therefore, incorrect.

60.50 m *Euhoplites* cf. *subcrenatus*, BGR 13856 (Lehmann et al. 2007: Fig. 10b).

56.10 m *Euhoplites armatus*, BGR 13853 (Lehmann et al. 2007: Fig. 9f).

51.00 m *Euhoplites* sp., BGR 13850. The former identification as *Euhoplites opalinus* (Lehmann et al. 2007: Fig. 10f), is too definite considering the fragmentary nature of the specimen.

50.24 m *Euhoplites* cf. *subcrenatus*, BGR 13846. Former identification is non det.

43.92 m *Hysteroceras subbinum*, BGR 13826a (Lehmann et al. 2007: Fig. 11i).

43.92 m *Hamites* cf. *maximus*, BGR 13826b (Lehmann et al. 2007: Fig. 11b).

43.83 m *Hamites* sp., BGR 13825.

43.78 m *Euhoplites* cf. *serotinus*, BGR 13824 (Lehmann et al. 2007: Fig. 10g). The former identification as *Callihoplites patella* is incorrect because of the lack of a peripheral zig-zag pattern in ventrolateral clavi seen in *Callihoplites*. *Euhoplites serotinus* Spath is treated as a separate species and documented with a new, better quality, photo of the holotype (Spath 1930: Pl. 26, fig. 6) as Pl. 1, fig. 8. It is close to the late variant of the variable species *Euhoplites opalinus* Spath, 1930 (see Spath 1930: Pl. 28, Fig. 6), but comparing both specimens at about the same size there are differences: The ventrolateral tubercles on the first half of the ultimate whorl of the holotype of *E. serotinus* are slightly more distant, the tubercles on the inner flank (close to the umbilical rim) appear to be more prominent and more rounded, the ventrolateral tubercles are slightly more distant at this stage and the ribs are less flexuous compared the late form of *E. opalinus*.

43.69 m *Euhoplites* sp., BGR 13823. The former identification as *Callihoplites* cf. *auritus* is incorrect because of the lack of a peripheral zig-zag pattern in ventrolateral clavi seen in *Callihoplites*.

43.40 m *Euhoplites* sp., BGR 13819. The former identification as *Callihoplites* cf. *patella* is incorrect because of the lack of a peripheral zig-zag pattern in ventrolateral clavi seen in *Callihoplites*.

42.73 m *Hysteroceras* sp., BGR 13816.

42.40 m ?*Euhoplites*, BGR 13814b. The specimen formerly identified as *Callihoplites* sp. is too poorly preserved for formal identification, but *Callihoplites* can be excluded because of the lack of a peripheral zig-zag pattern in ventrolateral clavi seen in *Callihoplites*.

42.40 m *Euhoplites* cf. *ochetonotus*, BGR 13814a (Lehmann et al. 2007: Fig. 10j): BGR 13814a shows the large and pronounced ventrolateral bullae typical for *Euhoplites ochetonotus*, more pronounced than in *Euhoplites inornatus*, but smaller that in *Euhoplites subrenatus* and *Euhoplites serotinus*. This strengthens the arguments by Lehmann et al. (2007) for the identification and fits well with Spath's (1930, Pl. 28, fig. 9) var. *nodosa* of *E. ochetonotus* in terms of retaining the umbilical bullae.

42.37 m *Hysteroceras orbignyi*, BGR 13813 (Lehmann et al. 2007: Fig. 11c). A comparison of uncrushed whorls of *H. orbignyi* and *H. varicosum* indicate a more delicate regular and closer ribbing in the former even at a very early stage of ontogeny as in the present specimen. In *H. varicosum* a prolonged smooth stage is followed by very coarse and distant ribbing (compare Spath 1934: p. 485). Thus the former identification *Hysteroceras* cf. *varicosum* is changed.

42.21 m *Mortoniceras*?, BGR 13812. The former identification was *Mortoniceras* sp., but a re-evaluation of the low number of features, weakens the argument for a certain assignment to this genus.

