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An integrated study (inoceramid bivalves, ammonites, calcareous nannofossils, planktonic foraminifera, stable carbon isotopes) of the Ten Mile Creek section, Lancaster, Dallas County, north Texas, a candidate Global boundary Stratotype Section and Point for the base of the Santonian Stage

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ABSTRACT:

GALE, A.S., KENNEDY,W.J., LEES, J.A., PETRIZZO, M.R. & WALASZCZYK, I. 2007. An integrated study (inoceramid bivalves, ammonites, calcareous nannofossils, planktonic foraminifera, stable oxygen and carbon isotopes) of the Ten Mile Creek section, Lancaster, Dallas County, north Texas, a candidate Global boundary Stratotype Section and Point for the base of the Santonian Stage. *Acta Geologica Polonica*, **57** (2), 113-160. Warszawa.

The WalMart section on Ten Mile Creek, Lancaster, Dallas County, Texas, exposes a 23 metre section of Austin Chalk that can be integrated into a more than 60 m composite sequence for the Dallas area on the basis of bed-by-bed correlation. The section was proposed as a possible candidate Global Boundary Stratotype at the 1995 Brussels meeting on Cretaceous Stage boundaries, with the first occurrence of the inoceramid bivalve *Cladoceramus undulatoplicatus* (ROEMER, 1852) as the potential boundary marker. An integrated study of the inoceramid bivalves, ammonites, planktonic foraminifera, and calcareous nannofossils places the first occurrence of *Cl. undulatoplicatus* in a matrix of ten ancillary biostratigraphic markers. The candidate Global boundary Stratotype Section and Point (GSSP) is located within a composite stable carbon isotope curve for the Austin Chalk as a whole. This shows it to lie 3.5 m below the Michel Dean stable carbon isotope event, originally recognised in the English Chalk. The first occurrence of *Cl. undulatoplicatus* lies in the same position in relation to stable carbon isotope events in both Texas and England that can in principle be recognised globally in marine sediments. The WalMart section satisfies many of the criteria required of a GSSP for the base of the Santonian Stage, although ownership and access require clarification.

Key words: Ammonites, Inoceramid Bivalves, Foraminifera, Calcareous Nannofossils, Carbon Isotopes, Santonian, Texas.

INTRODUCTION

At the meeting of the Santonian Working Party, held at the Second International Symposium on Cretaceous Stage Boundaries in Brussels, 8-16th September, 1995, the following statements were made with respect to the base of the Santonian Stage:

'Primary marker: The lowest occurrence of *Cladoceramus undulatolplicatus.* It is a taxon easily recognisable and widespread. It is known from N. America, Europe, Africa, Madagascar, and central Asia.

This proposal was supported by a majority at Brussels. (Yes=23; no=1; Abstentions=2).

Postal vote; 20 votes (out of 39 WG members) were returned. (Yes =17; No =1; Abstentions=2).'

'Boundary Stratotype Section: As yet, we cannot make a formal proposal, because we need to know and integrate the biostratigraphy better. We have selected three candidates:

1) Olazagutia Quarry (Navarra, Spain). M. LAMOLDA would collate data and report to the Chairman.
2) Seaford Head (Sussex, England). R. MORTIMORE and C. J. WOOD would collate data and report to the Chairman.
3) Ten Mile Creek (Dallas, Texas). E.G. KAUFFMAN and A.S. GALE would collate data, and report to the Chairman.

This proposal was supported UNANIMOUSLY. (yes=34; No=0; Abstentions=1).

The postal ballot supported this proposal (Yes=18; No=1; Abstention=1) (LAMOLDA & HANCOCK 1996, pp. 99-100).'

Twelve years on, the purpose of the present contribution is a simple one: to document the candidate boundary section in Ten Mile Creek, Lancaster, Dallas County, Texas, and place the first occurrence of *Cladoceramus undulatoplicatus* (ROEMER, 1852) (Text-fig. 1), which was originally described from the Austin Chalk of New Braunfels, Texas, in its stratigraphic context.

Throughout this account we use first occurrence (FO) and last occurrence (LO) to describe the limits of the range of taxa based on our present observations, unless indicated otherwise.

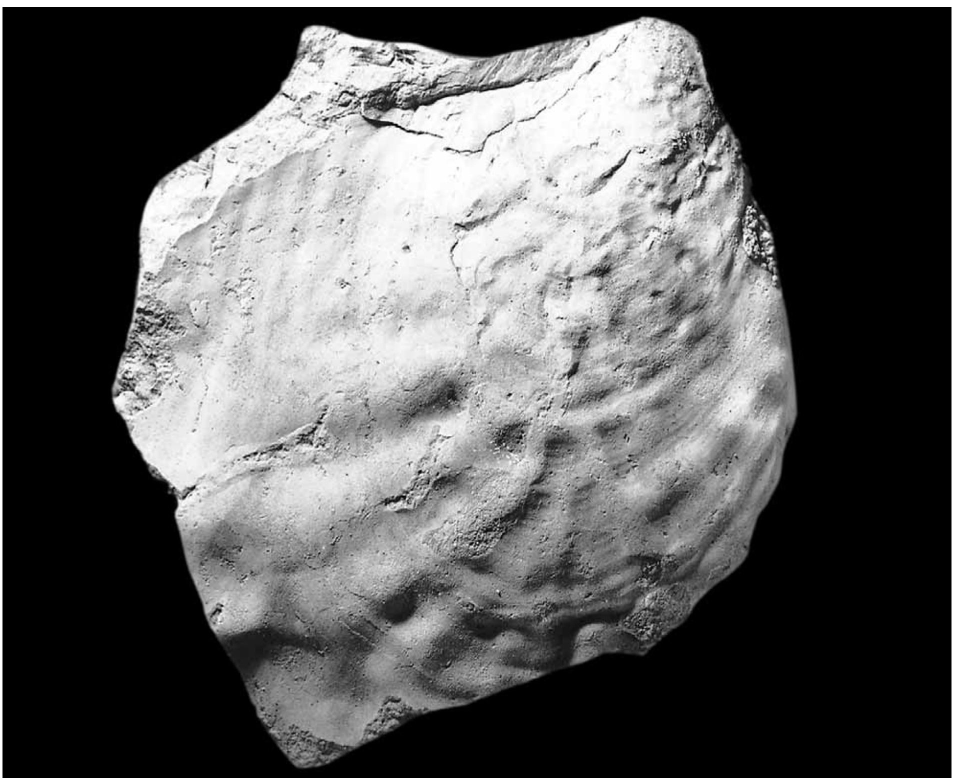


Fig. 1. The lectotype of *Cladoceramus undulatoplicatus* (ROEMER, 1852), PIB ROEMER Collection 03, the original of ROEMER (1852, pl. 7, fig. 1), from the Austin Chalk on the banks of the Guadalupe River below New Braunfels, Comal County, Texas. Geologisches und Paläontologisches Intitut Collections, Universität Bonn

THE AUSTIN CHALK IN DALLAS COUNTY, TEXAS

The Austin Chalk Formation is approximately 161 metres (530 feet) thick in Dallas County, Texas (Text-fig. 2), and is a rhythmically bedded, bioturbated hemipelagic chalk with a variable clay content of about 5-30%. It rests with marked disconformity upon the Eagle Ford Shale Formation. The Austin Chalk has been divided into three members, successively, the Atco Chalk, the Bruceville Marly Chalk and the Hutchins Chalk (LARSON & *al*. 1991). The Atco Chalk is rich in carbonate, and contains a number of thin, hard limestones and several bentonitic clays, representing altered volcanic ashfalls. The Bruceville Marly Chalk has a higher clay content, and therefore does not form such good exposures. The Hutchins Chalk was not investigated in Dallas County during the present study, but is evidently similar to the carbonate-rich hemipelagic chalk facies developed 100 km to the south, at Waxahachie in Ellis County (GALE & *al*. in press).

The Atco and lower Bruceville members display rhythmic alternations of more and less marly chalk on a decimetre to metre scale, which are very conspicuous in weathered outcrops. These are rather irregular in thickness, and were interpreted by LARSON & *al.* (1991) as representing climatic cyclicity in the Milankovitch Band, with frequencies corresponding to the mode of precession at 20 kyr. LARSON & *al.* also tentatively identified long and short eccentricity signals (400 and 100 kyr) in the Atco. The upper part of the Atco Member also contains several broad, shallow erosional channels, about 5-10 m across and 1-1.5 m deep, which display bedded chalk infills.

The Austin Chalk ranges from Late Turonian to earliest Campanian in age (HANCOCK & WALASZCZYK 2004; GALE & *al*. in press). The Atco-Bruceville boundary falls well within the Late Coniacian, not at the Coniacian-Santonian boundary as reported by LARSON & *al.* (1991). Their assignation was based upon presumed occurrences of Santonian inoceramids, expected to co-occur with the ammonite *Texanites* sp. and has not been supported in the present study. The succession described herein spans the boundary of the Atco and Bruceville members and is of Late Coniacian to Early Santonian age.

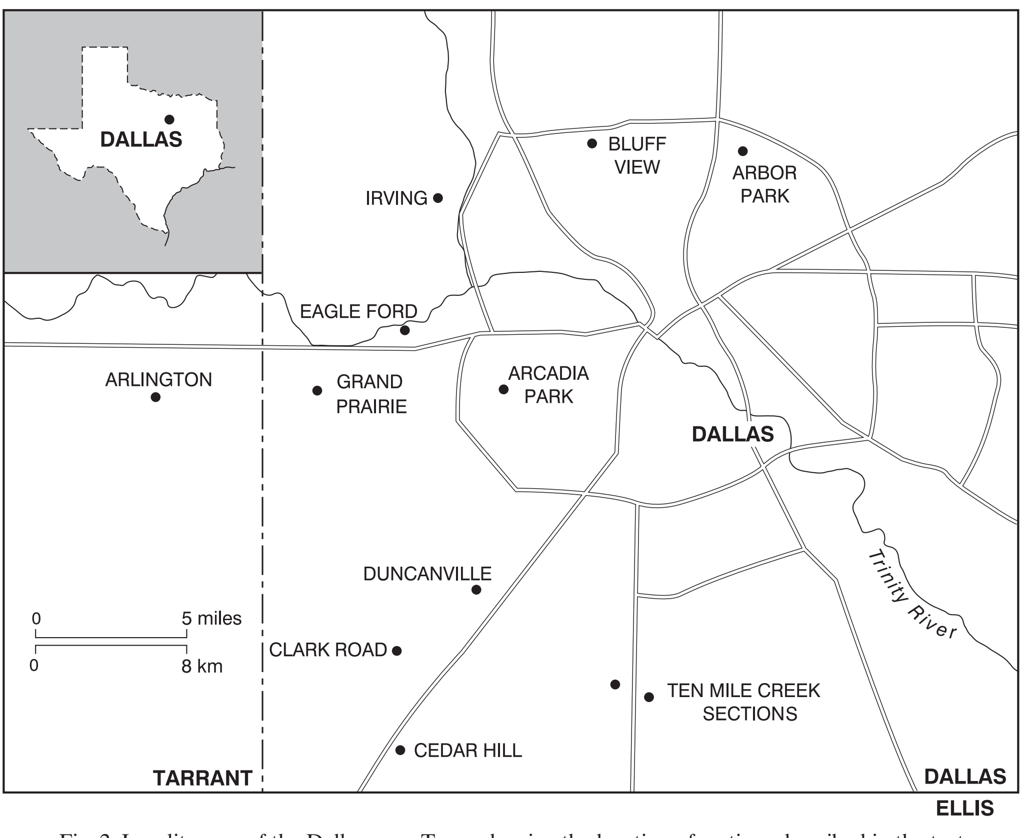


Fig. 2. Locality map of the Dallas area, Texas, showing the location of sections described in the text

LOCALITY DETAILS

Church of the Nazarene

This section comprises cuttings in the sides and floor of Ten Mile Creek for approximately 200 m north of the intersection of the Creek with Pleasant Run Road in Desoto, Dallas County. Access is possible behind the Church of the Nazarene, on the east side of the Creek (Text-fig. 3). Access to the lower section is only possible when the water level is low, and requires some shallow wading. The section was numbered 9 by WILLIAMS (1957) and referred to as the Williams 9 section by LARSON & *al*. (1991). The precise relationships of the base of this section with the underlying part of the Atco Member are uncertain, but LARSON & *al.* (1991) argued that a small gap of a few metres separates the base of this section from the underlying Jacobsen 3 locality to the north. The northern part of the Nazarene section is bisected by an approximately east-west fault, which downthrows the Bruceville Marly Chalk Member against the upper part of the Atco Member. From detailed stratigraphical correlation, the fault can be calculated to downthrow approximately 28 m to the north.

The (stratigraphically) lower part of the section exposes 15 m of uppermost Atco Member, and 2 m of basal Bruceville Member (Nazarene 1: Text-fig. 4). The highest part of the succession is exposed in bluffs adjacent to the Church of the Nazarene, and progressively lower levels are seen in the floor and sides of the creek to the north. The lower 7 m comprise rhythmic, strongly bioturbated alternations of paler grey chalks and darker grey marls of variable thickness. The upper part (7-15 m) is made up of regular alternations of hard limestones and thin, dark, recessing marls. A conspicuous channel, about 1 m in depth, is present between 8 and 9 m (LARSON & *al*. 1991, fig. 29a, b). A supposedly bentonitic yellowish marly clay is present approximately 0.3 m beneath the summit of the Atco Member.

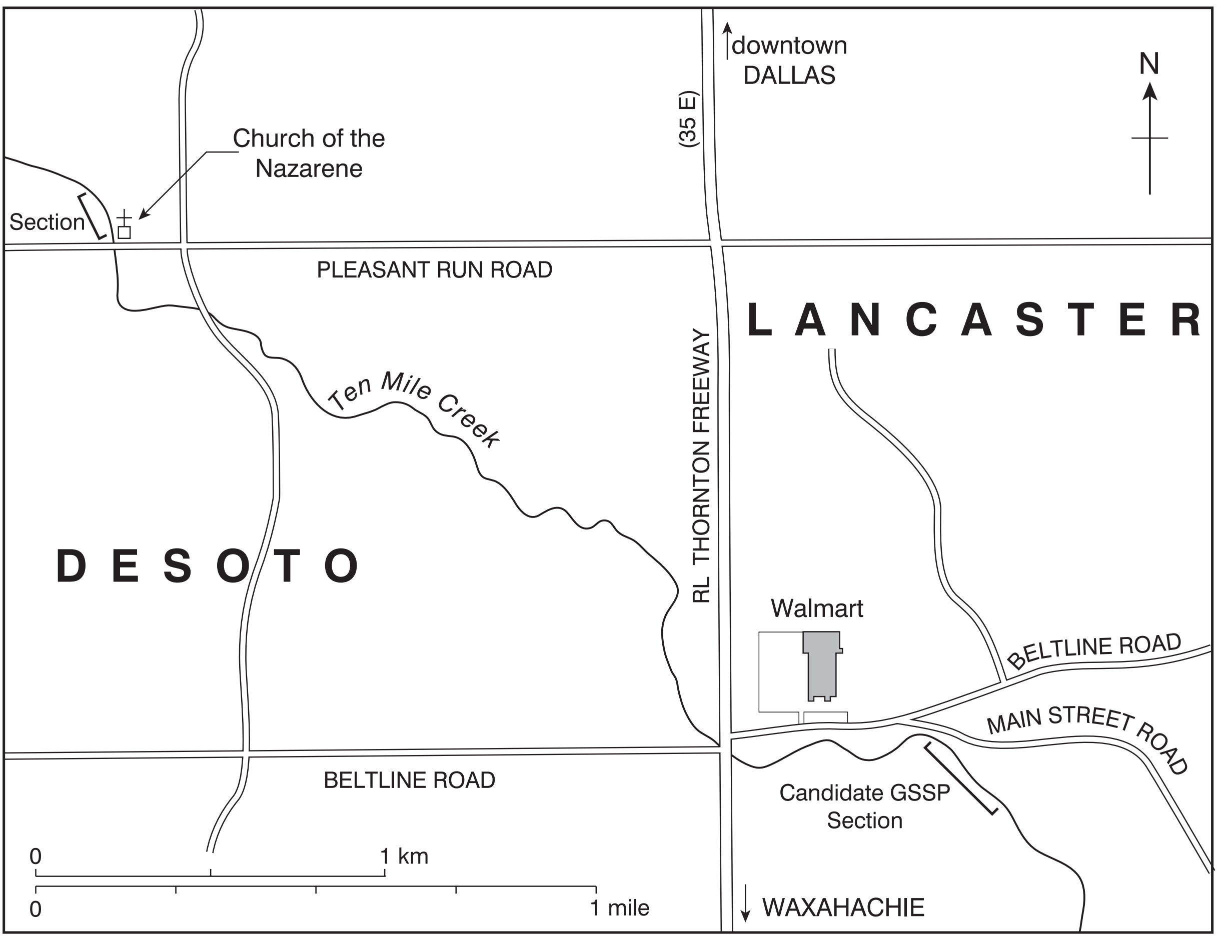


Fig. 3. The location of the Church of the Nazarene and the WalMart candidate GSSP section on Ten Mile Creek, Dallas County, Texas

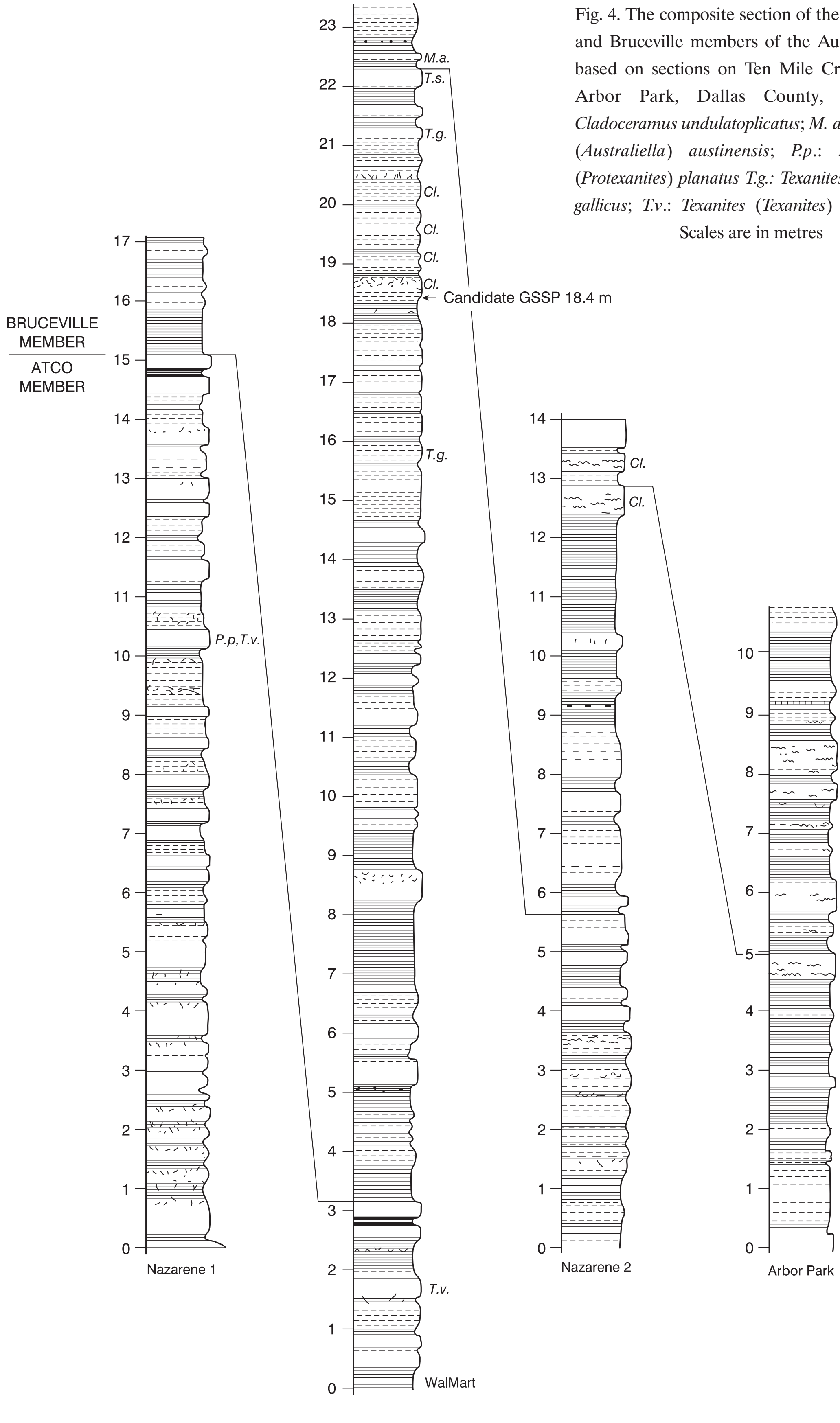


Fig. 4. The composite section of the upper Atco and Bruceville members of the Austin Chalk, based on sections on Ten Mile Creek, and in Arbor Park, Dallas County, Texas. *Cl*: *Cladoceramus undulatoplicatus*; *M. a.*: *Menabites* (*Australiella*) *austinensis*; *P.p.*: *Protexanites* (*Protexanites*) *planatus T.g.*: *Texanites* (*Texanites*) *gallicus*; *T.v.*: *Texanites* (*Texanites*) *vanhoepeni*. Scales are in metres

The uppermost 2 metres of the succession are more marly and are assigned to the basal Bruceville Marly Chalk Member. The uppermost 5 m of the Nazarene section overlaps with the base of the WalMart locality to the south-east (see below) and all the beds in this interval can be confidently correlated between the two localities.