42.20 m *Euhoplites* cf. *subcrenatus*, BGR 13811 (Lehmann et al. 2007: Fig. 10c, left side of the specimen; right side is figured here as Pl. 1, fig. 2). Former identification is *Callihoplites patella* is incorrect be-

cause of the lack of a peripheral zig-zag pattern in ventrolateral clavi seen in *Callihoplites*. The ribs are fairly indistinct and the umbilical tubercles are fairly strong. The whorl height of the crushed specimen is approximately 55 mm at its ad-apertural end. Although it is of much larger size, it corresponds in all main aspects to the neotype recently proposed by Cooper & Owen (Cooper and Owen in press, as fig. 5g & h). BGR 13811 has a coarser rib pattern to a greater diameter and reduced ventro-lateral clavi compared to *E. sublautus*. The latter bears pronounced ventro-lateral clavi at a much smaller diameter than is apparent in BGR 13811.

40.35 m *Euhoplites* cf. *serotinus*, BGR 13805 (Lehmann et al. 2007: Fig. 10h). Former identification as *Callihoplites patella* is incorrect because of the lack of a peripheral zig-zag pattern in ventrolateral clavi seen in *Callihoplites*.

39.53 m *Hysteroceras orbignyi*, BGR 13800 (Lehmann et al. 2007: Fig. 11h).

39.38 m *Mortoniceras* (*Deiradoceras*) *bipunctatum*, BGR 13799 (Lehmann et al. 2007: Fig. 11E).

38.88 m *Euhoplites* sp., BGR 13797a (Lehmann et al. 2007: Fig. 11a). Former identification as *Callihoplites auritus* is incorrect because of the lack of a peripheral zig-zag pattern in ventrolateral clavi seen in *Callihoplites*.

38.88 m *Goodhallites* cf. *goodhalli*, BGR 13797b (Lehmann et al. 2007: Fig. 11g). Former identification as *Hysteroceras binum*. The small-size specimen resembles *Hysteroceras* spp. particularly in its flattened state, but a larger whorl height compared with *Hysteroceras* and fragments of a keel that is visible under the microscope favours assignment to *Goodhallites*.

38.78 m *Hysteroceras* cf. *varicosum*, BGR 13795 (Pl. 1, fig. 4). After comparing the specimen with uncrushed, early whorls of *Hysteroceras binum* the former identification of *H.* cf. *binum* is changed due to the generally coarser and more pronounced ribbing in BGR 13795. The latter is a juvenile stage with a maximum diameter of 20 mm. At that size, *H. orbignyi* would have much finer ornament, whereas this specimen is already robustly ornamented with somewhat flexuous and dense ribs (there are about 27 ribs per whorl in BGR 13795). The pattern of distortion suggests that the specimen originally showed a quadrate whorl section, typical for *Brancoceras binodosum* Stieler, 1922, later referred to as a variety of

Hysteroceras varicosum (Spath 1934) or inaccurately as a subspecies of *H. varicosum* (J. de C. Sowerby, 1824) (e. g. Marcinowski and Wiedmann 1990). The ribbing and tuberculation of Stieler's species is extremely coarse in contrast to the comparatively thin and dense very regular, but prominent ribbing in the present specimen.

38.75 m *Hysteroceras* sp., BGR 13794.

38.60 m *Hysteroceras* cf. *orbignyi*, BGR 13791.

38.46 m *Euhoplites* cf. *serotinus*, BGR 13790 (Lehmann et al. 2007: Fig. 10k). Formerly identified as *Callihoplites patella*, is not a *Callihoplites* because of the lack of a peripheral zig-zag pattern in ventrolateral clavi seen in *Callihoplites*.

38.20 m *Euhoplites* cf. *vulgaris*, BGR 13788 (Lehmann et al. 2007: Fig. 10i). Former identification as *Callihoplites patella* is regarded as inaccurate because of the narrow channel visible in this crushed flat specimen and the lack of a peripheral zig-zag pattern in ventro-lateral clavi seen in *Callihoplites*.

37.65 m *Callihoplites auritus*, BGR 13785, as in Lehmann et al. (2007: Fig. 11j).

37.11 m *Callihoplites* cf. *patella*, BGR 13783b (Pl. 1, fig. 6). The present specimen needs to be referred to *C. strigosus* Spath, 1927, because of the larger whorl height compared to *C. patella* Spath, 1927. Marcinowski and Wiedmann (1990), however, discussed the variability in these two morphotypes and considered dimorphism. Lehmann et al. (2007) regarded *C. strigosus* and *C. patella* as synonymous, the latter having page priority (see Spath 1927). Here this general concept is followed, with respect to BGR 13783b the former identification as *Callihoplites patella* is only slightly modified due to its poor preservation.

37.11 m *Hysteroceras* cf. *binum*, BGR 13783b, as in Lehmann et al. (2007: Fig. 11f).

## 5.   Lithostratigraphic units

Based on the Kirchrode borings, the Gault Group succession in the Hannover area consists of the Minimus Ton, of latest Early and Middle Albian age, overlain by the Kirchrode Mergel of Late Albian age (Owen 2007, therein classified as Gault Formation). The Minimus Ton Member is a long established term (e. g. Stolley 1937) and the Kirchrode Mergel

Member was introduced by Wiedmann and Owen (2001; originally called Kirchrode Marls). The lithostratigraphic subdivision of the Minimus Ton Member is dated as latest part of the Early Albian (*Douvilleiceras mammillatum* Zone, *Otohoplites auritiformis* Subzone) to the earliest Late Albian (*D.cristatum* Subzone) by ammonites (Owen 2007). The overlying Kirchrode Mergel Member is of Late Albian age (*H.orbignyi* Subzone at its base). For more detailed information see Owen (2007).

The Lahe core section shows a continuous record of claystones, with a carbonate content of about 25% in average, for the interval 66.30 m–98.35 m. There are no carbonate content data available for the interval between 30 m and 50 m core depth, a succession that is regarded as critical for a distinction between the Minimus Ton Member and Kirchrode Mergel