To the north of the fault, 14 m of Bruceville Member are exposed (Nazarene 2: Text-fig. 4). The lower part of the succession (0-3.5 m) comprises inconspicuously rhythmic, weakly indurated grey marls. These are overlain by four alternations of paler limestones and darker marls (3.5-6 m), then a succession of marls and weakly developed limestones (6-12.3 m). The section is capped (at 12.3-14 m) by a group of 3 marly limestones containing abundant specimens of the inoceramid *Cladoceramus undulatoplicatus* (ROEMER, 1852). The lower 6 m of this section overlap with the uppermost part of the WalMart section, and individual beds can be matched precisely between the two localities. The uppermost 6 m of the Nazarene 2 Bruceville succession also can be correlated bed by bed to the Arbor Park section in north Dallas (see below).

WalMart

This section (Text-figs 3, 4, 6) comprises low bluffs in the sides of Ten Mile Creek, 1-2 km east-south-east of the WalMart store north of Main Street, Lancaster, Dallas County, east of the freeway 35E.The section has only been briefly mentioned in the literature as localities 40/48 of JACOBSEN (1961). Access to the Creek is most easily obtained from the south side of Main Street opposite the WalMart store, and the section can be easily worked when the water level is low.

The lower section comprises a series of bluffs on the northern side of the creek, and exposes the

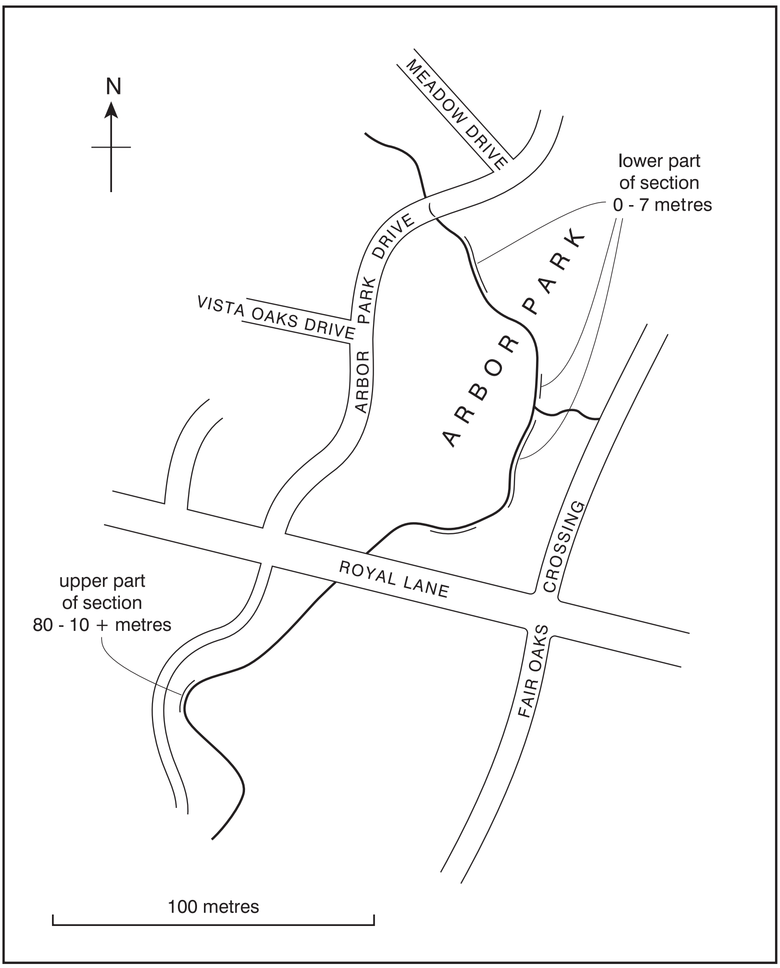


Fig. 5. Locality map for the Arbor Park sections in Dallas County, Texas

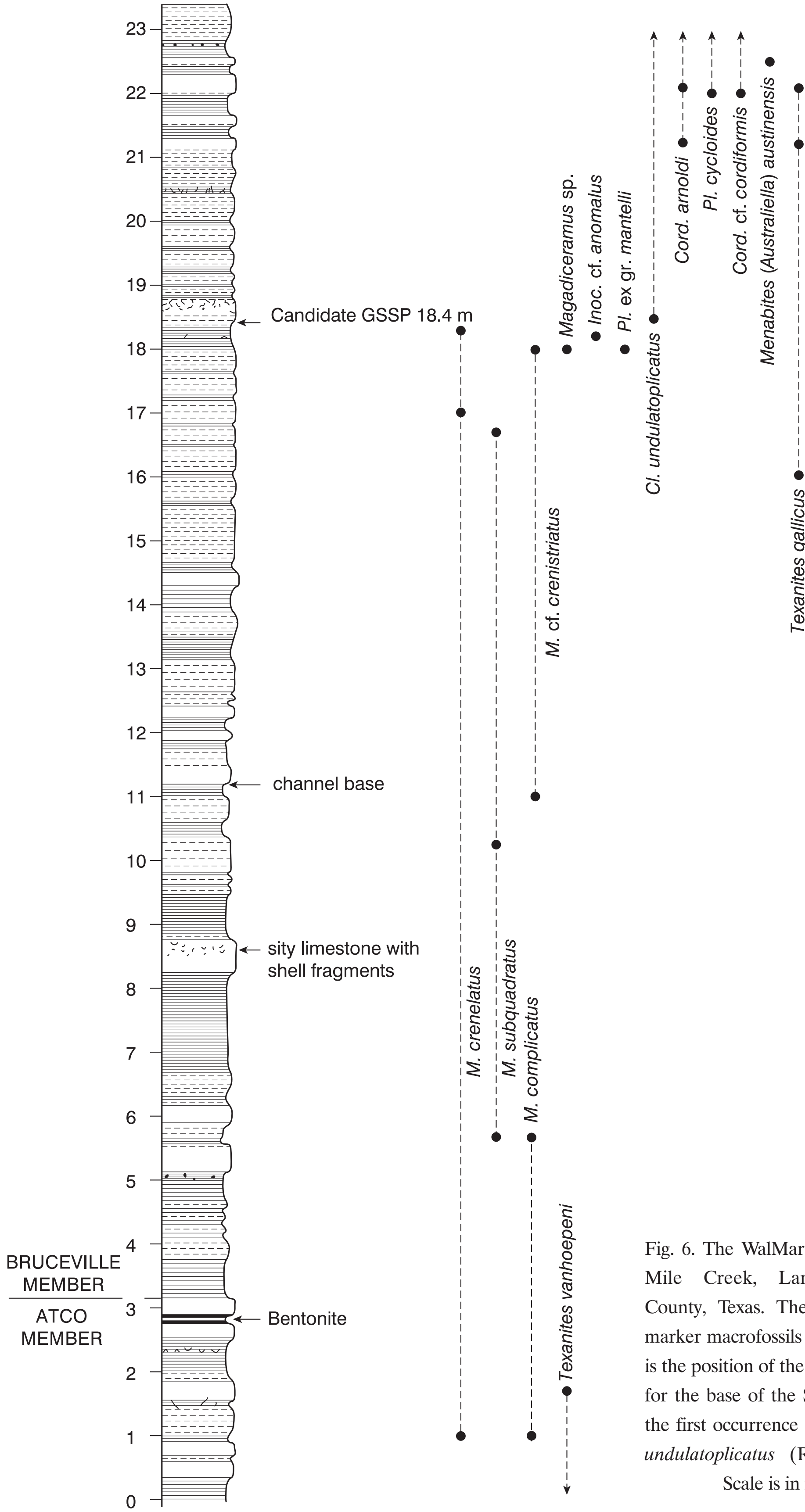


Fig. 6. The WalMart section on Ten Mile Creek, Lancaster, Dallas County, Texas. The ranges of key marker macrofossils are indicated, as is the position of the candidate GSSP for the base of the Santonian Stage, the first occurrence of *Cladoceramus undulatoplicatus* (Roemer, 1852). Scale is in metres

uppermost 3 m of the Atco Member and approximately the lowest 7 m of the Bruceville Member, dipping gently to the south-east. The beds making up the lower 5 m of the section, including the putative bentonite (2.8 m), exactly match those exposed adjacent to the Church of the Nazarene. At 8.2 m, a conspicuous 0.3-0.35 silty limestone containing oysters is present. The succession continues in low cliffs to the south-east on the southern side of the Creek, and an erosion channel is present at 11 m. The overlying strata (11-21 m) comprise poorly defined beds of marl and marly limestone, containing oysters and inoceramid bivalves at some levels. The candidate GSSP falls at the 18.4 m level in this succession, and is marked by the first occurrence of *Cladoceramus undulatoplicatus*. The uppermost 3 m exposed include four thin limestones, which alternate with dark grey marls containing pyrite nodules, and correlate with beds exposed to the north of the fault in the Nazarene section (see above).

Arbor Park

The uppermost part of the succession described here is exposed in the sides of the un-named creek that runs through Arbor Park in north Dallas (Text-figs 4, 5). A total of 11 m of Bruceville Member are exposed here. The lower, marly part of the succession correlates well with the Nazarene 2 succession in Desoto, and correlation is confirmed by the distinctive triplet of marly limestones full of *Cladoceramus undulatoplicatus* present between 4.7 and 6.2 m at Arbor Park and between 12.3 and 14 m in the Nazarene section. The higher part of the Arbor Park succession is made up of rhythmic alternations of marls and marly limestones, and a possibly bentonitic clay is present at 9.2 m.

THE COMPOSITE DALLAS SECTION

The detailed bed-by-bed logs of the Nazarene, WalMart and Arbor Park sections can be precisely correlated on the basis of marker beds, as discussed in the previous section. These provide the basis for the composite log shown in Text-fig. 4, which places the WalMart candidate GSSP section in its regional stratigraphic context of approximately 50 m of the Atco and Bruceville members of the Austin Chalk Formation.

REPOSITORIES OF MATERIAL STUDIED

GPIM: Geologisch-Paläontologisches Institut und Museum, Münster;

GWB: Geologische Abteilung der Westfälischen Bergewerkschaftenkasse, Bochum;

NLBH: Niedersächsiches Landesamt für Bodenforschung, Hannover

OUM: Oxford University Museum of Natural History;

PIB: Paläontologisches Institut und Museum of the Friedrich Wilhelms University, Bonn;

TMM: Texas Memorial Museum, Austin, Texas.

UWFG: Faculty of Geology, University of Warsaw, Warsaw.

Foraminiferal samples are housed in the collections of the Sezione di Geologica et Paleontologia of the Dipartimento di Scienze della Terra “Ardito Desio”, Milan.

Nannofossil samples are housed in the Micropalaeontology Unit, Department of Earth Sciences, University College, London.

Stable isotope samples are housed in the Geological Collections, Oxford University Museum of Natural History.

INOCERAMID BIVALVES (I. WALASZCZYK)

Introduction

The WalMart section on Ten Mile Creek offers an exceptionally rich inoceramid record across the Coniacian - Santonian boundary interval. It provides a representative record for the southern Euramerican biogeographical region (biogeographic terminology used here is that defined by KAUFFMAN 1973), characterized by a *Magadiceramus*-dominated Upper Coniacian and a *Cladoceramus*-rich Lower Santonian, south of the regular occurrence of *Sphenoceramus*. The change to the *Cladoceramus* fauna, marking the base of the Santonian, is quite rapid, but the inoceramid succession appears to be complete in terms of that currently recognised elsewhere in this interval.

Most of the material from the WalMart section comes from four fossiliferous horizons (levels around 11 m, 17 m, 18.4-18.5 m and 22 m) but the fauna is in no way limited to them. Inoceramids are quite well preserved, although specimens from marly beds are usually crushed.

The late Coniacian inoceramid assemblages are dominated by *Magadiceramus*, represented mostly by *M. crenelatus* (SEITZ, 1970) (Text-figs 7.1-7.2, 7.6-7.7, 7.9; 8.3-8.4) and *M. complicatus* (HEINE, 1929) (Text-figs 7.3, 7.4, 8.6). *Magadiceramus subquadratus* (SCHLÜTER, 1887) (Text-figs 7.5, 7.8) is rare. There are also two specimens of *M.* cf. *crenistriatus* (Text-figs 8.1, 8.5), a characteristic albeit poorly recognised magadiceramid species, from the 11.3 m level, and from the 18 m level, just below the candidate GSSP, the FO of *Cladoceramus undulatoplicatus* in the section, at the 18.4 m level. A number of juvenile magadiceramid specimens (mostly fragments) are specifically indeterminate and left in open nomenclature as *Magadiceramus* sp. Non-magadiceramid inoceramids are rare; there are only two specimens from a level just below the candidate GSSP in the material at hand. These are *Inoceramus* sp. (Text-fig. 9.8), which is compared here to *Inoceramus anomalus* (HEINE, 1929), and a platyceramid species (Text-fig. 9.7), which clearly belongs to the *mantelli* group. The former is rarely recorded, but it is worthy of note that single specimens of this species, from an equivalent stratigraphical level, have recently been described from the Pueblo section in Colorado in the US Western Interior (WALASZCZYK & COBBAN 2006, 2007). The exact stratigraphic horizon of the German type specimen is unknown.

Cladoceramus undulatoplicatus (Text-figs 1, 9.4 and 10.2), the boundary marker for the base of the Santonian, first appears at the 18.4 m level, and is quite common in the overlying metre of section. It becomes less common in the higher parts of the WalMart succession. A single specimen, referred to herein as *Cl.* cf. *undulatoplicatus* comes from slightly above the 19 m level. There is a second abundance peak in the Bruceville Member in other sections: between 12.5 and 14 m in the Nazarene 2 section, and between 4.6 and 8 m in the Arbor Park section. The lowest *Cordiceramus* comes from the 18.4 m level; these are juvenile fragments, referred here to *C. arnoldi* (SEITZ, 1961), a member of the *bueltenensis* group. Cordiceramids dominate the highest assemblage studied, from the 22 m level (Text-figs 9.1-9.3, 9.5, 9.6, 9.9-9.10). This also marks the first occurrence in the section of the characteristic Santonian inoceramid *Platyceramus cycloides* (WEGNER, 1905) (Text-fig. 10.1).

Correlation

Correlation of the WalMart sequence with other sections in the southern part of the Euramerican biogeographical region is straightforward. Problems may, however, arise when attempting precise correlation with sections in the northern part of the region, because of the absence or irregular occurrence of *Cl. undulatoplicatus*. Sphenoceramids of the *cardissoides-pachti* group, the approximate markers for the Coniacian-Santonian boundary interval in this area, are known to make their first appearance slightly below the first occurrence of cladoceramids (SEITZ 1965). Other potential inoceramid markers are *Cordiceramus* of the *cordiformis* group, and representatives of the *Platyceramus cycloides* group, which appear at approximately the same level as the first *Cl. undulatoplicatus*.

Direct correlation, based on the occurrence of *Cl. undulatoplicatus*, is also possible within the northern Tethyan Realm. This species is widely known from the Caribbean (KAUFFMAN 1970), and the Mediterranean province (Spain: LÓPEZ 1992; Italy: DHONDT & DIENI 1990; Bulgaria: TZANKOV 1981; Kopet-Dagh, Turkmenistan: ATABEKIAN 1974). For some reason, *Cl. undulatoplicatus* did not become established along the southern margins of the Tethys. Documentation from these areas is still highly incomplete, but reports from Egypt by SEIBERTZ (1996) and Tunisia (SALAJ 1987, ROBASZYNSKI & *al*. 2000) indicate that inoceramids of the *Pl. cycloides* group may serve as secondary markers for the base of the Santonian there.

Cladoceramids are also present in the East African Province, occurring in KwaZulu-Natal, South Africa (KENNEDY & *al*. in press) and Madgascar (SORNAY 1964, 1969). Based on associated ammonite faunas, the group was regarded here as of middle and even late Santonian age (SORNAY 1969). New data from both these regions suggest, however, that the first occurrence of cladoceramids here corresponds to their first occurrence in the Euramerican region (see KENNEDY & *al.* in press).

Cladoceramids are widely known from the Japanese-East Asian Subprovince of the North Pacific Province where, however, they are apparently much younger, and are dated as latest Santonian to early Campanian (MATSUMOTO & UEDA 1962; MATSUMOTO & *al*. 1982; NODA 1983), or exclusively early Campanian (TOSHIMITSU 1988; TOSHIMITSU & *al*. 1995, 1998). In inoceramid terms the base of the Santonian is defined in Japan by the first occurrence of '*Inoceramus*' *amakusensis*, an apparently endemic platyceramid species. Its correlation with the European or East African schemes, i.e., with the base of the *undulatoplicatus* Zone, is based on ammonites, specifically on the first appearance of *Texanites*. But it is now well established that this genus first appeared in the late Coniacian (KAPLAN & KENNEDY 2000, KENNEDY & KAPLAN 2000), as confirmed here.

Biostratigraphy

The interval studied in the WalMart section on Ten Mile Creek represents two inoceramid zones. The Coniacian part belongs to the *Magadiceramus crenelatus* Interval Zone and the Santonian part represents the *Cladoceramus undulatoplicatus* Taxon Range Zone. The *M. crenelatus* Zone is dated as late Late Coniacian. The base of the zone is defined by the first occurrence of the index species. The top is defined by the first occurrence of *Cl. undulatoplicatus*. The zone can be recognised throughout the southern and central parts of the Euramerican biogeographical region, and in the northern Tethyan province. Less clear is the upper stratigraphic boundary of the *Cl. undulatoplicatus* Zone. In the Euramerican biogeographical region the zone, as currently defined, is regarded as equivalent to the Lower Santonian. Single specimens of *Cladoceramus* have been reported, however, from levels well above the interval with common cladoceramids, which is taken as marking the top of the zone (SEITZ 1965, p. 135). SEITZ (1965) compared these specimens with *Cl. japonicus*, but their actual affinities are currently unresolved. The zone can be recognised throughout the Euramerican biogeographical region and in the northern Tethyan Realm. Its equivalent in the East African Province is the *Cladoceramus hokkaidoensis* Zone.

Systematic palaeontology

Genus *Magadiceramus* HEINZ, 1932

TYPE SPECIES: *Inoceramus subquadratus* SCHLÜTER, 1887, p. 43.

REMARKS: See discussion in WALASZCZYK & COBBAN (2006). The genus is known from the Upper Coniacian of the Euramerican region.

Magadiceramus subquadratus (SCHLÜTER, 1887)
(Text-figs 7.5, 7.8, 8.7)

1887. *Inoceramus subquadratus* SCHLÜTER, p. 43.
2006. *Magadiceramus subquadratus* (SCHLÜTER, 1887); WALASZCZYK & COBBAN, p. 297, text-figs 12.2-12.5, 23.4, 33.1, 33.4-33.5, 34.2, 35.4, 38.5 (with synonymy).

TYPE: The lectotype is PIB ADKINS 1, the original SCHLÜTER specimen figured by ADKINS (1928, pl. 34, fig. 6) from the Austin Chalk of Texas, USA.

MATERIAL: Three specimens: OUM KT10002 from the 10.2 m level, OUM KT10011 from the 5.7 m level, and OUM KT10026 from the 16.7 m level in the WalMart section.

DESCRIPTION: OUM KT10002 is an internal mould of a single LV, with its ventral part missing. The specimen is moderately large, with L = 97 mm. The valve is weakly inflated, quite oblique (with δ = 50°). The anterior margin is short, convexly rounded with the anterior face flattened. The hinge line is long and straight. In the juvenile and early adult stage the valve has an obliquely ovate outline; the subquadrate outline appears later in ontogeny. The posterior auricle is small, triangular. The ornament up to h = 63 mm consists of one generation of concentric rugae; further ventrally two generations of rugae appear, with the two to three smaller rugae in the interspaces between the main rugae.

OUM KT10011 is a moderately large internal mould of a double-valved specimen, subquadrate in outline, with its postero-dorsal part (including the posterior auricle) missing. The specimen is geniculated. Umboward of the geniculation the disc is weakly inflated. Posterior to the growth axis there is a narrow, step-wise radial sulcus. The ornament consists of concentric rugae typical for *Magadiceramus*, with superimposed, raised growth lines.

OUM KT10026 is an internal mould of a quite large LV. The juvenile stage (umboward of the geniculation) of the valve is oval in outline, resembling a *Platyceramus*; the postero-dorsal part is missing.

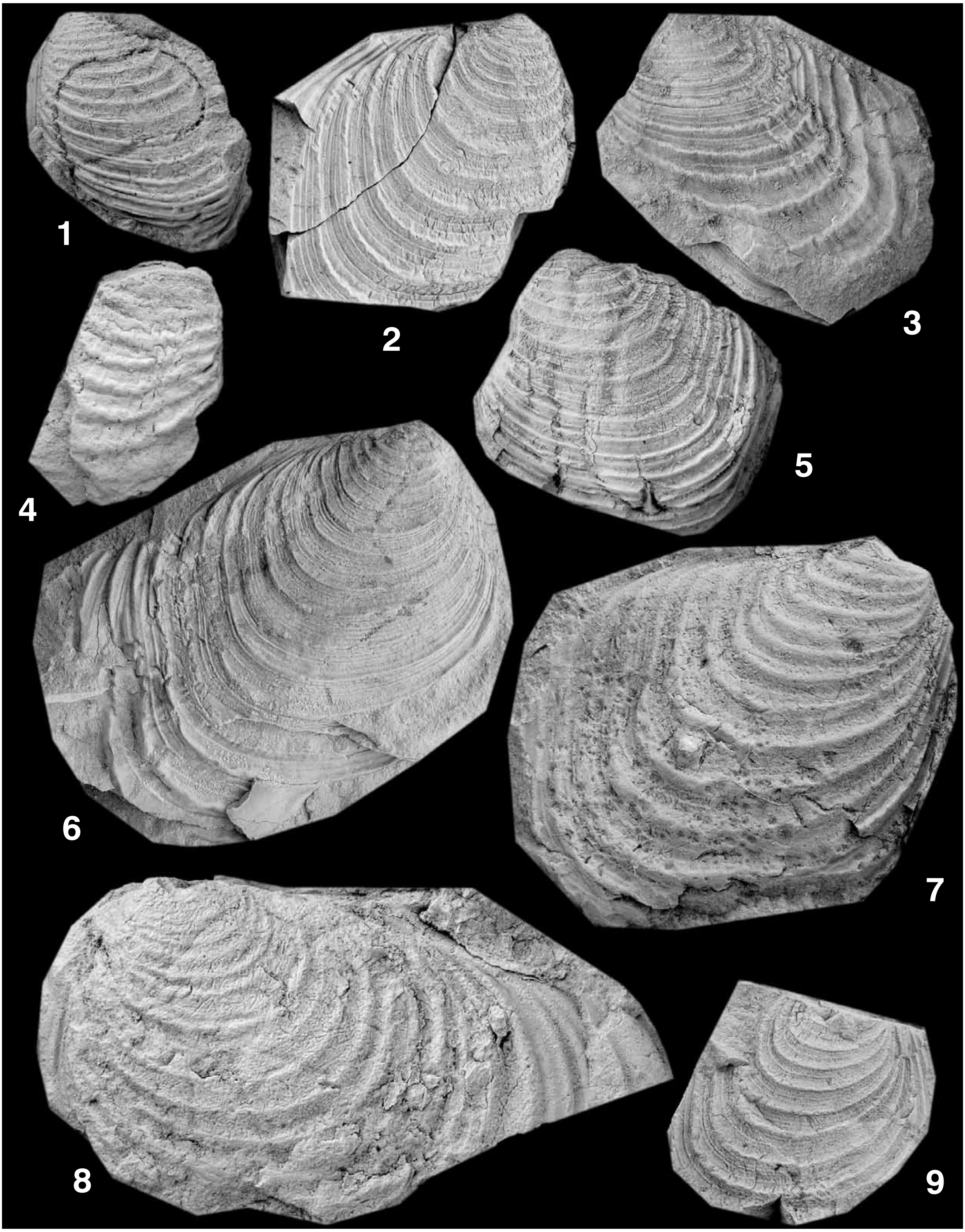


Fig. 7. Inoceramids from the Bruceville Member of the Austin Chalk of the WalMart section on Ten Mile Creek, Lancaster, Dallas County, Texas. **1-2, 6-7, 9** – *Magadiceramus crenelatus* (Seitz, 1970); 1 – OUM KT10021, 11.3 m level; 2 – OUM KT10013, 11 m level; 6 – OUM KT10020, 11 m level; 7 – OUM KT10010, 1 m level; 9 – OUM KT10014, 11 m level. **3-4** – *Magadiceramus complicatus* (Heine, 1929); 3 – OUM KT10016, 11 m level; 4 – OUM KT10012, 5.7 m level. **5, 8** – *Magadiceramus subquadratus* (Schlüter, 1887); 5 – OUM KT10011, 5.7 m level; 8 – OUM KT10002, 10.2 m level. All figures are natural size

REMARKS: The status of the currently recognised species of *Magadiceramus* still needs further clarification. *Magadiceramus crenelatus*, *M. complicatus* and the nominate subspecies are separated on the basis of their ornament, but the mutual differences are often very slight. Moreover, juveniles or juvenile fragments, which dominate collections, are indistinguishable, so that determining the actual record of species is often difficult. Because the stratigraphical appearance of crenelation and of radial ribs appears to be the same in all successions described, a simple morphological (typological) concept is applied here. The consequent extension of morphological variability within species as currently defined indicates that the original subspecies level categories as applied to these taxa by SEITZ (1970) cannot be maintained.

OCCURRENCE: *Magadiceramus subquadratus* is known from most of the Euramerican biogeographic region, although apparently absent in its most northerly parts. It ranges through the entire Upper Coniacian.

Magadiceramus complicatus (HEINE, 1929)
(Text-figs 7.3, 7.4, 8.6)

1929. *Inoceramus subquadratus* var. *complicata* HEINE, p. 38, pl. 2, fig. 7.
2006. *Magadiceramus complicatus* (HEINE, 1929); WALASZCZYK & COBBAN, p. 303, figs 30.1-3, ?30.4, 30.5, ?31.5 (with synonymy).

TYPE: The lectotype is GPIM B666, the original of HEINE (1929, pl. 2, fig. 7) from the Upper Coniacian of the Wetterschacht of the Grimberg Mine 3, Westphalia, Germany, at a depth 140 m.

MATERIAL: Three specimens: OUM KT10012 from the 5.7 m level; OUM KT10016 and KT10025b from the 11 m level in the WalMart section.

DESCRIPTION: All specimens studied are incomplete internal moulds of single valves. They have well-preserved ornament. The best preserved are OUM KT10016 and KT10025. Both specimens have a *subquadratus* type juvenile stage (in OUM KT10025 it becomes transitional to *crenelatus* type) followed by radial ribbing that produces the complex ornament of the adult stage. The radial ribs are strongest at or near the edges of the concentric rugae. OUM KT10012 is an antero-ventral fragment of an adult, with well-developed radial ornament.

REMARKS: The present specimens are typical representatives of *M. complicatus*, comparing well with the type (HEINE 1929, pl. 2, fig. 7). The species resembles *Inoceramus americanus* WALASZCZYK & COBBAN (2006, p. 263, figs 11.1, 11.7, ?12.9, 12.13-12.15, 23.2), from which it differs in its subquadrate valve outline.

OCCURRENCE: Upper Upper Coniacian of the Euramerican biogeographical region.

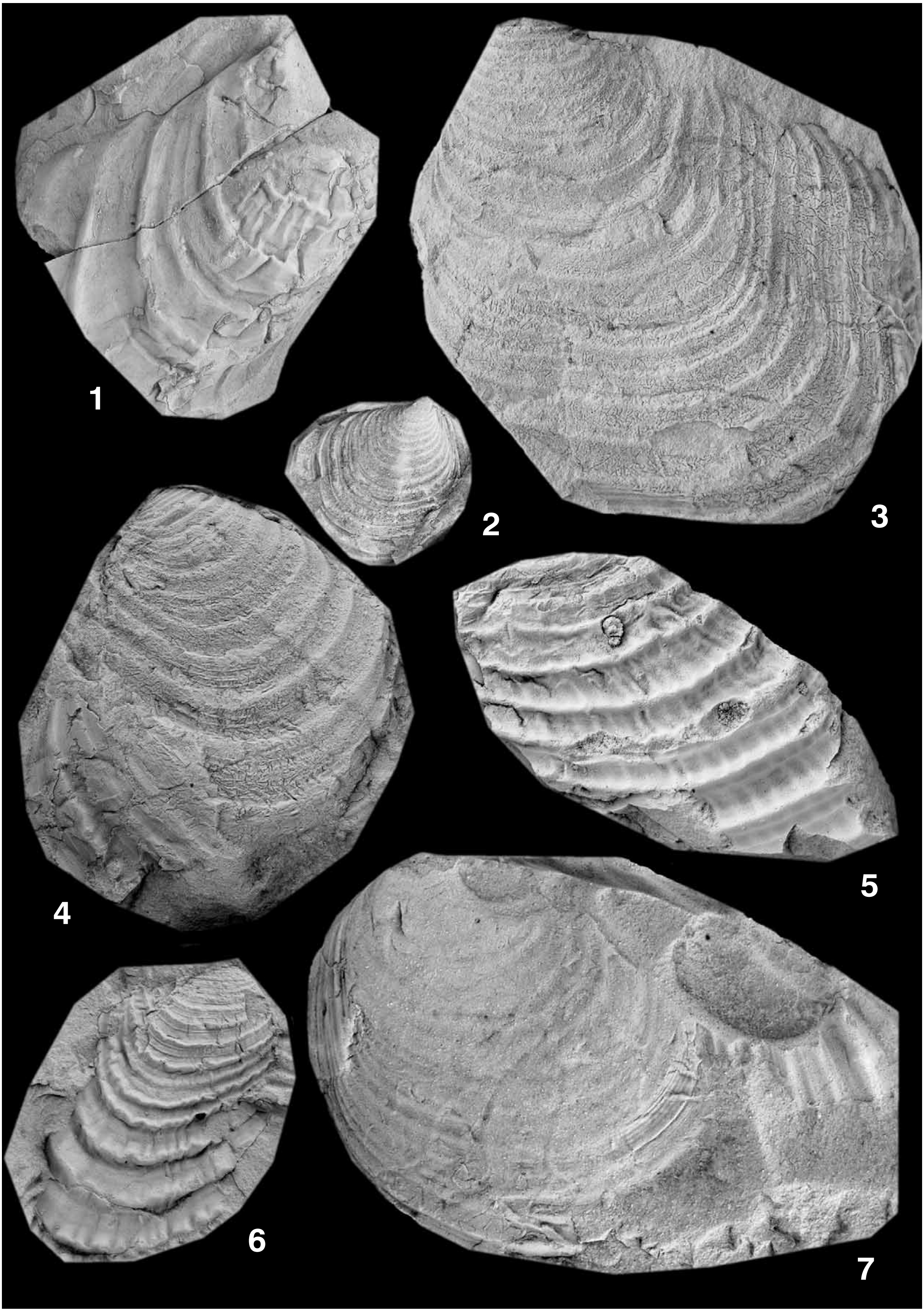
Magadiceramus crenelatus (SEITZ, 1970)
(Text-figs 7.1, 7.2, 7.6, 7.7, 7.9, 8.3, 8.4)

1929. *Inoceramus subquadratus* SCHLÜTER; HEINE, p. 34, pl. 1, figs 1-2.
2006. *Magadiceramus crenelatus* (SEITZ, 1970); WALASZCZYK & COBBAN, p. 301, text-figs 33.2, 33.6, 33.8; 34.4, 36.1 (with synonymy).

TYPE: The holotype, by original designation, is GWB S 528 Wb, the original of SEITZ (1970, pl. 4, fig. 2) from the Upper Coniacian of mine section 5 of Minister Stein, Westphalia, Germany.

MATERIAL: UWFG ZI/31/081 and OUM KT10010 from the 1 m level; OUM KT10013/18 (part and counterpart), OUM KT10014, OUM KT10017, OUM KT10019, and OUMKT10020 from the 11 m level; OUM KT10021 from the 11.3 m level; UWFG ZI/31/082, from just below the 18.4 m candidate GSSP level.

Fig. 8. Inoceramids from the Bruceville Member of the Austin Chalk of the WalMart section on Ten Mile Creek, Lancaster, Dallas County, Texas. **1, 5** – *Magadiceramus* cf. *crenistriatus* (HEINZ, 1928); 1 – UWFG ZI/31/080, 18.4 m level; 5 – OUM KT10024, 11.3 m level. **2** – *Magadiceramus* sp.; OUM KT10025a, 11 m level. **3, 4** – *Magadiceramus crenelatus* (SEITZ, 1970); 3 – UWFG ZI/31/081, most probably from the 1 m level; 4 – UWFG ZI/31/082, 18.4 m level. **6** – *Magadiceramus complicatus* (HEINE, 1929); OUM KT10025b, 11 m level. **7** – *Magadiceramus subquadratus* (SCHLÜTER, 1887); OUM KT10026, 16.7 m level. All figures are natural size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DESCRIPTION: All specimens are moulds of single valves. UWFG ZI/31/081, OUM KT 10010 and OUM KT 10020 are quite complete, with well- preserved details of ornament. All specimens are subquadrate in outline with a distinct radial sulcus, developed posteriorly of the growth axis. The sulcus is wide and shallow. The posterior auricle is narrow, elongated parallel to the hinge line, and separated from the disc with a distinct step, as is well seen in OUM KT10020 and OUM KT10018/13. The other specimens are fragments of adults with crenelated portions preserved.

Crenelation starts at various distances from the umbo. When present, it is usually developed subregularly on all of the main rugae. The interspaces bear well-developed, sharp-edged growth lines.

Juveniles and young adults of *M. crenelatus* are indistinguishable from those of *M. complicatus*.

OCCURRENCE: This species first appears slightly later than *M. subquadratus* and appears to extend almost to the top of the Coniacian throughout most of the Euramerican biogeographic region, apart from the most northerly parts (see COBBAN & *al*. 2005; WALASZCZYK & COBBAN 2006).

Magadiceramus cf. *crenistriatus* (HEINZ, 1928)
(Text-figs 8.1, 8.5)

Compare:

pars 1909. *Inoceramus subquadratus* ROEMER; SCHROEDER, p. 63, pl. 16, fig. 1.

2006. *Magadiceramus crenistriatus* (HEINZ, 1928); WALASZCZYK & COBBAN, p. 302, figs 28.3, 28.7.

MATERIAL: Two specimens: OUM KT10024 from the 11.3 m level and UWFG ZI/31/080, from the 18 m level in the WalMart section.

DESCRIPTION: Both specimens are adult, fragmentary internal moulds. OUM KT10024 is the antero-ventral part of an individual, and is apparently undeformed, UWFG ZI/31/080 is an adult fragment with the juvenile part missing, and the anterior margin deformed. Both specimens show the typical *crenistriatus* ornament, composed of relatively widely spaced concentric rugae and radial ribs. There are two generations of concentric rugae: one or two smaller second-generation rugae are present between successive larger first-generation rugae, forming a reticulate ornament. As in *Magadiceramus complicatus*, the radial ribs occur only on the anterior half of the disc, disappearing at the radial sulcus and absent posterior of it.

REMARKS: *Magadiceramus crenistriatus* differs from the other *Magadiceramus* species in its ornament, which is composed of strong and widely spaced concentric rugae, with smaller rugae in between and with superimposed radial ribs, variously developed, together producing the characteristic reticulate ornament.

OCCURRENCE: Upper Upper Coniacian of the US Western Interior, Texas and Germany.

Genus *Cordiceramus* HEINZ, 1932

TYPE SPECIES: *Inoceramus cordiformis* J. DE C. SOWERBY, 1823, p. 61, pl. 44.

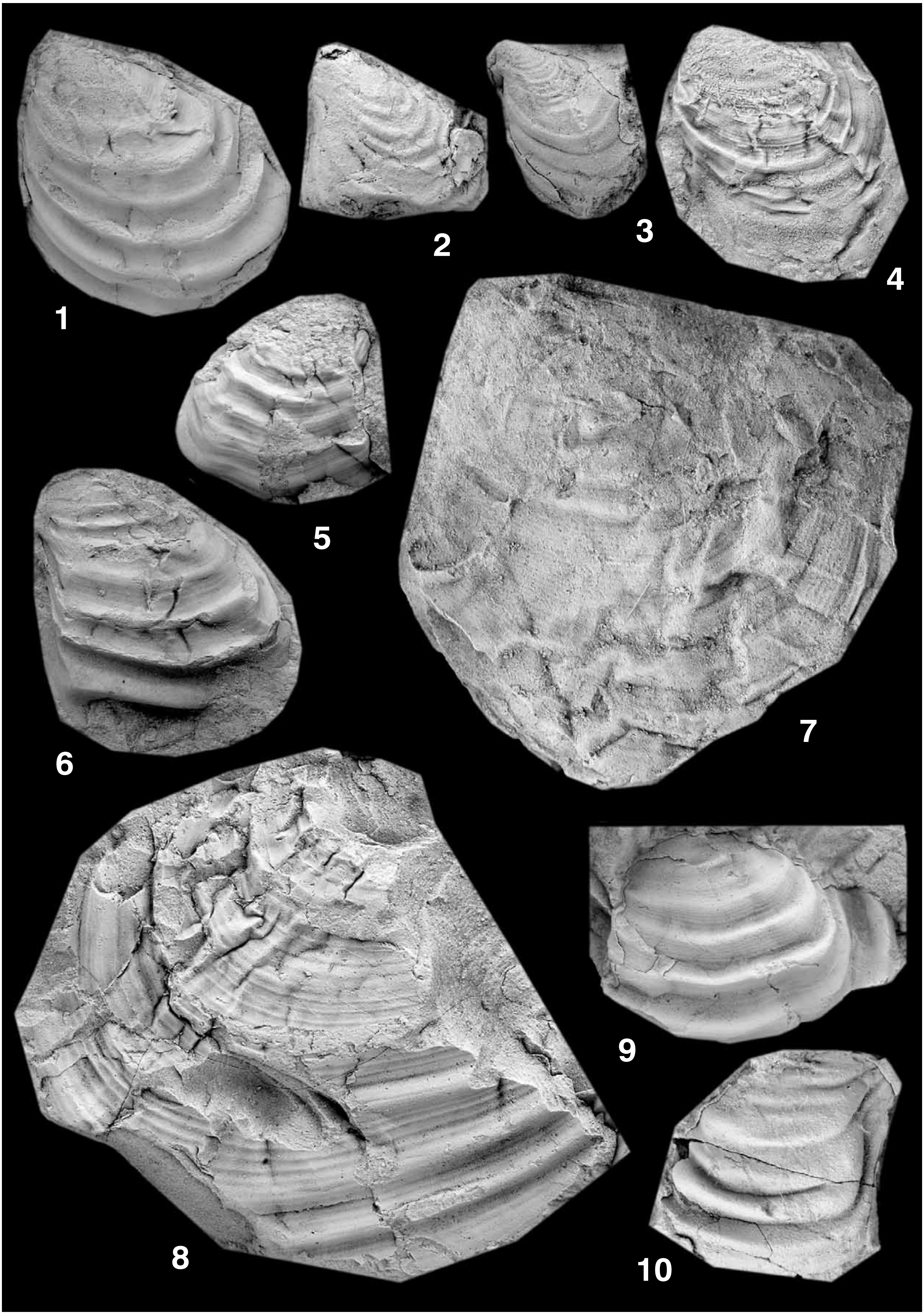
OCCURRENCE: *Cordiceramus* first appeared in the Late Coniacian (e.g. NODA 1986) and ranged into the mid-Campanian (SEITZ 1961, 1967; WALASZCZYK & *al*. 2001; WALASZCZYK 2004).