Member according to biostratigraphical results. The more common occurrence of belemnite rostra (primarily of *Neohibolites minimus*) is a feature distinguishing the Minimus Ton Member from the overlying Kirchrode Mergel. *Neohibolites* is less common above a core depth of around 46 m and although this is statistically not significant (a total of 34 specimens is recorded from the Lahe core), the correlation of ammonite zones with the Kirchrode II core presented in Fig.3 agrees well with assuming that the lithostratigraphic discrimination between the Minimus Ton Member and the Kirchrode Mergel is at around 46 m. Furthermore, Lehmann et al. (2007) reported that the claystones above approximately 40 m are slightly lighter in colour although the lithology does not change macroscopically. This colour change is believed to discretely trace the boundary between the
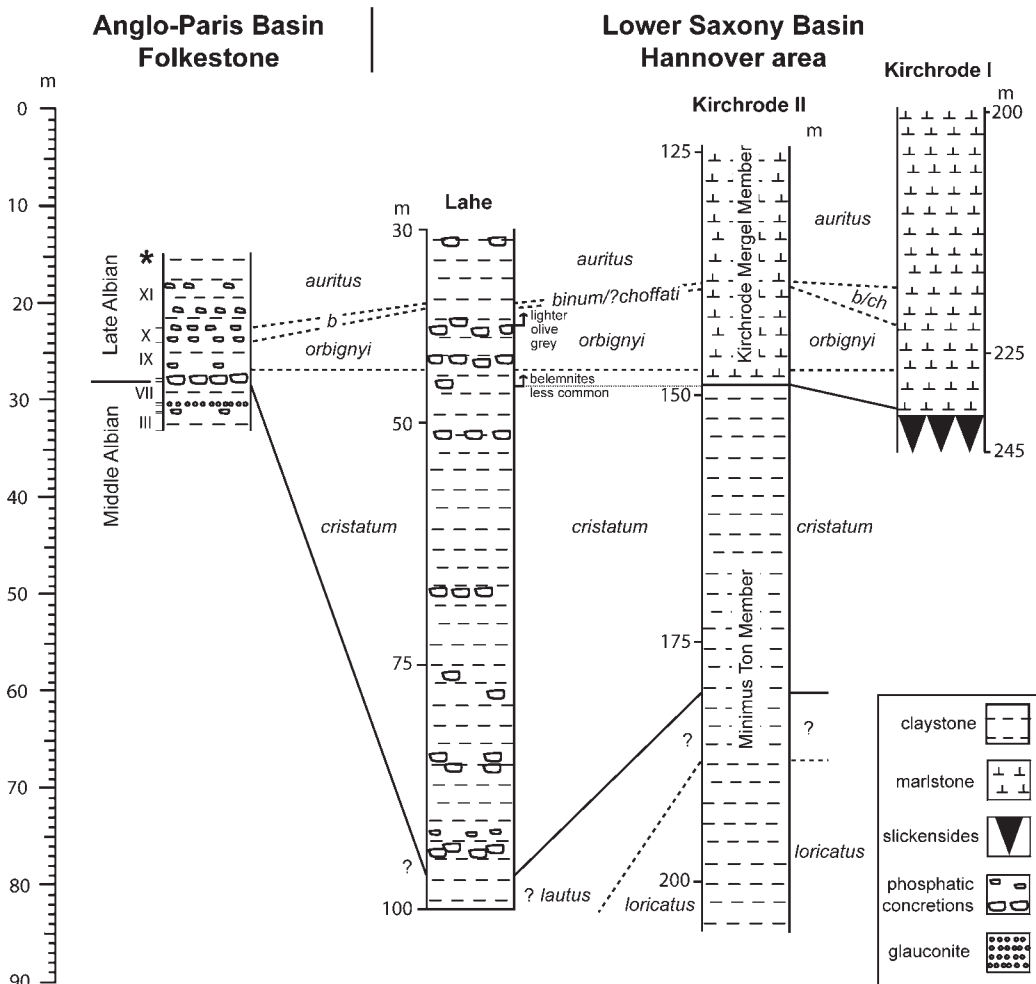
Fig. 3. Correlation of the Lahe and Kirchrode boreholes in Hannover, NW-Germany, with the Gault standard section at Folkestone, SE-England. The asterisk is indicating the bed numbers of Price (1874). Data for Kirchrode cores after Owen (2007), Lahe core after Lehmann et al. (2007) and Folkestone section after Gale and Owen (2010).

two members mentioned at the Kirchrode II and Schacht Konrad 1 sites (Owen 2007). In the Lahe core both members can not be unequivocally distinguished.

6.   Correlation

Figure 3 presents a correlation of the Middle/Late Albian boundary interval based on the ammonite bearing cores in the Hannover area together with a correlation with the section at Copt Point near Folkestone, southeastern England. The latter was choosen for comparison since it is the most comprehensive of the sections of the Gault Clay relevant to the Anglo-Paris Basin (Gale and Owen 2010). Moreover, the Copt Point section constitutes an ideal succession in the Boreal Realm with respect to its well established ammonite ranges based on an extensive research history (e. g. Spath 1923–1943; Casey 1966).

6.1   Middle/Late Albian boundary

The definition of the Middle/Late Albian boundary itself in the Hannover area by ammonites is based on the FO of the early Late Albian index *Euhoplites trapezoidalis* (e. g. Casey 1966) at 96.50 m (Lehmann et al. 2007: Fig. 9b). Additionally, the occurrence of the phylogenetic sequence within the genus *Actinoceramus* provides biostratigraphical information. *Actinoceramus sulcatus* forma A and *A. sulcatus* forma B are index fossils that are frequent in sections of the basalmost Late Albian in the Boreal Realm. These species are missing in the basalmost few meters of the core, and this might indicate a latest Middle Albian age for this interval (Figs. 2 and 3).