Cordiceramus cf. *cordiformis* (J. De C. SOWERBY, 1823)
(Text-figs 9.5, 9.9)

Compare:

1823. *Inoceramus cordiformis* J. DE C. SOWERBY, p. 61, pl. 44.

Fig. 9. Inoceramids from the Bruceville Member of the Austin Chalk of the WalMart section on Ten Mile Creek, Lancaster, Dallas County, Texas. **1-3, 6, 10** – *Cordiceramus arnoldi* (SEITZ, 1961); 1 – OUM KT10044, 22 m level; 2 – OUM KT10041, 21.2 m level; 3 – OUM KT10040, 21.2 m level; 6 – UWFG ZI/31/084, from slightly above the 22 m level; 10 – OUM KT10045, 22 m level;. **4** – *Cladoceramus undulatoplicatus* (ROEMER, 1852); UWFG ZI/31/083, 18.5 m level. **5, 9** – *Cordiceramus* cf. *cordiformis* (J. DE C. SOWERBY, 1823); 5 – UWFG ZI/31/088, 22 m level; 9 – OUM KT10043, 22 m level. **7** – *Platyceramus* ex gr. *mantelli* (DE MERCEY) BARROIS, 1879, UWFG ZI/31/085, from slightly above the 18 m level. **8** – *Inoceramus* cf. *anomalus* (HEINE, 1929), OUM KT10032, from the 18.35 m level. All figures are natural size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1912. *Inoceramus cordiformis* SOWERBY; WOODS, p. 334, pl. 53, fig. 8; pl. 54, fig. 4.
1961. *Inoceramus* (*Cordiceramus*) *cordiformis cordiformis* SOW.; SEITZ, p. 114, text-fig. 26a, b.
pars 1961. *Inoceramus* (*Cordiceramus*) *cordiformis* subsp. indet.; SEITZ, p. 120, pl. 8, fig. 5.

TYPE: The holotype is the original of J. DE C. SOWERBY (1823, pl. 44, re-illustrated by WOODS 1912, pl. 53, fig. 8), from the (inferred) Santonian of Gravesend, England.

MATERIAL: Two specimens: UWFG ZI/31/088 and OUM KT10043 from the 22 m level in the WalMart section.

DESCRIPTION: TMC 38 is a small (h max = 30 mm) internal mould of a right valve. The posterior auricle is not preserved. It has a moderately long anterior margin and distinctly sulcate ventral one. The disc is moderately oblique (precise measurement cannot be made). There is a shallow but distinct radial sulcus posterior to the growth axis, which becomes progressively stronger ventrally. The ornament consists of weak, round-edged rugae and distinct, raised growth lines.

OUM KT10034 is a juvenile fragment of a single left valve, with portions of the shell preserved. The umbonal part and posterior auricle are not seen. The length of the exposed part is 38 mm. The disc is subtriangular, slightly oblique. Posteriorly of the growth axis there is a weak radial sulcus. The disc surface is ornamented with concentric, round-edged rugae, which become stronger when traced ventrally. The rugae appear to have been weak or absent in the umbonal region.

REMARKS: Valve outline, presence of the posterior disc sulcus, and the same type of ornament, show these specimens to be *Cordiceramus cordiformis* (J. DE C. SOWERBY, 1823) in the narrow sense of the nominate subspecies *C. cordiformis cordiformis* of SEITZ (1961). The specimens resemble the smallest individual illustrated by WOODS (1912, pl. 54, fig. 4), from Micheldever, Hampshire, England. Also referred here is the original of SEITZ (1961, pl. 8, fig. 5), unassigned to subspecies by him, from the basal Middle Santonian.

OCCURRENCE: The present specimens are from the 22 m level in the Lower Santonian. *Cordiceramus cordiformis*, in the narrow sense of SEITZ, is known from the Lower and Middle Santonian of the Euramerican biogeographic region. SEITZ (1961, 1967) recorded it from the Lower, Middle and lower Upper Santonian of Germany.

Cordiceramus ex gr. *cordiformis* (J. DE C. SOWERBY, 1823)
(not illustrated)

MATERIAL: UWFG ZI/31/089 from the 21.2 m level in the WalMart section.

DESCRIPTION AND REMARKS: UWFG ZI/31/089 is an internal mould of a single incomplete left valve. The beak part is missing. The valve is subquadrate, with a long anterior margin, passing sharply into a long, broadly convex ventral margin. The anterior face is steep and moderately high. The posterior auricle is small, triangular and well separated from the disc. The ornament is composed of round-edged, subregularly spaced concentric rugae.

The specimen differs from *C. cordiformis* in the narrow sense, in that it lacks the disc sulcus, more closely resembling either subspecies *gravis* or *stimmbergensis* of SEITZ.

OCCURRENCE: Lower Santonian, 21.2 m level in the WalMart section.

Cordiceramus arnoldi (SEITZ, 1961)
(Text-figs 9.1-9.3, 9.6, 9.10)

1953. *Inoceramus cycloides* WEGNER; ØDUM, p. 14, pl. 2, fig. 6.
1961. *Inoceramus* (*Cordiceramus*) *bueltenensis arnoldi* SEITZ, p. 147, pl. 11, figs 1-4, 7; pl. 13, fig. 2.
2006. *Cordiceramus arnoldi* (SEITZ, 1961); WALASZCZYK & COBBAN, figs 35.1-35.3, 36.2, 37.5 (with synonymy).

TYPE: The holotype, by original designation, is NLBH Ko 456, the original of SEITZ (1961, pl. 11, fig. 2) from the Lower Santonian of shaft 8 of the Hugo Mine, Westphalia, Germany.

MATERIAL: OUM KT10040 and OUM KT10041 from the 21.2 m level; OUMKT10044, OUM

KT10045 and UWFG ZI/31/084, from the 22 m level of the WalMart section.

DESCRIPTION: All specimens are internal moulds of single left valves of the juvenile inflated stage. OUM KT10040 and KT10041 are small specimens, with h max = 32 and 36 mm, respectively. They are preserved to the first geniculation, with a fragment of a part of the valves between the first and second geniculation. Their postero-dorsal portions are not preserved. Up to the first geniculation the valve is ornamented with fine concentric rugae, with interspaces apparently increasing ventrally. Ventrally of the geniculation, the ornament changes to distinctly stronger rugae, with larger interspaces. Fragments OUM KT10044 and UWFG ZI/31/084 are larger (h max = 50 and 44 mm, respectively), and their ornament is composed of markedly stronger rugae, with interspaces reaching up to 7 mm (versus 3 mm in OUM KT 10040 and KT10041).

REMARKS: The problems surrounding *Cordiceramus arnoldi* have recently been discussed by WALASZCZYK & COBBAN (2006) and their interpretation is followed here.

OCCURRENCE: *Cordiceramus arnoldi* first appears very close to the base of the Santonian. In the US Western Interior the species is known from the Lower Santonian of the Pueblo section (starting at USGS Denver Mesozoic Locality D3490 and ranging up to D3495: WALASZCZYK & COBBAN 2006, text-fig. 2), and from the Lower Santonian (*Clioscaphites saxitonianus* ammonite Zone) of the Cody Shale, Carbon County, Montana (see WALASZCZYK & COBBAN 2006). It is also well known from the Lower and Middle Santonian of Europe (SEITZ 1961).

Genus *Platyceramus* HEINZ, 1932

TYPE SPECIES: *Inoceramus mantelli* (DE MERCY) BARROIS, 1879, p. 454, pl. 4, figs 1, 2.

OCCURRENCE: The earliest representatives of *Platyceramus* are known from the mid-Lower Coniacian; the genus probably ranges to the mid-Maastrichtian, and has a cosmopolitan distribution.

Platyceramus ex gr. *mantelli* (DE MERCEY) BARROIS, 1879
(Text-fig. 9.7)

Compare:

1962. *Inoceramus* (*Platyceramus*) *mantelli* MERCEY (BARROIS); SEITZ, pp. 355-369; pls 10-13.
1985. *Inoceramus mantelli mantelli* MERCEY, 1872; SZÁSZ, p. 171, pl. 33, figs 1-2; pl. 34, fig. 1.
1985. *Inoceramus mantelli beyenburgi* SEITZ; SZÁSZ, p. 171, pl. 33, fig. 3; pl. 34, fig. 2; pl. 40, fig. 1.

TYPE: The lectotype, by subsequent designation of SEITZ (1962, p. 356), is the original of BARROIS (1879, pl. 4, fig. 1; photographically illustrated by SEITZ 1962, pl. 10, fig. 1a) from the Coniacian of Lezennes, near Lille, northern France.

MATERIAL: UWFG ZI/31/085, from just below the candidate GSSP level at 18 m in the WalMart section.

DESCRIPTION AND REMARKS: UWFG ZI/31/085 is an internal mould of a single left valve. The specimen is rather poorly preserved with its beak and posterior parts missing. The general outline and ornament, composed of subregular, low concentric rugae, with raised growth lines allow to refer it to the *mantelli* group.

OCCURRENCE: This specimen was found just below the candidate GSSP level in the WalMart section. Elsewhere, *P. mantelli* appears near the base of the Middle Coniacian and ranges almost the top of the stage. The species is known from the Euramerican biogeographical region and from the North Pacific Province.

Platyceramus cycloides (WEGNER, 1905)
(Text-fig. 10.1)

1905. *Inoceramus cycloides* nov.sp., WEGNER, p. 162, pl. 7, fig. 3 and text-fig. 6.
2006. *Platyceramus cycloides* (WEGNER, 1905); WALASZCZYK & COBBAN, p. 294, text-figs 32.1, 34.1.

TYPE: The lectotype, indicated by BÖHM (1915) and formally designated by SEITZ (1961, p. 55), is the original of WEGNER (1905, p. 163, text-fig. 6 and pl. 7, fig. 3) from the Santonian of the Blumenthal

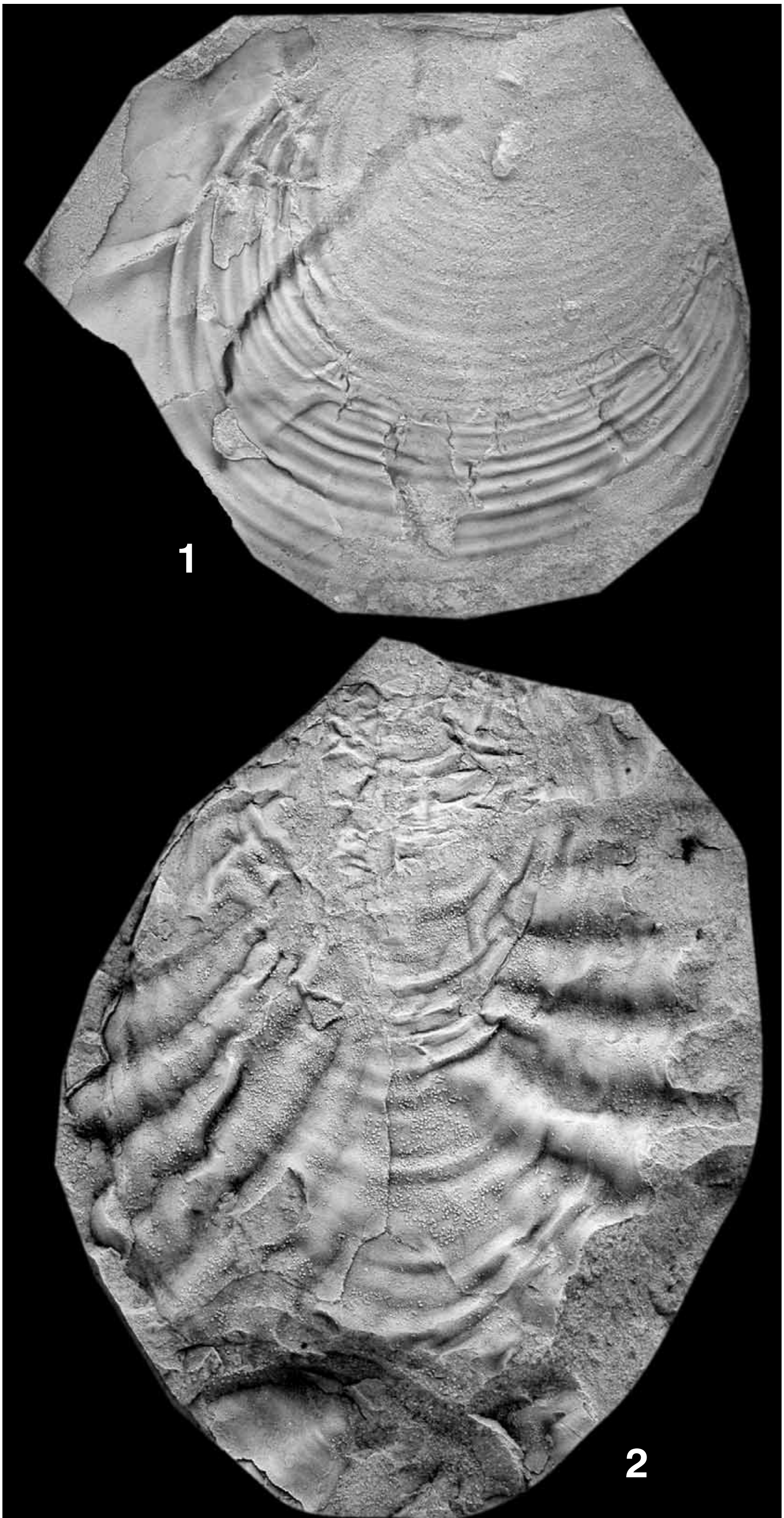

Fig. 10. Inoceramids from the Bruceville Member of the Austin Chalk of the WalMart section on Ten Mile Creek, Lancaster, Dallas County, Texas. 1 – *Platyceramus cycloides* (WEGNER, 1905), UWFG ZI/31/086, 22 m level. 2 – *Cladoceramus undulatoplicatus* (ROEMER, 1852), UWFG ZI/31/090, 18.5 m level. Both figures are natural size

mineshaft (Schacht V), in the Münsterland Basin, northern Germany.

MATERIAL: UWFG ZI/31/086, from the 22 m level in the WalMart section.

DESCRIPTION: The specimen is an internal mould of a right valve, incomplete in the ventral and postero-ventral parts. The valve is subquadrate, moderately oblique and almost flat; these features are to some extent due to secondary lateral compression. The beak is small, pointed, projecting slightly above the hinge line, which is straight and long. The anterior margin is broadly convex, relatively long (61% of the respective axial length). The ornament is composed of closely and regularly spaced concentric rugae, with l/h ratio approximating 95 %. Only the rugate part of the specimen is preserved. However, as indicated at the posterior part of the valve, the regularly rugate juvenile part of the valve was followed by the smooth to irregularly rugate adult stage.

REMARKS: The specimen is referred to *Platyceramus cycloides* on the basis of its ornament, the l/h ratio and the valve outline.

OCCURRENCE: The specimen is from the 22 m level, 3.6 m above the base of the Santonian. The species is known to appear first close to the base of the Santonian in Europe (SEITZ 1961); it apparently ranges up to the top of the stage, and possibly higher.

Genus *Cladoceramus* SEITZ, 1961

TYPE SPECIES: *Inoceramus undulatoplicatus* var. *michaeli* HEINZ, 1928 (=*Inoceramus digitatus* SCHLÜTER, 1877, *non Inoceramus digitatus* J.DE C. SOWERBY, 1829).

REMARKS: See discussion in WALASZCZYK & COBBAN (2006).

Cladoceramus undulatoplicatus (ROEMER, 1852)
(Text-figs 1, 9.4, 10.2)

1849. *Inoceramus undulato-plicatus* ROEMER, p. 402.
1852. *Inoceramus undulato-plicatus* ROEMER, p. 59, pl. 7, fig. 1.
2006. *Cladoceramus undulatoplicatus* (ROEMER); WALASZCZYK & COBBAN, p. 308, figs 39.1-3, 40.4 (with synonymy).

TYPE: The lectotype is PIB ROEMER Collection 03, the original of ROEMER (1852, pl. 7, fig. 1; see Text-fig. 1 herein) from the Lower Santonian *undulatoplicatus* Zone of the Austin Chalk, on the banks of the Guadalupe River, below New Braunfels, Texas, USA.

MATERIAL: UWFG ZI/31/083, ZI/31/090, and a numerous fragmentary specimens from the 18.4 to 19 m level of the WalMart section.

DESCRIPTION AND DISCUSSION: All of the three morphotypes within the species recognised by SEITZ (1961) are present in the Texas material: (1) the slender forms, similar to the lectotype; (2) subrectangular to subquadrate forms, referred by SEITZ to *Cl. undulatoplicatus* ssp. indet., and (3) *michaeli* morphotypes, with asymmetrical radial ornament pattern.

The species is referred herein to the genus *Cladoceramus* following recent discussion by WALASZCZYK (in KENNEDY & *al.* in press).

OCCURRENCE: In the sections studied, the species first occurs at the 18.4 m candidate basal Santonian GSSP level in the WalMart section, where it is quite common. It becomes less common in the higher parts of the WalMart succession. A single specimen, referred herein to as *Cl.* cf. *undulatoplicatus* comes from slightly above the 19 m level. Elsewhere in the sections studied here, there is a second abundance peak in the Bruceville Member: between 12.5 and 14 m in the Nazarene 2 section, and between 4.6 and 8 m in the Arbor Park section (Text-fig. 4). The species is known from the Lower Santonian throughout the Euramerican biogeographic region, and from the East African Province.

AMMONITES (W.J. KENNEDY)

Order Ammonoidea VON ZITTEL, 1884
Suborder Ammonitina HYATT, 1889
Superfamily Acanthoceratoidea DE GROSSOUVRE, 1894
Family Collignoniceratidae WRIGHT & WRIGHT, 1951

Subfamily Texanitinae COLLIGNON, 1948
Genus and Subgenus *Protexanites* MATSUMOTO, 1955

TYPE SPECIES: *Ammonites bourgeoisianus* D' ORBIGNY, 1850, p. 212, by the original designation of MATSUMOTO (1955, p. 38).

Protexanites (Protexanites) planatus (LASSWITZ, 1904)
(Text-figs 11, 12)

1904. *Schloenbachia quattornodosum* var. *planata* LASSWITZ, p. 32, pl. 7, fig. 4.
1963. *Protexanites planatus* (LASSWITZ, 1904); YOUNG, p. 76, pl. 26, figs 3, 4; pl. 35, fig. 4; pl. 36, figs 1, 2; pl. 37, figs 2-4; text-figs 20a, 25 m, 29c (with additional synonymy).
1991. *Protexanites planatus* (LASSWITZ, 1904); LARSON & *al*., fig. 10.3.
1991. *Paratexanites sellardsi* YOUNG, 1963; LARSON & *al*., fig. 10.4.

MATERIAL: Two specimens in the P. A. LARSON collection, Dallas, from the 10.3 m level in the Atco Formation in the Nazarene 1 section (Text-fig. 4).

TYPE: The holotype, by monotypy, is the original of LASSWITZ (1904, pl. 7, fig. 1), reillustrated by

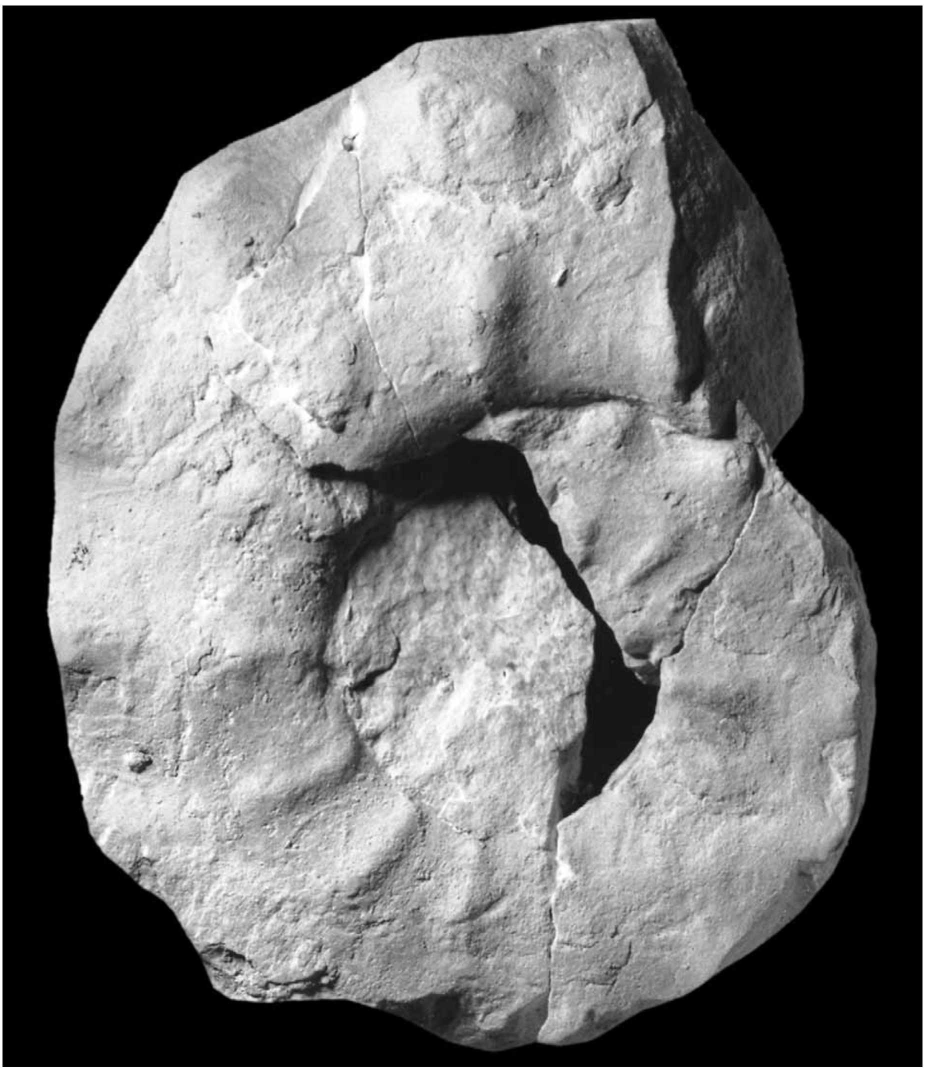

Fig. 11. *Protexanites* (*Protexanites*) *planatus* (LASSWITZ, 1904). A specimen in the P.A.LARSON collection, Dallas, from the 10.3 m level in the Upper Coniacian Atco Member of the Austin Chalk of the Nazarene 1 section on Ten Mile Creek, Desoto, Dallas County, Texas. The figure is natural size

ADKINS (1928, pl. 34, fig. 3), from the Capitol excavations in Austin, Texas. The holotype appears to have been destroyed in the Second World War, and could not be found in the collections of the Henryk Teisseyre Museum in Wrocław in 1993 (Dr. J. GORYCZYCA-SKALA in a letter to Dr. H.C. KLINGER dated 2.04.1993).

DESCRIPTION: There are two specimens from the Nazarene 1 section on Ten Mile Creek. The smaller (Text-fig. 11) is the original of LARSON & *al*. 1991, fig. 10.3, a rather battered individual with a maximum preserved diameter of 155 mm. Coiling is very evolute, with the umbilical wall crenulated to accommodate the submarginal tubercle of the preceding whorl. The broad umbilicus comprises 42% of the diameter and is shallow, with a rounded, undercut wall and broadly rounded umbilical shoulder. The original whorl section cannot be reconstructed, because of extensive *post-mortem* crushing.

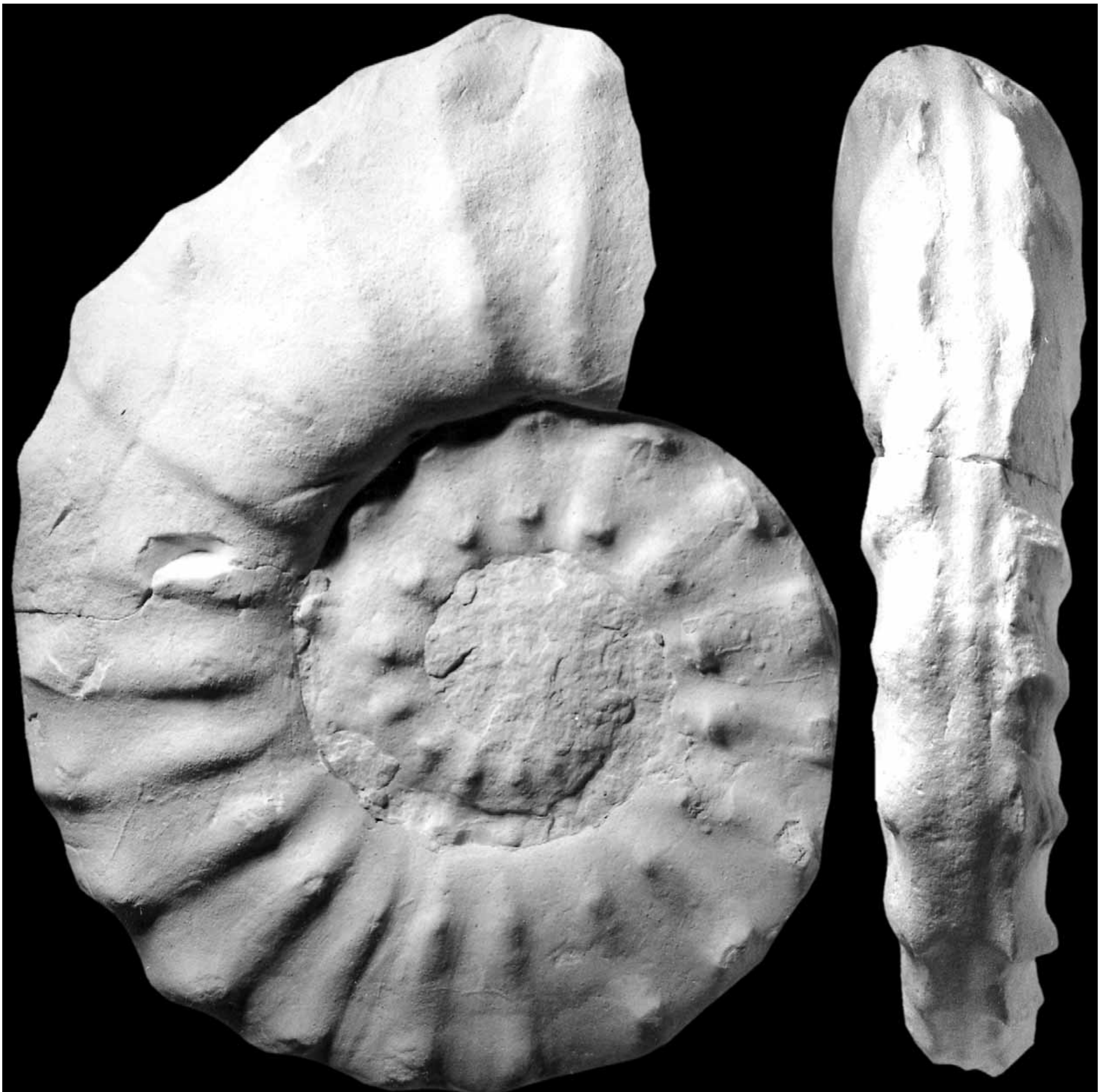

Fig. 12. *Protexanites* (*Protexanites*) *planatus* (LASSWITZ, 1904). A specimen in the P.A. LARSON collection, Dallas, from the 10.3 m level in the Upper Coniacian Atco Member of the Austin Chalk of the Nazarene 1 section on Ten Mile Creek, Desoto, Dallas County, Texas. The figures are natural size

There are fifteen coarse, very distant, straight prorsiradiate ribs on the outer whorl. They arise at the umbilical seam and strengthen across the umbilical wall and shoulder, where they are feebly concave. The ribs coarsen markedly across the flanks. There is doubled umbilical tuberculation with a weak umbilical and stronger inner lateral node. The marginal tubercle is massive and conical-clavate, the external tubercle weaker and markedly clavate. A pronounced groove separates the external clavi from the strong, undulose siphonal keel, such that the external clavi appear to be linked by a weak ridge. The second specimen (Text-fig. 12) is much better preserved, and is the original of LARSON & *al*. (1991, fig. 10.4), where it was referred to as *Paratexanites sellardsi* YOUNG, 1963. The specimen is a crushed composite mould with a maximum preserved diameter of 170 mm. The coiling is very evolute, with the umbilical wall notched to accommodate the marginal tubercle of the previous whorl. The wide umbilicus comprises 42% of the diameter, the umbilical wall is convex, the umbilical shoulder inclined outward. The whorl section is very compressed, as a result of *post-mortem* crushing. At a diameter of 96 mm there are 15-16 coarse, distant primary ribs per whorl. They arise at the umbilical seam and strengthen across the umbilical wall and shoulder, where they are feebly concave. They are straight and prorsirardiate and strengthen progressively across the flanks. There is a coarse umbilicolateral bulla, displaced out from the umbilical shoulder, and a stronger conical-clavate marginal tubercle. There are 20-21 coarse, distant primary ribs on the outer whorl. The umbilicolateral tubercles weaken progressively, and show a slight outward migration. An incipient umbilical bulla appears. The marginal tubercles weaken progressively; one is incipiently doubled. There are very elongate external clavi, separated by a groove from the coarse, undulose siphonal keel. The penultimate rib bears what appears to be a feeble lateral tubercle.

DISCUSSION: The smaller specimen differs in no significant respects from the holotype, having the same rib density and the conspicuous doubling of umbilical and umbilicolateral tubercles. The larger specimen has inner whorls as coarsely ribbed as in the holotype, but without showing the conspicuous doubling of the umbilical/umbilicolateral tubercles. The outer whorls, with a higher rib density, match those of the well-preserved specimen figured by YOUNG (1963, pl. 37, fig. 2).

LARSON & *al*. (1991) referred this specimen to *Paratexanites sellardsi*. YOUNG states this species to have a doubled marginal tubercle. This is not developed in the present specimen except for a single rib, and the specimen has more characteristics of *Protexanites* than of *Paratexanites.*

OCCURRENCE: Upper Coniacian, *Prionocycloceras gabrielense* Zone of YOUNG (1963) in Williamson County, Texas. The present specimens are from the 10.3 m level in the Atco Member of the Nazarene 1 section.

Genus and subgenus *Texanites* SPATH, 1932

TYPE SPECIES: *Ammonites texanus* ROEMER (1852, p. 31, pl. 3, fig. 1), by the original designation of (SPATH 1932, p. 379).

Texanites (*Texanites*) *gallicus* COLLIGNON, 1948
(Text-figs 13, 14)

1894. *Mortoniceras texanum* F. ROEMER sp.; DE GROSSOUVRE, p. 80, pl. 16, figs 2, 4; pl. 17, fig. 1.
1987. *Texanites* (*Texanites*) *gallicus* COLLIGNON, 1948; KENNEDY, p. 770, pl. 80, figs 4-7; pl. 81, figs 1-6 (with synonymy).
1994. *Texanites* (*Texanites*) *gallicus* COLLIGNON; WIEDMANN in GISCHLER et al., p. 238, pl. 44, figs 1, 3, pl. 35, figs 3-6; text-fig. 16e.
1995. *Texanites* (*Texanites*) *gallicus* COLLIGNON, 1948; KENNEDY, p. 420, pl. 22, fig. 11; text -fig. 25.

TYPE: Lectotype, by the subsequent designation of COLLIGNON (1948, p. 42 (99)) is the original of DE GROSSOUVRE (1894, pl. 17, fig. 1), from the 'Marnes Bleues à petits fossiles situées au bas du Chemin de Sougraine aux Croûtets (Aude) sous la couche à *Lima marticensis*'.

MATERIAL: Three specimens, OUM KT9368, from the 16 m level, OUM KT9366, from the 21.2 m level, and OUM KT9367, from the 22.1 m level in the Bruceville Member in the WalMart section.

DESCRIPTION: Of the three specimens, the best preserved is OUM KT9366 (Text-fig. 13), a very crushed composite mould with a maximum preserved diameter of 140 mm. Coiling is very evolute, the umbilicus broad and shallow, comprising 40% of the diameter, the umbilical wall convex, the umbilical shoulder broadly rounded. There are 23 strong, prorsiradiate ribs on the outer whorl, all primaries. There are well-developed bullae perched on the umbilical shoulder, rounded to feebly clavate tubercles at the junction of the middle and inner third of the flank, weaker, clavate submarginal tubercles, stronger, clavate marginal tubercles and external clavi, separated by a groove from the siphonal keel. OUM KT 9367 (Text-fig. 14) is a crushed juvenile with an estimated original diameter of 76-80 mm. OUM KT 9368 (not figured) comprises a nucleus 60 mm in diameter and a fragment of the succeeding whorl with a maximum preserved whorl height of 48 mm.

DISCUSSION: These rather poor specimens are referred to the widespread *Texanites* (*Texanites*) *gallicus*, previously recorded from Texas by YOUNG (1963). They differ most obviously from the larger specimen from Ten Mile Creek described below as *T.* (*T.*) *vanhoepeni* in their lower expansion rate.

OCCURRENCE: The present specimens are from the Bruceville Member in the WalMart section; OUM KT9368 is from the 16 m level, and is Upper Coniacian; OUM KT9366 is from the 21.2 m level, and OUM KT9367 is from the 22.1 m level and both are Lower Santonian. The species is also

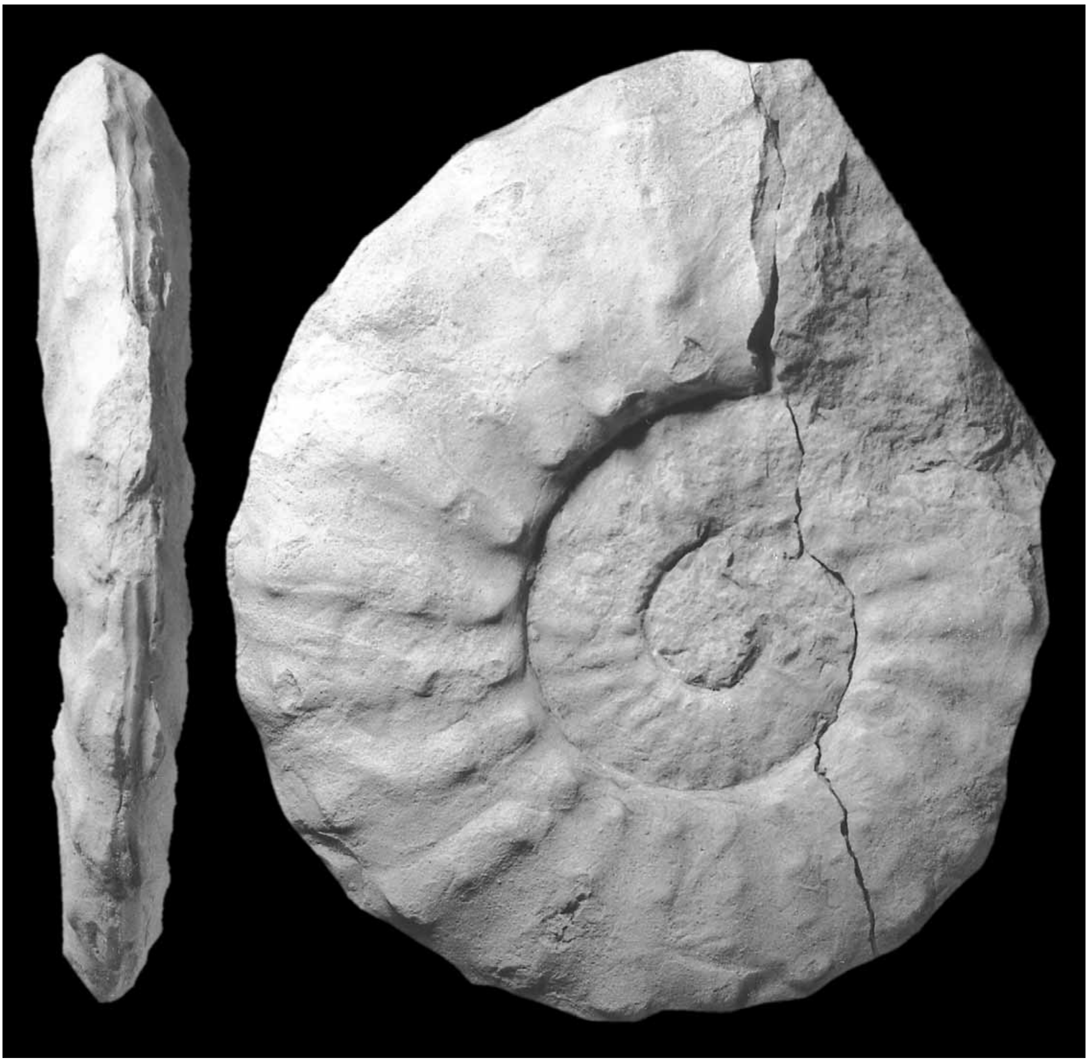

Fig. 13. *Texanites* (*Texanites*) *gallicus* COLLIGNON, 1948. OUM KT 9366, from the 21.2 m level in the Lower Santonian part of the Bruceville Member of the WalMart section on Ten Mile Creek, Lancaster, Dallas County, Texas. The figures are natural size

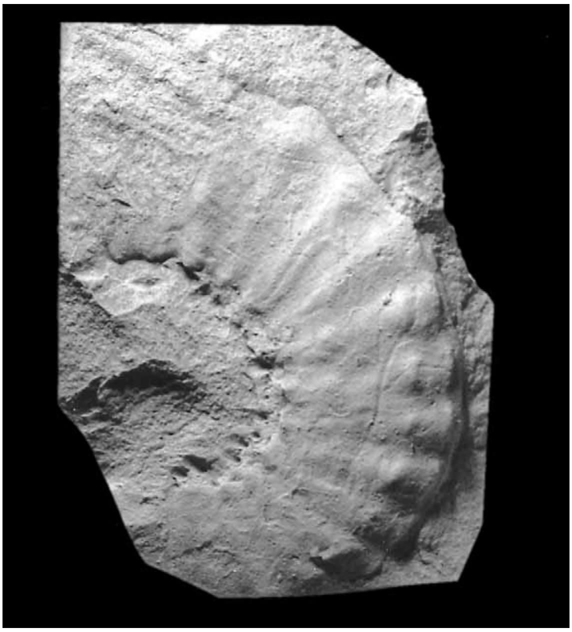

Fig. 14. *Texanites* (*Texanites*) *gallicus* COLLIGNON, 1948. OUM KT 9367, from the 22.1 m level in the Lower Santonian part of the Bruceville Member of the WalMart section on Ten Mile Creek, Lancaster, Dallas County, Texas. The figures are natural size

known from southern France, Austria, Spain, Hokkaido, Japan, Madagascar, Zululand (South Africa) and, doubtfully, Angola. It has traditionally been regarded as Lower Santonian in these areas.

Texanites (*Texanites*) *vanhoepeni* KLINGER & KENNEDY, 1980
(Text-fig. 15)

1980. *Texanites* (*Texanites*) *vanhoepeni* KLINGER & KENNEDY, p. 144, figs 109-117.
1990. *Texanites* sp. cf. *texanus* (ROEMER); LARSON & *al*., fig. 10.6.

MATERIAL: A specimen in the P. A. LARSON Collection, Dallas, from the 10.3 m level in the Atco Formation in the Nazarene 1 section (Text-fig. 4).