6.2   Dipoloceras cristatum Zone

At Lahe the revised ammonite biostratigraphy (Fig. 2) is evident of a *Dipoloceras cristatum* Zone age and comprises the longest interval of the core containing early Late Albian species of *Euhoplites*, namely *E. trapezoidalis*, *E. sublautus* and *E. armatus*. At Folkestone the FO of all of these lies in the basal *D. cristatum* Zone (bed VIII, e. g. Casey 1966). *E.* cf. *subcrenatus* is recorded from the higher part of the *D. cristatum* Zone in the Lahe core (Fig. 2; Lehmann et al. 2007: Fig. 10b), this agrees with the FO of *E. subcrenatus* at Folkestone in bed IX. Owen (2007) recorded distinctly less numerous specimens from the *D. cristatum* Zone of the Kirchrode II core, *E.* cf. *opalinus*, *Dimor-*

phoplites sp. *chloris* group, *Anahoplites* cf. *planus* and *Hamites* sp. All of these taxa are not restricted to this stratigraphic interval, and thus the lower limit of the *D. cristatum* Zone is unclear in the core and the upper limit is defined by the lower limit of the *H. orbignyi* Subzone.

The Lahe and Kirchrode II sections show a well-developed *D. cristatum* Zone succession with a thickness of more than 50 m in the former and more than 30 m in the latter. This contrasts very sharply with a thickness of less than 2 m at Folkestone; thus the succession in the Hannover area is vastly thicker than in any other Central and Western European section that is well-dated (see Conclusions).

6.3   Hysteroceras varicosum Zone

Based on ammonite data, the base of the *H. varicosum* Zone cannot be defined precisely in the Lahe core. The base of the *Hysteroceras orbignyi* Subzone is taken at a depth of 43.92 m in the Lahe core with the first appearance of *Hysteroceras subbinum* (Lehmann et al. 2007: Fig. 11i) a form which occurs in the *H. orbignyi* Subzone in Bed IX at Folkestone (e. g. Casey 1966). Above occurs *Hysteroceras* sp. (42.73 m core depth), *H. orbignyi* (at 42.37 m core depth, figured by Lehmann et al. 2007: Fig. 10c), *Mortoniceras* (*Deiradoceras*) *bipunctatum* (39.38 m core depth, figured by Lehmann et al. 2007: Fig. 11e), *H. varicosum* (38.78 m core depth) and less significant, due to open nomenclature, *E.* cf. *subcrenatus* (42.20 m core depth; figured by Lehmann et al. 2007: Fig. 10c and herein as Pl. 1, fig. 2) and *H.* cf. *orbignyi* (at 38.60 m core depth) associated with *A. sulcatus* forma A. Following Owen (1984, 1999) it is possible to trace the lower boundary of the *Hysteroceras binum* Subzone by the morphological change from strongly ribbed *Actinoceramus sulcatus* (*A. sulcatus* forma A herein, see Fig. 1) to the smooth *Actinoceramus sulcatus forma* D ('*Actinoceramus concentricus*, late form' of Owen (1984, 1999). Despite different taxonomic concepts and slight differences in observation, more recent papers agree that this change in morphology does not occur before the base of the *H. binum* Subzone (the *varicosum* Subzone of Spath (1923–43) and others (Crampton in Kennedy et al. 1999, discussed in Lehmann et al. 2007; Crampton and Gale 2005, 2009).

Apart from the morphological change in *Actinoceramus* at a depth of 36.50–36.70 m, there is no evidence for the *H. binum* or *H. choffati* Subzones in the Lahe core. The *Hysteroceras choffati* Subzone is missing at

Folkestone as is the upper *H. binum* Subzone, this non sequence might find its correspondence in the missing or strongly reduced *H. binum* Subzone in the Lahe core.