DESCRIPTION: The specimen, previously illustrated by LARSON & *al*. (1990, fig. 10.6) is a very crushed section of a 120° sector of body chamber with a maximum preserved whorl height of 75 mm. Parts of nine ribs are preserved on the fragment. They are coarse, low, broad and straight, with sharp umbilical bullae, strong, rounded lateral, strong clavate submarginal amd marginal tubercles and weaker external clavi. There is a strong siphonal keel. The umbilical, lateral, submarginal and marginal rows are approximately equidistant.

DISCUSSION: The fragment appears to have a relatively higher whorl and a smaller umbilicus than *Texanites* (*Texanites*) *gallicus*. It closely resembles the holotype (KLINGER & KENNEDY, 1980, figs 109-111).

OCCURRENCE: The types are from the Upper Coniacian to Lower Santonian of Zululand. The present specimen is from the Upper Coniacian 10.3 m level in the Atco Member of the Nazarene 1 section. An external mould comparable to this specimen was observed at the 1.7 m level in the Bruceville Member in the WalMart section, and is also Upper Coniacian.

Genus *Menabites* COLLIGNON, 1948

TYPE SPECIES: *Menabites menabensis* COLLIGNON, 1948, p. 7 (64), pl. 17, figs 3, 4; pl. 18, fig. 1, by original designation by COLLIGNON, 1948, p. 64 (19).

Subgenus *Australiella* COLLIGNON, 1948

TYPE SPECIES: *Mortoniceras australe* BESAIRIE, 1930, pl. 64, fig. 2, by original designation by COLLIGNON, 1948, p. 64 (19).

Menabites (*Australiella*) *austinensis* YOUNG, 1963
(Text-fig. 16)

1963. *Australiella austinensis* YOUNG, p. 115, pl. 64, figs 3, 4; pl. 65, fig. 6; pl. 67, figs 4-6; text-fig. 28e (with synonymy).

TYPE: The holotype is TMM WSA-65, the original of YOUNG (1963, pl. 65, fig. 6; pl. 67, fig. 6), from the Austin Chalk one and a half miles (2.4 km) southeast of Austin, Texas. According to YOUNG (1963, p. 116) it is probably from the Lower Santonian, but could be Lower Campanian.

MATERIAL: OUM KT10046, from the 22.5 m level in the Bruceville Member in the WalMart section.

DESCRIPTION: The specimen is a very crushed composite mould with an estimated maximum preserved diameter of 100 mm. The umbilicus comprises an estimated 35% of the diameter. There are an estimated 7-9 well-developed umbilical bullae on the outer half whorl. These give rise to low, broad, straight, prorsiradiate ribs, while additional ribs intercalate on the flank. All ribs bear strong, conical to feebly clavate inner ventrolateral tubercles. There are numerous small, very elongate outer ventrolateral clavi that are two to three times as numerous as the inner ventrolateral tubercles. There is a coarse, feebly undulose siphonal keel.

Fig. 15. *Texanites* (*Texanites*) *vanhoepeni* KLINGER & KENNEDY, 1980. A specimen in the P. A. LARSON Collection, Dallas, from the 10.3 m level in the Upper Coniacian Atco Formation in the Nazarene 1 section on Ten Mile Creek, Desoto, Dallas County, Texas. the figures are slightly reduced

Fig. 16. *Menabites* (*Australiella*) *austinensis* YOUNG, 1963. OUM KT 10046, from the 22.5 m level in the Lower Santonian part of the Bruceville Member of the of the Austin Chalk of the WalMart section on Ten Mile Creek, Lancaster, Dallas County, Texas. The figure is natural size

DISCUSSION: Although crushed, this specimen can be referred to *M*. (*A*.) *austinensis*, a species characterised by the presence of three rows of tubercles throughout the known ontogeny. This is a problematic form; all other well-dated *Menabites* (*Australiella*) are Campanian.

OCCURRENCE: Lower Santonian, 22.5 m level in the Bruceville Member in the WalMart section; Santonian or Lower Campanian of the Austin area, Texas.

CALCAREOUS NANNOFOSSILS (J.A. LEES)

Introduction

Although calcareous nannofossil data were presented at the Cretaceous Stage Boundaries Symposium held in Copenhagen in 1983 (PERCH-NIELSEN 1983), no particular nannofossil events were discussed or published in relation to the boundary in the proceedings of the meeting (*Bulletin of the Geological Society of Denmark* 33 (1-2)). It was further accepted, at the 1995 Brussels Symposium, that there were no published nannofossil events that approximated the recommended inoceramid boundary event, the FO of *Cladoceramus undulatoplicatus* (LAMOLDA & HANCOCK 1996), but it *was* suggested that this event lay in SISSINGH'S (1977) Nannofossil Zone CC15 in the Ten Mile Creek section (J.A. BURNETT, written communication, based on preliminary data, in LAMOLDA & HANCOCK 1996), that is, above the first occurrence of *Lithastrinus grillii* (i.e., equivalent to Nannofossil Subzone UC11a of BURNETT 1998). However, analysis of additional samples from Ten Mile Creek leads to a revision of this position. The boundary has now been determined to lie within the younger Nannofossil Subzone UC11c (which is almost equivalent to Nannofossil Zone CC16 of SISSINGH 1977).

These data are compared to nannofossil results from the other two candidate sections, Olazagutía (Navarra, northern Spain: LAMOLDA & *al.*, 1999; MELINTE & LAMOLDA 2002; HOWE & *al*. 2007) and Seaford Head (Sussex, southern England: HAMPTON & *al.* 2007; HOWE & *al*. 2007) to see how well the identified nannofossil events correlate over distance.

Methods and material

The samples comprise soft, bioturbated, predominantly olive-grey marls. Smear-slides were made following the technique described in BOWN & YOUNG (1998). Semi-quantitative estimates, based on three traverses of each slide, were made using a Zeiss Axio Imager A1 light microscope at a magnification of 1250x. The calcareous nannofossil biostratigraphy of twenty-six samples, taken from variable intervals in the composite section from the four outcrops studied (Nazarene 1, WalMart, Nazarene 2, Arbor Park: Text-fig. 4), was determined, using the 'UC' biozonation of BURNETT (1998). The defunct 'CC' biozonation of SISSINGH (1977), as modified by PERCH-NIELSEN (1985), was also applied to the data. All sample material and slides are stored in the Micropalaeontology Unit, Department of Earth Sciences, University College London.

Results

Preservation, abundance and species richness

Calcareous nannofossils are a moderately abundant component of the overall sediment. The marls yielded nannofloras showing typical Late Cretaceous preservation, that is, predominantly moderate levels of overgrowth and etching. Identification of taxa was not impaired by this. Species richness (all taxa) ranges from 28 to 77 taxa per sample.

Nannofossil biostratigraphy

Illustrations of all calcareous nannofossil taxa referred to here, along with full author references, can be found in BURNETT (1998) and BOWN (1998), respectively. The nannofossil data, presented semi-quantitatively, are shown in Text-fig. 17, which includes a biostratigraphic summary. On this chart, 'R' = rare (1 specimen per >20 fields of view), 'F' = few (1specimen per <20 fields of view), 'C' = common (1-10 specimens per field of view) and 'A' = abundant (>10 specimens per field of view)

Application of the biozonation was not straightforward in these sections, particularly in the middle part, the WalMart outcrop that includes the candidate GSSP. A number of LOs, one of them a biostratigraphical marker-event used in the UC biozonation, here lie above the levels indicated by BURNETT (1998), in a different stratigraphical order. There is no clear indication from the data that these nannofossils are reworked, although they *are* rare and spasmodic in their stratigraphical distributions. Local palaeobiogeographical influences cannot be ruled out. These events include the LOs of: *Quadrum gartneri*, the marker for UC11b, which lies at the 18.3 m level in the WalMart outcrop, just below the candidate GSSP; *Marthasterites furcatus* at 18.35 m and *Flabellites oblongus* at 22.0 m, both of which BURNETT (1998) showed to lie within UC11b. All of these events lie in UC11c here.

The oldest sample examined comes from the 0.4 m level in the Nazarene 1 section (Text-fig. 4), and lies within UC10, based on the presence of the marker *Micula staurophora* (= *M. decussata* of some authors), together with *Lucianorhabdus arcuatus* and *Rhagodiscus achlyostaurion*, the respective FO and LO of which BURNETT (1998) showed to lie within this biozone. The next sample above this, from the 3.3 m level, contains rare *Lithastrinus grillii*, the marker for UC11a. The marker for UC11c, *Lucianorhabdus cayeuxii*, lies above this, at the 11.0 m level in the WalMart outcrop (Text-fig. 4). This biozone is somewhat confirmed by the FOs of some taxa that BURNETT (1998) indicated to lie within this zone, including *Micula concava* (at 18.35 m), *Amphizygus minimus* (at 21.2 m) and *Microrhabdulus undosus* (at 11.5 m).

At 23.0 m, at the top of the WalMart outcrop, *Lithastrinus septenarius* (= *L. moratus* of some authors) is still present, but is then absent from the lowest sample in the Nazarene 2 section (10.6 m: Text-fig. 4). Thus, the base of UC12 lies at 10.6 m in Nazarene 2. The sample from the 8 m level in the Arbor Park section that makes up the highest part of the composite section does not contain *Arkhangelskiella cymbiformis*, nor *Broinsonia parca parca*, and so UC12 extends to the top of the sequence studied.

The FO of the boundary marker, the inoceramid *Cladoceramus unduloplicatus*, lies in the WalMart outcrop at the 18.4 m level, that is, within UC11c. This is consistent with the placement of the Coniacian/Santonian in this biozone by BURNETT (1998). Consequently, the order of utilisable nannofossil occurrences around the boundary appears to be, with the most reliable emboldened (in stratigraphical order, youngest at the top):

LO *L. septenarius* (base UC12)
FO *A. minimus* (within UC11c)
FO *Cl. undulatoplicatus* (inoceramid; boundary marker)
FO *M. concava* (within UC11c)
FO *L. cayeuxii* (base UC11c)
FO *L. grillii* (base UC11a)
LO *R. achlyostaurion* (within UC10)
FO *L. arcuatus* (within UC10)
FO *M. staurophora* (base UC10)

Correlation of calcareous nannofossil events across the boundary interval between the candidate sections

The other Coniacian-Santonian boundary stratotype candidates are the Cantera de Margas Quarry in Olazagutía (Navarra, northern Spain) and Seaford Head (Sussex, southern England). The nannofloras of the Olazagutía section have

STAGE	UPPER CONIACIAN *pars*																		LOWER SANTONIAN							
SECTION (COMPOSITE)	Nazarene 1					WalMart																		Nazarene 2		Arbor Park Road
LITHOSTRATIGRAPHY	Atco Member Austin Chalk Formation																									
ORIGINAL SAMPLE SUITE NUMBERS	TW1	TW4	TW7	TW10	TW13		TW15	TW18	TW21			TW24	TW27			TW30					TW33		TW36	TW39	TW42	TW45
HEIGHT IN SECTION	0.4m	3.3m	6.1m	8.3m	12.5m	1.0m	1.3m	5.0m	8.0m	11.0m	11.5m	11.7m	14.6m	16.7m	17.0m	17.1m	18.3m	18.35m	18.5m	21.2m	21.4m	22.0m	23.0m	10.6m	13.0m	8.0m
PRESERVATION	M	M	P-M	M	P-M	VP-M	M	M	P-M	VP-M	VP-M	P-M	M	VP-M	VP-M	M	VP-M	VP-M	VP-M	VP-M	M	VP-M	M	M	M	M
ABUNDANCE	M	M	M	M	M	M	M	M	M	M	M	L-M	M	M	M	M	M	L-M	M	M	M	M	M	M	M	M
SPECIES RICHNESS	51	45	49	41	42	66	35	49	50	62	77	37	36	56	50	46	40	45	63	42	28	60	31	39	45	34
Acuturris scotus										R					R		R	R	R							
Ahmuellerella octoradiata	F		F				R	R	R	R	F	R	R	F	F	F		R	F	R		F	R		R	F
Amphizygus brooksi dark-rimmed form						R		F									R									
Amphizygus brooksi bright-rimmed form						R																				
Amphizygus minimus																				**R**						
Biscutum cf. *B. ellipticum*						R				R	R			F	F				R			R				
Biscutum ellipticum	R	R	F	F	F	F		F		F	F	R	R	F	F	F	R	R		R	F	F	F	F	F	
Braarudosphaera bigelowii							R		F	R	R	R		R	R		F	F	F	F		F			R	C
Broinsonia enormis	R	F	F	F	F	R	R	F	F		R	R	F	R	R	F	R	R	R		R		F	F	F	F
Broinsonia furtiva										F	F			F	F		R		F	F						
Broinsonia matalosa						R					R			F			R	R				R				
Broinsonia parca expansa	F	F	R		R	F	F	F	F	F	F	R	R	F	F	R	R		R			R		R	R	R
Broinsonia signata	F		R	F	R			F	F			R	R			R					R		R	F	F	F
Bukrylithus ambiguus		R								R	R			F				R	R			R				
Bukrylithus ambiguus large form						R				R	F											R				
Calciosolenia fossilis						R	R																			
Calculites cf. *C. additus*									R		R			R												
Calculites obscurus		R		R	R			R	F	R		F				F	R			R		R		F	R	F
Calculites ovalis	R		R	R		R	R	F	F	F	F	R	F	F	F	F	R	F	F	R	F	F	R	F	R	
Calculites percenis						R								F	R				R	R						
Chiastozygus bifarius					R					R	R			R	F		R	F	R			F				
Chiastozygus cf. *C. bifarius-anceps*						R				R	R			F	R		F	R	R	F		R				
Chiastozygus cf. *C. bifarius* with yellow bars										R	R			R	F											
Chiastozygus spissus						R																				
Chiastozygus synquadriperforatus	F	R							F			R	R												R	
Chiastozygus trabalis										R	R			R						R		R				
Corollithion exiguum								R																		
Corollithion madagaskarensis	R					R	F																			R
Corollithion signum	F	F	F	R		F		F			R	R		R		F		R	R	R			R	F	F	
Cretarhabdus cf. *C. conicus*						R																				
Cribrosphaerella ehrenbergii	F	F	F	F	F	R		F	R	R	F	F	F	F	F	F			F	R	R	F			F	R
Cyclagelosphaera margereli																					R					
Cyclagelosphaera rotaclypeata														R												
Cylindralithus coronatus?						R				R	R			R			R	R	R			F				
Cylindralithus nudus		R																								
Cylindralithus serratus						R													R							
Discorhabdus ignotus	F		F	C	C	C		R		F	F		F	R	F	R		R	R	F	F	F	R	F		R
Discorhabdus ignotus large form						F				R	F			R					R			R				
Eiffellithus eximius	C	F	F	F	F	F	F	C	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
Eiffellithus gorkae	R	R	F	F	R	F		F	R	F	F	R	F	R	R	F		R	R	F		F	F	F	F	F
Eiffellithus turriseiffeli	F	R	F	F	F	F	R	F	F	R	R	R	F		F	F		R	F	R				R		R
Eiffellithus cf. *E. windi*						R																				
Eprolithus floralis																										R
Flabellites oblongus	**F**	**F**			**R**				**R**				**R**							**R**		**R**				

Fig. 17.1. Calcareous nannofossil distributions in the Atco and Bruceville members of the Austin Chalk in the Nazarene 1 and 2 sections and the WalMart section on Ten Mile Creek, and the Bruceville Member in the Arbor Park section in Dallas County, Texas

SECTION (COMPOSITE)	Arbor Park Road	Nazarene 2		WalMart																		Nazarene 1				
HEIGHT IN SECTION	8.0m	13.0m	10.6m	23.0m	22.0m	21.4m	21.2m	18.5m	18.35m	18.3m	17.1m	17.0m	16.7m	14.6m	11.7m	11.5m	11.0m	8.0m	5.0m	1.3m	1.0m	12.5m	8.3m	6.1m	3.3m	0.4m
Gartnerago cf. *G. praeobliquum*					R											R										
Gartnerago segmentatum	F	F	F	F	F	F	F	F	C	F	C	F	F	F	F	F	F	F	F	F	F	F	C	F	F	F
Hagius circumradiatus																	R						R			R
Helicolithus anceps	F	F	F	F		R					F			F	F			R	F	F		F	F	F	F	C
Helicolithus compactus								R								R					R					
Helicolithus trabeculatus							F										R									
Helicolithus trabeculatus large form	F	C	C	C	C	C	F	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	F	F	C
Kamptnerius magnificus										R							R		R							
Lapideacassis sp.																					R					
Lithastrinus grillii	F	R			F	R	F	R	F	F	R		F												R	
Lithastrinus septenarius				R	R			R	R			R		R		R	R	F	F		R		F	R	F	F
Lithraphidites carniolensis	R	F	F	F	F	F		R	R	R	F	R	F	R	R	F	F	F	F	R	R	F	F	F	F	F
Loxolithus armilla					R			R								R										
Loxolithus thiersteinii																R										
Lucianorhabdus arcuatus		R	R						R		R							R								F
Lucianorhabdus cayeuxii					R			R				R	F			F	F									
Lucianorhabdus maleformis long form	F	C	F	F	F	F	F	F	F	F	F	F	F	F	R	F	F	F	F	F		F	F	F	F	F
Lucianorhabdus maleformis short form		F	F	F	F		R	R		R	F	R	F			F	R	F	F		R		F		R	R
Lucianorhabdus quadrifidus		F	C	F	R	F	R	R	R	R	F				F	F		F	C	R		F	F	F		R
Manivitella pemmatoidea	R	R			F	R		R		R	R	F	F			F	F	F	F		R	R	F	R	F	F
Marthasterites furcatus									R	R																
Microrhabdulus belgicus											R		R			R		F	F			R			R	F
Microrhabdulus decoratus			R			R					F	R							R			R	R	R	R	R
Microrhabdulus helicoideus			F	R										R	R	R				R	R	R		R	R	
Microrhabdulus undosus										R						R										
Micula adumbrata												R														
Micula concava									R																	
Micula cubiformis	F		F	F	F	R	F	F	R	F	R	F	F			R	R	F	F	F		F	F	R	R	
Micula staurophora	C	C	F	C	F	F	A	F	C	F	C	F	F	C	C	F	F	F	F	C	F	C	C	F	C	F
Micula swastica			R	R			R	R							R		R					R				
Nannoconus sp. x-section			R		R		R	R					F	F			R									
Octolithus multiplus					R		R		R			R				R	R				R					
Placozygus cf. *P. fibuliformis*					R			R																		R
Placozygus fibuliformis	F	F	C	F		F		F	R		F			R	F	R		R	C		R	C	F	F	F	F
Prediscosphaera bukryi											F							F	F	R		R	F	R	R	
Prediscosphaera cretacea	F	C	F	F	F		F	R	F	R	F	F	F	C	F	F	F	F	C	F	F	F	F	F	F	F
Prediscosphaera cf. *P. grandis*													R			R			R							
Prediscosphaera ponticula	R	F	F	R		R	F	F	F	R	F	F	F	R	F	F	F	F	F	F	F	F	F	F	F	F
Prediscosphaera spinosa medium form								R	R							F										
Prediscosphaera spinosa small form	R	R						R				R				F					R					
Prediscosphaera stoveri	R				cfR																					
Quadrum gartneri										R										R						F
Reinhardtites anthophorus	F	R	R	F	F	R		R	R			R	R		R	F	F	F	F	F	F	R	R	R	F	
Repagulum parvidentatum					R											R					R					
Retecapsa angustiforata		F	R	F	R	F					F	R		R	R	F	F	R	F		R	R	R	F	F	F
Retecapsa crenulata	F	F	R		R		R	R	R	R		R	R	F	R	F		F	F	R	F	F	R	F		F
Retecapsa surirella					R			R								R					F			R		R
Rhagodiscus achlyostaurion																										R
Rhagodiscus angustus		R						R								R	R	R		R						F
Rhagodiscus plebeius											R							R	R			R		R	F	
Rhagodiscus reniformis																		R			R					
Rhagodiscus splendens		F			R						R					R				R	R		R	R		
Rotelapillus biarcus		R									R			R	R	R	R	R	R	R		R			F	F
Rotelapillus crenulatus		F						R								R	R		F					R		
Seribiscutum gaultensis					R		R	R	F	R		R	R			F					R					
Sollasites horticus																					R					