A single *H.* cf. *binum* from 37.11 m core depth co-occurs with *Callihoplites* cf. *patella* (Pl. 1, fig. 6), but this level is already placed into the *Callihoplites auritus* Subzone (*M. inflatum* Zone, see Table 1).

6.4   Mortoniceras inflatum Zone

The basal *Mortoniceras inflatum* Zone is determined by a record of the *Callihoplites auritus* Subzone species *Callihoplites auritus* (Fig. 2; figured by Lehmann et al. 2007: Fig. 11j) in the Lahe core. This places the boundary at a core depth of 37.65 m. Taken into account the LO of *Actinoceramus sulcatus* s.l. at a core depth of 36.50–36.70 m mentioned above, the stratigraphic assignment appears consistent, since this inoceramid lineage probably became extinct before the *C. auritus* Subzone (Crampton and Gale 2009). The Lahe core records only the basal part of the *C. auritus* Subzone succession in comparison with a full succession seen in Kirchrode I (40 m) and a nearly complete succession seen in the Kirchrode II core (35 m), the latter commencing below the top of the *C. auritus* Subzone succession (Owen 2007). The greatly expanded succession of *C. auritus* Subzone sediments is explained by an increase in sedimentation rates of biogenic carbonate as well as terrigenous detritus as a result of a regional change to a more humid climate and by the increased tectonic subsidence of the Lower Saxony basin intensified by local halokinetic movements (Fenner 2001a).

7.   Conclusions

The correlation of sections in the Hannover area presented in Fig. 3 demonstrates that the sedimentation rates in this part of the Lower Saxony Basin were overall high compared to other shelf sections in Europe. This is true for the standard section for ammonite biostratigraphy at Folkestone, S-England (Fig. 3), but also when compared to other successions in the Anglo-Paris Basin (e. g. Amédro and Destombes 1978; Amédro 1992; Amédro et al. 2004).
The main features of the succession focused here are:
1) Very high sedimentation rates during the earliest Albian *D. cristatum* Zone and the *H. orbignyi* Subzone of the *H. varicosum* Zone.

2) A distinctly reduced sediment accumulation during the *H. binum/choffati* Subzones.

The reduced thickness of the Folkestone section in the *D. cristatum* Zone compared with the Hannover area, might be due to the effect on sedimentation of a basement ridge (Owen 1971). This contrasts with the high sedimentation rates in the deeply subsiding sub-basin of the Hannover area proven by the Lahe and particularly, the Kirchrode cores (Prokoph and Thurow 2001). Besides the geometry of the depositional realm, assuming a large availability of accommodation space in the Hannover area (Prokoph and Thurow 2001), the sea level fluctuations need to be considered. According to Lehmann et al. (in press) the *D. cristatum* Zone bears witness to the Transgressive Systems Tract (TST) and possibly early Highstand Systems Tract (HST) in Folkestone, this accords with a succession that is characterized by condensed deposits in a distal environment (Sturrock 1996) and is confirmed by phosphatic pebble nodule layers indicating current winnowing (see also Fig. 3 herein). The expanded sedimentary succession at Hannover indicates that sediment accumulation is not primarily ruled by sea level changes. The uplift of the Rhenish-Bohemian massif (Fig. 1), induced a local subsidence of the Lower Saxony Basin producing fairly deep sub-basins for accommodation. The attenuation of sedimentation during the *H. binum* and *H. choffati* Subzones (Fig. 3) is due probably to the effect of halokinesis engendered by the adjoining salt domes (Baldschuhn et al. 1996; Fenner 2001c). The Kirchrode Mergel in general contains a higher carbonate content than the Minimus Ton below. Fenner (2001a) considered climate change as a factor; an increased humid climate might have enhanced the marine productivity and thus accumulation of carbonate during the *Callihoplites auritus* Subzone.

8.   References

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