Fig. 17. 2. Calcareous nannofossil distributions in the Atco and Bruceville members of the Austin Chalk in the Nazarene 1 and 2 sections and the WalMart section on Ten Mile Creek, and the Bruceville Member in the Arbor Park section in Dallas County, Texas

HEIGHT IN SECTION	NANNOFOSSIL EVENT FO = first (evolutionary) occurrence LO = last occurrence (extinction)	*Staurolithites crux*	*Staurolithites* cf. *S. ellipticus* with bright inner cycle	*Staurolithites flavus ?*	*Staurolithites laffittei*	*Staurolithites minutus*	*Tetrapodorhabdus decorus*	*Tranolithus minimus*	*Tranolithus orionatus*	*Watznaueria* cf. *Cyclagelosphaera argoensis*	*Watznaueria barnesiae*	*Watznaueria biporta*	*Watznaueria fossacincta*	*Watznaueria manivitiae* s.l.	*Watznaueria manivitiae* s.s.	*Watznaueria quadriradiata*	*Zeugrhabdotus bicrescenticus*	*Zeugrhabdotus biperforatus*	*Zeugrhabdotus diplogrammus*	*Zeugrhabdotus embergeri*	*Zeugrhabdotus erectus*	*Zeugrhabdotus praesigmoides*	*Zeugrhabdotus scutula*	*Zeugrhabdotus* sp. with thick inner rim	*Zeugrhabdotus* sp. with dark double bar	*Zeugrhabdotus* cf. *Z. trivectis*	Indet. small coccolith	NANNOFOSSIL ZONE after Burnett (1998) - UC	STAGE	NANNOFOSSIL ZONE after Sissingh (1977, 1978) & Perch-Nielsen (1985) - CC	SECTION (COMPOSITE)	LITHOSTRATIGRAPHY
8.0m	*Arkhangelskiella cymbiformis, Broinsonia parca parca* absent							R	C		A			F			F											UC12 *pars*	LOWER SANTONIAN *pars*	CC16-17 *pars*	Arbor Park Road	Atco Member Austin Chalk Formation
13.0m					F				C		A		R	F		F	F	R	R		F										Nazarene 2	
10.6m								R	C		C	R		F			R	F			R											
23.0m	**LO *L. septenarius***								C		C			F			R	R										UC11c		CC16	WalMart	
22.0m	LO *F. oblongus*		R		R			F	C	R	C		R	C			F	R	R		R				R	R						
21.4m									F		C			F				R			F											
21.2m	FO *A. minimus*				F	F		F	F		C						F	R			R					R						
18.5m	**FO *Cladoceramus undulatoplicatus* (INOCERAMID)**		R		R			R	F		C		R	F	R	R	F	R	R							R	R					
18.35m	FO *M. concava*; local LO *M. furcatus*		R					R	F		C			F	R	R	F									F			UPPER CONIACIAN *pars*			
18.3m	LO *Q. gartneri*				R				F		C		R	R			R		R							F						
17.1m					R		R	R	C		C			F		F	F	R	F		F											
17.0m					R			F	F		C		R	F	R	R	F		R							F	R					
16.7m		R	R					R	F		C			C	F		F	R			R	R		R		F	R					
14.6m					R				C		C	F		F			F		R		F											
11.7m								R	C		C			F			F	F			R											
11.5m	FO *M. undosus*		F		R		R	F	F	R	C			C	R		F	R		R	R		R	R	R	R	F					
11.0m	**FO *L. cayeuxii***		R		R		R		C	R	C	R		C	F	R	F	R	R		F				R	F	R					
8.0m					F		R	R	F		C			F			F	F	F		R		R		R			UC11a-b		CC15		
5.0m					F			F	C		A			R			F	R		F	F											
1.3m					F			R	C		C	R		F			F				R											
1.0m			R		F	R	R	F	C	F	C			F			F	R	R	R	R			F	R	F						
12.5m								F	C		C			F			F	F	R		R										Nazarene 1	
8.3m								F	C		C		R	C		R	F	R	F													
6.1m				R	R		R	F	C		C		R	C		F	F	F	F	R	F											
3.3m	FO *L. grillii*			F	R		R	F	C		A			F			F	F			R											
0.4m	*M. staurophora, L. arcuatus* present; LO *R. achlyostaurion*				R		F	F	C		C		R	F			F	F	F		F							UC10 *pars*		CC14 *pars*		

Fig. 17. 3. Calcareous nannofossil distributions in the Atco and Bruceville members of the Austin Chalk in the Nazarene 1 and 2 sections and the WalMart section on Ten Mile Creek, and the Bruceville Member in the Arbor Park section in Dallas County, Texas

been studied by LAMOLDA & *al*. (1999), MELINTE & LAMOLDA (2002), and HOWE & *al.* (2007). HAMPTON & *al.* (2007) and HOWE & *al.* (2007) studied the Seaford Head section. Furthermore, HOWE & *al*. (2007) have also studied the Ten Mile Creek sections. All of these studies (as well as a further study of two Romanian sections by MELINTE & LAMOLDA (2007)) have found the boundary to lie in UC11c, so the FO of *Lucianorhabdus cayeuxii* and LO of *Lithastrinus septenarius* can be considered as reliable nannofossil events bracketing the boundary in diverse geographical locations. A number of other nannofossil events have been suggested, however, as closer proxies for the boundary, and these are discussed below.

The FO of *Micula concava* was identified at 5 cm below the boundary in the Ten Mile Creek section (see Text-fig. 17). This is in accordance with its placement at this level by BURNETT (1998). However, the event was not reported (and the full biostratigraphic data are not presented) by HAMPTON & *al.* (2007), and the nannofossil is not recorded at all by HOWE & *al.* (2007), in the Seaford Head section. In contrast, MELINTE & LAMOLDA (2002, 2007) *did* record it from the base of their studied intervals (in UC10) in, respectively, the Olazagutía section and two sections in Romania. HOWE & *al.* (2007), however, did *not* record it in the Olazagutía section. It is clear that this species is either being overlooked or misidentified, and further information is required on this event, so that we can clarify its FO. It is thus not currently a useful proxy for the boundary.

BURNETT (1998, fig. 6.4) was the first to identify the FO of *Amphizygus minimus* as a potential proxy for the Coniacian-Santonian boundary in mid to low latitudes (she showed that its FO was possibly transgressive, the species arriving later – in UC12 – in higher latitudes). The present study shows this event to lie just above the boundary, at the 21.2 m level in the WalMart section in Ten Mile Creek, with a single occurrence in one sample. HOWE & *al.* (2007) found only single specimens, in two different samples, but from *below* the boundary in Ten Mile Creek. Clearly, its utility as a marker in Ten Mile Creek is severely undermined by its rarity and sporadic stratigraphical occurrence. *Amphizygus minimus* was not identified in the Olazagutía section by MELINTE & LAMOLDA (2002), although HOWE & *al*. (2007) *did* record it from there. Because data for this section are presented by HOWE & *al*. (2007) in an unusual way (specimens per mm^2), it is not possible to ascertain how relatively abundant the species is, in comparison to other sections. However, it *can* be seen that *A. minimus* has a consistent stratigraphical occurrence in Olazagutía (throughout their studied interval). HAMPTON & *al*. (2007) recorded the FO of *A. minimus* at ~4 m above the inoceramid-defined Coniacian-Santonian boundary at Seaford Head (coincident with the FO of *Prediscosphaera grandis*, which BURNETT (1998) placed lower and coincident with the FO of *M. concava*, and which was not found at Ten Mile Creek). Consequently, the distribution of *A. minimus*, both geographical and biostratigraphical, is clearly mediated by palaeobiogeography. Because it also clearly ranges through the boundary, and its FO and LO cannot be determined from these studies, it cannot be considered as a proxy for the boundary.

Amphizygus brooksii (herein termed '*A. brooksii* dark-rimmed form' in Text-fig. 17) is rare and sporadically distributed at Ten Mile Creek. Its (local) LO is below the Coniacian-Santonian boundary, according to data presented here, although HOWE & *al*. (2007) showed it to continue to 10.74 m in their Arbor Park section. MELINTE & LAMOLDA (2002) found it to range, consistently, to the top of their studied interval at Olazagutía, that is to say well above the inoceramid-defined boundary. (They also found it to range to the tops of the Romanian sections they studied across this interval (MELINTE & LAMOLDA 2007)) HOWE & *al*. (2007), however, queried its occurrence above the boundary, both at Olazagutía and Seaford Head. They recorded it as occurring only very rarely and very sporadically in both sections. HAMPTON & *al*. (2007) did *not* recognise this event in the Seaford Head section. It should be noted that this taxon has been recorded as high as the Lower Maastrichtian (e.g., LEES 2002, Indian Ocean; LEES & BOWN 2005, Pacific Ocean). So, again, the LO of this species is not to be considered a proxy for this boundary.

Helicolithus trabeculatus was found commonly throughout the Ten Mile Creek and Arbor Park sections (the taxon here recorded as 'large form' in Text-fig. 17), as recorded both herein and by HOWE & *al*. (2007). At Olazagutía, MELINTE & LAMOLDA (2002) recorded it as common throughout their studied interval, whilst HOWE & *al.* (2007) showed

STAGE	PLANKTONIC FORAMINIFERA ZONE (Robaszynski & Caron, 1995)	Section (composite)	height is section in meters	Samples	*Marginotruncana schneegansi* (SIGAL, 1952)	*Marginotruncana sigali* (REICHEL, 1950)	*Marginotruncana sinuosa* PORTHAULT, 1970	*Marginotruncana marginata* (REUSS, 1845)	*Marginotruncana pseudolinneiana* PESSAGNO, 1967	*Marginotruncana renzi* (GANDOLFI, 1942)	*Marginotruncana coronata* (BOLLI, 1945)	*Marginotruncana tarfayaensis* (LEHMANN, 1963)	*Contusotruncana fornicata* (PLUMMER, 1931)	*Dicarinella concavata* (BROTZEN, 1934)	*Heterohelix globulosa* (EHRENBERG, 1840)	*Archaeoglobigerina cretacea* (D'ORBIGNY, 1840)	*Archaeoglobigerina bosquensis* PESSAGNO, 1967	*Archaeoglobigerina blowi* (PESSAGNO, 1967)	*Heterohelix moremani* (CUSHMAN, 1938)	*Laeviheterohelix pulchra* (BROTZEN, 1936)	*Laeviheterohelix glabrans* (CUSHMAN, 1938)	*Eohastigerinella watersi* (CUSHMAN, 1931)	*Globigerinelloides prairiehillensis* PESSAGNO, 1967	*Globigerinelloides bollii* PESSAGNO, 1967	*Globigerinelloides messinae* (BROENNIMANN, 1952)	*Pseudotextularia nuttalli* (VOORVIJK, 1937)	*Heterohelix reussi* (CUSHMAN, 1938)	*Hedbergella planispira* (TAPPAN, 1940)	*Heterohelix planata* (CUSHMAN, 1938)	*Whiteinella baltica* DOUGLASS & RANKIN, 1969	*Hedbergella simplex* (MORROW, 1934)	*Marginotruncana paraconcavata* PORTHAULT, 1970	*Heterohelix sphenoides* MASTERS, 1976	*Heterohelix striata* (EHRENBERG, 1840)	*Hedbergella flandrini* PORTHAULT, 1970	*Hedbergella holmdelensis* OLSSON, 1964	*Costellagerina bulbosa* (BELFORD, 1960)	*Costellagerina tradinghousensis* (PESSAGNO, 1967)	*Heterohelix papula* (BELFORD, 1960)	*Pseudoguembelina costellifera* MASTERS, 1936	*Dicarinella asymetrica* (SIGAL, 1952)	*Hastigerinoides alexanderi* (CUSHMAN, 1931)	*Globigerinelloides ultramicrus* (SUBBOTINA, 1949)	*Ventilabrella austinana* (CUSHMAN, 1938)	*Globotruncana arca* (CUSHMAN, 1926)	*Rugoglobigerina rugosa* (PLUMMER, 1926)	PRESERVATION	BENTHICS	OTHER COMPONENTS
LOWER SANTONIAN (pars)	*Dicarinella asymetrica* (pars)	Arbor Park Road	8,00	W45		VR	F	R	R	VR	R		C	R	F	F	F	R	R	F	R		F	F	F	R		C	R			VR	R	R		R	F	F	R	F	F	F	F	R	?	VR	P	C calc - F aggl	ostracods, inoceramids A, pyrite
		Nazarene 2	13,00	W42			F	C	F		R		C	F	F	F	C	R				F		F			?	C								?	F	F	R		F			R	VR	?	P/M	F calcareous	echinoids, inoceramids, pyrite, ostracods
		Nazarene 2	10,60	W39			F	C	F		F		C	R	F	C	F	F	F					C	F	F	?	F	R		R	R		R	?	VR	F	R	R	R	F		F	R	VR	VR	P/M	C calc - F aggl	ostracods, inoceramids
		WalMart	23,00	W36			R	F	F				C	F	C	C	F	C	F	F	R	R	F	F	F	F	VR	R	R			F	?	F		?	F	F	R	R	F			?	?	?	M	C calc - F aggl	ostracods, inoceramids A, pyrite
		WalMart	21,40	W33			R	F	F		R		C	R	C	F	F	F	F		F		R	R		C	F	R	F			R	R	R		?	F	R	F	R	C		R	VR			P	C calc - F aggl	ostracods, inoceramids
UPPER CONIACIAN (pars)		WalMart	17,10	W30				F	F		R		R	F	F	F	F	F	F	F			F	F	F	R		R	F			R	R	?			R	F	R	R	F		R				P/M	F calc - F aggl	ostracods, inoceramids
		WalMart	14,60	W27			F	F	F	R	F		R	R	F	C	C	F	R	F	F	F		R		R		R	F		R	R		?			F	F	F	R	C						P	C calc - F aggl	ostracods
		WalMart	11,70	W24			F	R	F	F	R		R	R	F	C	C	C	R		F	C		F	F	VR	C	R	R	R	R			?	?		F	F	R	R	R	?					P	F calcareous	pyrite
		WalMart	8,00	W21	R	R	F	F	F	F	F	R	C	R	F	C	C	C		R	F					F		R	F	R				?			F	F	F	F	F						P/M	F calc - A aggl	ostracods, pyrite
		WalMart	5,00	W18	R		F	F	F	R	F	R	C	R	C	C	F	C	F	F		C	F	F	C	F	C	F	R	R		R					VR		R	R							P/M	F calcareous	ostracods, pyrite
		WalMart	1,30	W15	R	R	F	F	R	R	F	R	R	R	F	C	R	C	R	R	R	R		F	R	R	C	F	R	R	R	R		F	F	F	?	?	?	?							P/M	R calcareous	inoceramids R
		Nazarene 1	12,50	W13	planktonic foraminifera present but not identifiable at species level																																										VP		
		Nazarene 1	8,30	W10	planktonic foraminifera present but not identifiable at species level																																										VP		
		Nazarene 1	6,10	W7	C	F	F	F	F	F	F	F	R	R		C	C	C	C	C	F	F	F	F	F	C	F	F		F	F	F	R	F	R	R	??	??	?	F	VR	?					M	R calcareous	inoceramids R, ostracods
	D. concavata (pars)	Nazarene 1	3,30	W4	F	F	F	C	R		R		R	F	C	F	F	C	F	C	F	C	R	C	F	F	R	R	C	R	C	C	R	R	R	R											P/M	R calcareous	inoceramids R, ostracods
		Nazarene 1	0,40	W1	planktonic foraminifera present but not identifiable at species level																																										VP		

calc = calcareous
aggl = agglutinated

it as possibly common (19 specimens per mm^2) only up to 3 m below the boundary there. At Seaford Head, it is less abundant (frequent but not common?) up to 4 m below the boundary (Howe & *al*. 2007), whereas Hampton & *al*. (2007) recorded a 'last influx occurrence' of the species above the boundary, at the same level as the FOs of *A. minimus* and *P. grandis*. There is thus no precise correlation between these clearly palaeobiogeographically-mediated abundance distributions, and so the abundance of *H. trabeculatus* cannot be considered as a useable event in relation to the Coniacian-Santonian boundary.

As a result of correlating and evaluating all the data currently available, the best succession of nannofossil events across the Coniacian-Santonian boundary interval is (in stratigraphical order, youngest at top):

LO *L. septenarius* (base UC12)
FO *Cl. undulatoplicatus* (inoceramid; boundary marker) within UC11c
FO *L. cayeuxii* (base UC11c)
FO *L. grillii* (base UC11a)
LO *R. achlyostaurion* (within UC10)
FO *L. arcuatus* (within UC10)
FO *M. staurophora* (base UC10).

PLANKTONIC FORAMINIFERA
(M.R. Petrizzo)

A total of sixteen samples from the composite section were analyzed for planktonic foraminifera. Samples were soaked in Neodesogen for 3 to 5 days, washed under running water through 38-150 µm, 150-250 µm, and >250 µm sieves and then dried. This procedure was repeated 4 to 5 times until the samples were totally disaggregated. Ultrasonic treatment was used to clean encrusted specimens to allow identification at species level.

Relative abundance counts of planktonic foraminifera are shown in Text-fig. 18, together with the foraminiferal preservation rating, the relative abundance ranking for benthic foraminifera, and notes on the contents of the residues. Species that are questionably present are denoted by a question mark. Planktonic foraminifera judged as having moderate (M) preservation show minor to moderate test fragmentation, and are overgrown with secondary calcite; poor (P) preservation is indicated for specimens that are fragmented and difficult to identify at species level. The number of specimens was calculated through semi-quantitative analysis from several fields of view at low magnification, using relative values as follows: abundant (A) = >26%, common (C)= 16-25%, few (F) = 6-15%, rare (R)= 2-5% and very rare (VR)= <2%. Selected species are illustrated in Text-figs 19-22. The taxonomic concepts follow Pessagno (1967), Masters (1977), Caron (1985), Loeblich & Tappan (1987), Nederbragt (1990), and the CHRONOS Mesozoic Planktonic Foraminiferal Taxonomic Dictionary located at http://portal.chronos.org.

In general, planktonic foraminifera are poorly to moderately preserved. In the large-sized fraction, marginotruncanids dominate the assemblages. *Marginotruncana sinuosa*, *M. marginata, M. renzi*, and *M. tarfayaensis* are the commonest species in the lower part of the stratigraphic interval studied. *Contusotruncana fornicata* is rare in the Nazarene 1 section; there is an increase in the number of specimens in the upper part of the composite section. The double-keeled globotruncanids are absent except for rare representatives of *Globotruncana arca* that occur in the upper part of the WalMart section, above the FO of the inoceramid *Cladoceramus undulatoplicatus. Archaeoglobigerina* dominates the assemblages throughout the section with common representatives of *A. bosquensis*, *A. cretacea* and *A. blowi*. Rare specimens of *Whiteinella baltica* are recorded in the lower part of the section. *Costellagerina bulbosa* and *C. tradinghousensis* first appear at the 1.3 m level in the WalMart section and increase in number of specimens at the top of the section. *Dicarinella concavata* is present from the base of the studied stratigraphic interval. Two specimens of *Dicarinella asymetrica* have been found at the 6.1 m level in the Nazarene 1 section, and the species is consistently present from the 8 m level upward. The single-keeled plano-convex globotrun-

Fig. 18. Distribution and abundance of planktonic foraminifera in the the Atco and Bruceville members of the Austin Chalk in the Nazarene 1and 2 sections and the WalMart section on Ten Mile Creek, and the Bruceville Member in the Arbor Park section in Dallas County, Texas. The classification scheme follows Pessagno (1967), Masters (1977), Caron (1985), Loeblich & Tappan (1987), Nederbragt (1990) and the CHRONOS Mesozoic Planktonic Foraminiferal Taxonomic Dictionary located at http://portal.chronos.org.

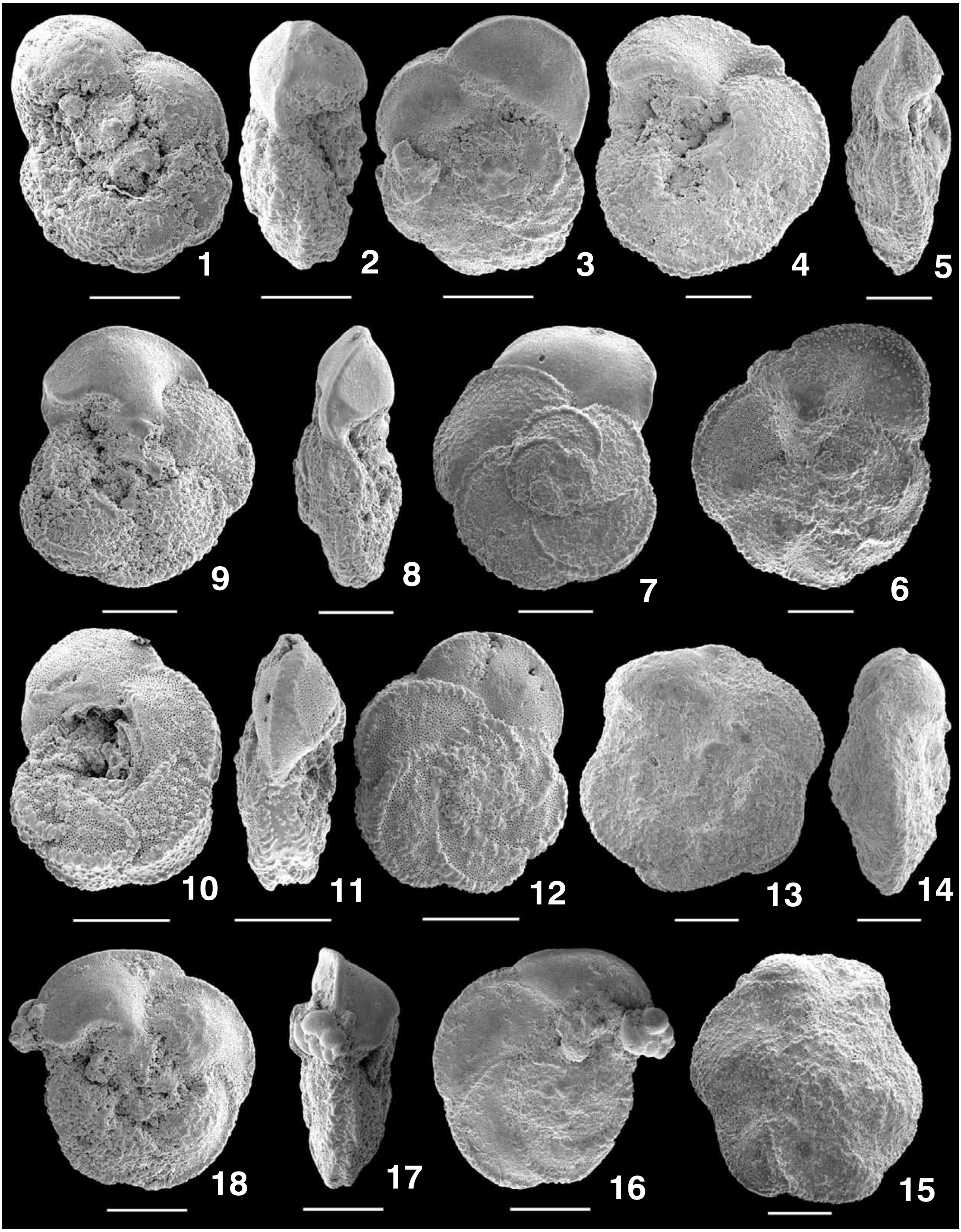

Fig. 19. **1-3** – *Marginotruncana marginata* (REUSS, 1845), sample W7; **4-6** – *Marginotruncana sinuosa* PORTHAULT, 1970, sample W45; **7-9** – *Marginotruncana* cf. *schneegansi* (SIGAL, 1952), sample W7; **10-12** – *Marginotruncana renzi* (GANDOLFI, 1942), sample W4; **13-15** – *Marginotruncana* cf. *sigali* (REICHEL, 1950), sample W21; **16-18** – *Marginotruncana renzi* (GANDOLFI, 1942), sample W7. Scale bars 200 μm

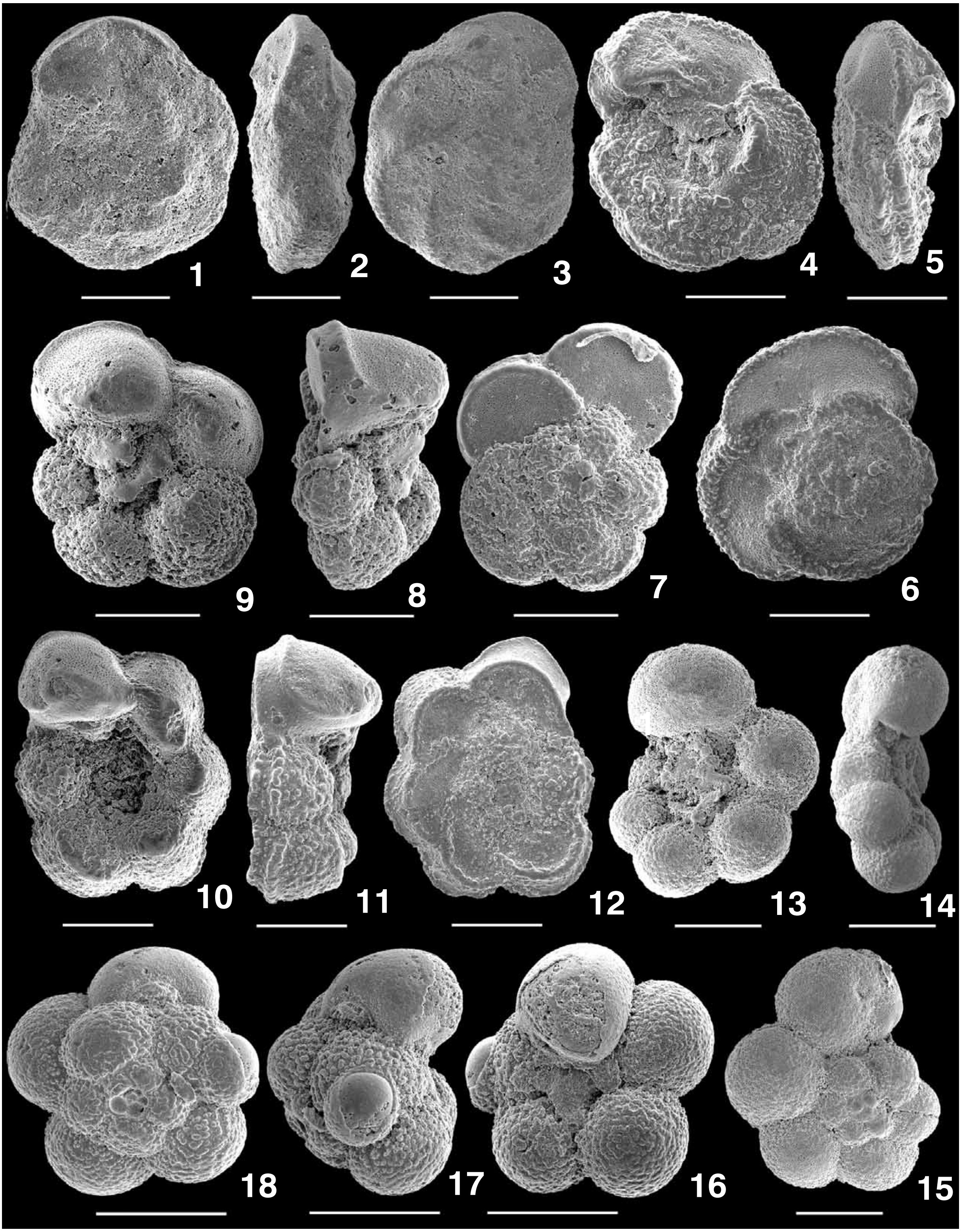

Fig. 20. **1-3** – *Marginotruncana* cf. *coronata* (BOLLI, 1945), sample W21; **4-6** – *Contusotruncana fornicata* (PLUMMER, 1931), sample W15; **7-9** – *Dicarinella concavata* (BROTZEN, 1934), sample W7; **10-12** – *Dicarinella asymetrica* (SIGAL, 1952), sample W7; **13-15** – *Archaeoglobigerina cretacea* (D'ORBIGNY, 1840), sample W7; **15-18** – *Costellagerina tradinghousensis* (PESSAGNO, 1967), sample W15. Scale bar 200 μm

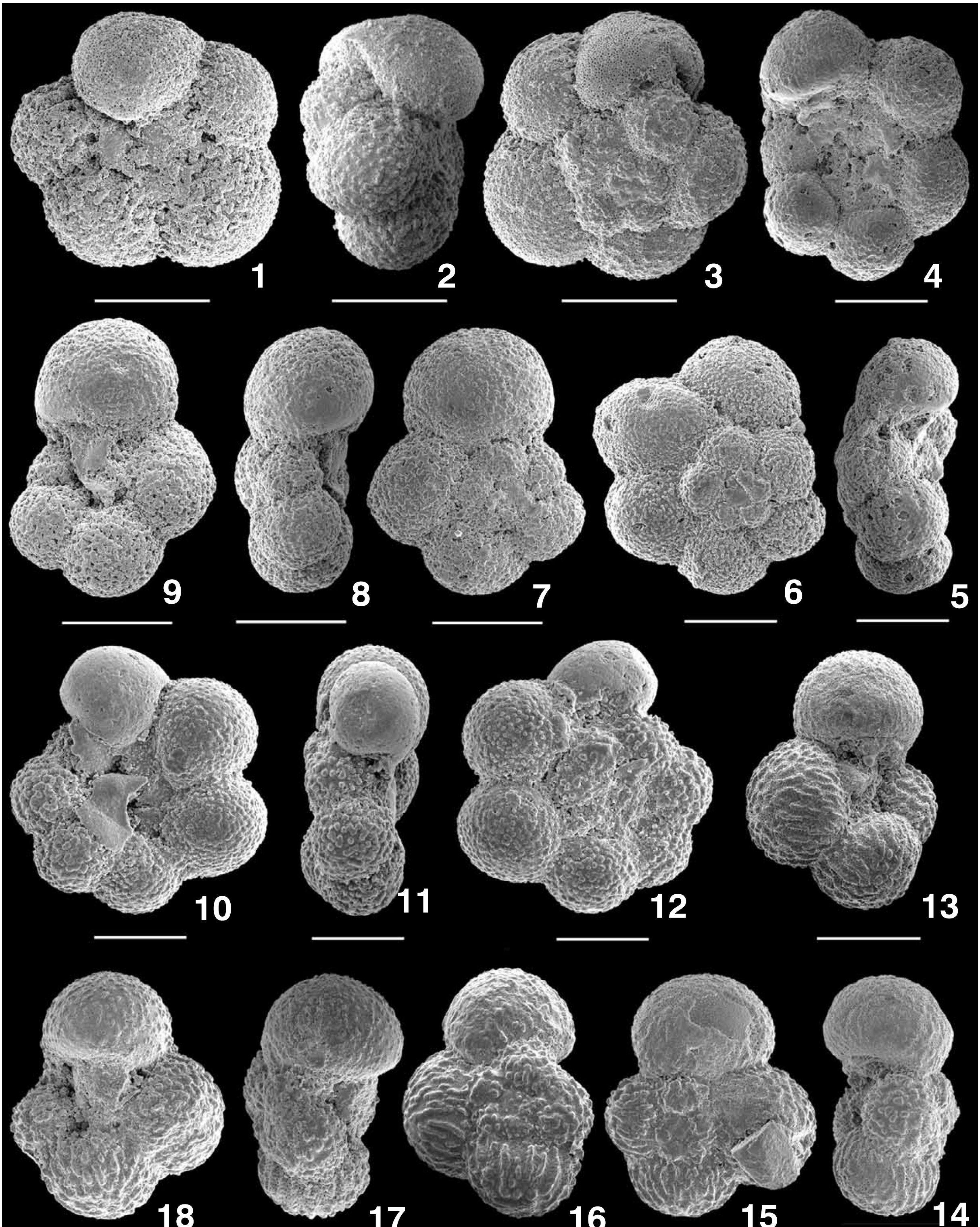

Fig. 21. **1-3** – *Archaeoglobigerina bosquensis* PESSAGNO, 1967, sample W7; **4-6** – *Archaeoglobigerina cretacea* (D'ORBIGNY, 1840), sample W7; **7-9** – *Archaeoglobigerina blowi* (BROTZEN, 1967), sample W7; **10-12** – *Hedbergella planispira* (TAPPAN, 1940), sample W45; **13-18** – *Costellagerina bulbosa* (BELFORD, 1960), sample W45. Scale bars 200 μm

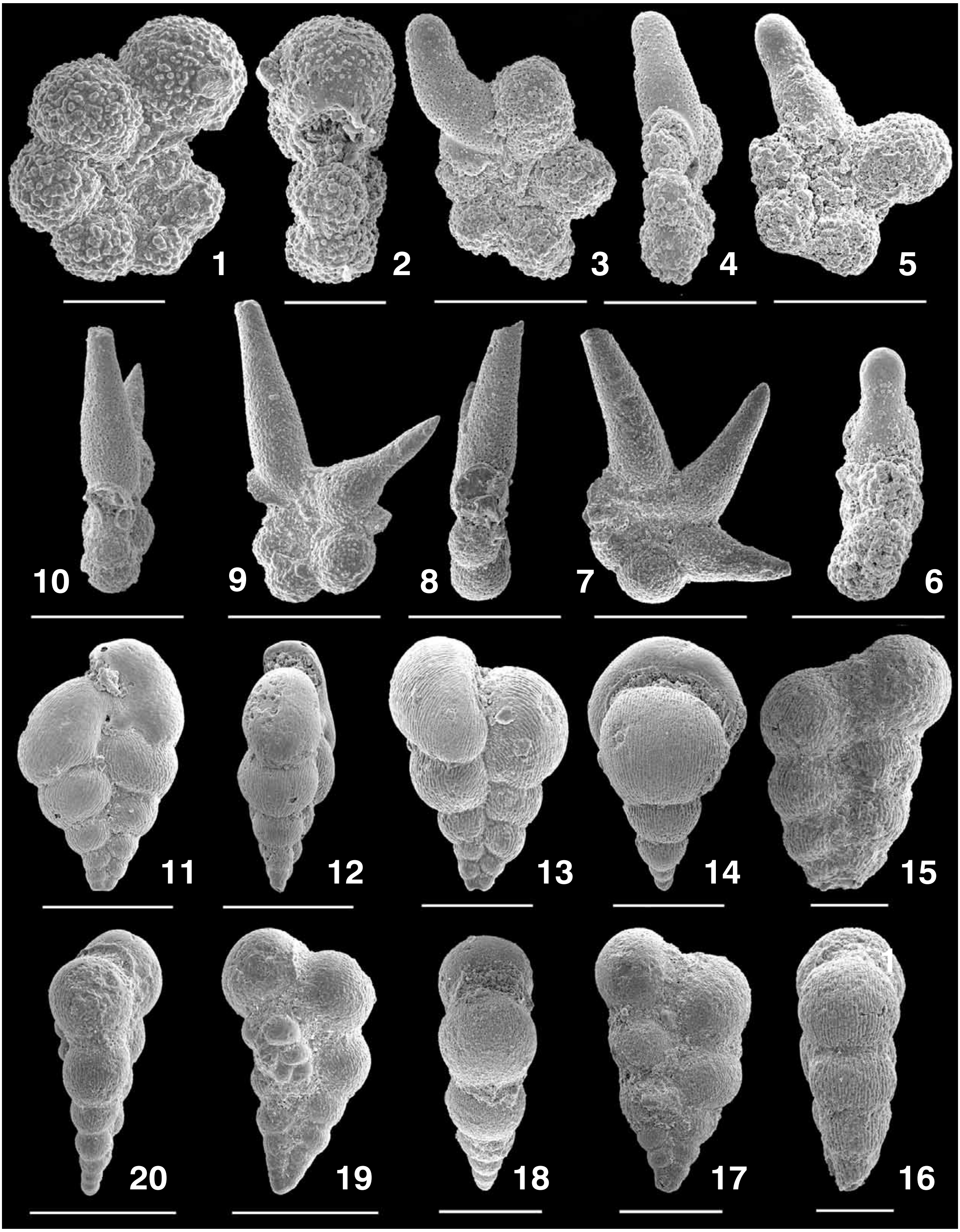

Fig. 22. **1-2** – *Globigerinelloides bollii* PESSAGNO, 1967, sample W4, scale bar 100 µm; **3-6** – *Eohastigerinella watersi* (CUSHMAN, 1931), sample W7; **7-10** – *Hastigerinoides alexanderi* (CUSHMAN, 1931), sample W45; **11-12** – *Pseudoguembelina costellifera* MASTERS, 1976, sample W7; **13-14** – *Pseudotextularia nuttalli* (VOORWIJK, 1937), sample W7; **15-16** – *Heterohelix papula* (BELFORD, 1960), sample W30, scale bar 100 µm; **17-18** – *Heterohelix papula* (BELFORD, 1960), sample W21; **19-20** – *Heterohelix moremani* (CUSHMAN, 1938), sample W45. Scale bars 200 µm.

canids (*Globotruncanita stuartiformis* and *G. elevata*) are totally absent.

The small-sized fraction is dominated by simple heterohelicids (*Heterohelix globulosa* and *H. reussi*) and *Laeviheterohelix*. *Pseudotextularia nuttalli* and *Pseudoguembelina costellifera* are consistently present. *Heterohelix papula* first occurs at the 5 m level in the lower part of the WalMart section. Complex heterohelicids (e.g. *Sigalia*) are totally absent and only rare representatives of *Ventilabrella austinana* occur in the upper part of the composite section above the FO of *Cl. undulatoplicatus*. The planispiral *Globigerinelloides* show a discontinuous range throughout the section, with few to common representatives of *G. bollii*, *G. prairiehillensis* and *G. messinae*. Sporadic specimens of *Eohastigerinella watersi* commonly occur in the lower part of the composite section, and rare specimens of *H. alexanderi* were found in the topmost sample (8 m level) collected from the Arbor Park section. Among the opportunistic simple morphotypes, the hedbergellids are represented by few to common *H. planispira*; rare *H. flandrini* occur at the base of the section and rare specimens close to *H. holmdelensis* were found at higher levels.

Based on the planktonic foraminiferal assemblages the stratigraphic interval from the first occurrence of *D. asymetrica* at the 6.1 m level in the Nazarene 1 section to the top of the composite section studied is assigned to the *Dicarinella asymetrica* Zone. Because of the absence of the *Sigalia* group, this interval cannot be further subdivided using the first appearance of *Sigalia carpathica*, a datum proposed as a secondary marker for the Coniacian/Santonian boundary during the Second International Symposium on Cretaceous Stage Boundaries (LAMOLDA & HANCOCK 1996). The lowermost samples, at the 0.4 m and 3.3 m levels of the Nazarene 1 section are attributed to the *Dicarinella concavata* Zone based on the absence of *D. asymetrica*. In the Ten Mile Creek sections, the FO of *D. asymetrica* precedes the FO of the inoceramid *Cladoceramus undulatoplicatus* that identifies the Coniacian/Santonian boundary. In contrast, in the Olazagutía section (Navarra province, North Spain), the FO of *D. asymetrica* is recorded 1.5 m above the FO of *Cl. undulatoplicatus* (LAMOLDA & *al*. 1999; LAMOLDA 2002; MELINTE & LAMOLDA 2002). However, recent studies on the planktonic foraminiferal assemblages of the Olazagutía section (LAMOLDA & *al*. 2007) have revealed the presence of rare specimens of *D. asymetrica* in the stratigraphic interval below the FO of *Cl. undulatoplicatus*, in agreement with that observed in the Ten Mile Creek record. This sequence of events also correlates with the record in the Elles and El Kef region (northwestern Tunisia). In both localities, the FO of *D. asymetrica* slightly precedes the appearance of *Platyceramus cycloides*, an inoceramid species that is thought to first occur close to the FO of *Cl. undulatoplicatus* (EL AMRI & ZAGHBIB-TURKI 2005); in the Walmart section it first appears 3.6 m above the FO of *Cl. undulatoplicatus*.

Despite the overall poor to moderate preservation of the planktonic microfauna, some events linked with the appearance of *D. asymetrica* and hence useful for worldwide correlation were found through detailed analysis of the planktonic foraminiferal assemblages. These events are discussed below in stratigraphic order.

1) The FO of *Costellagerina* at the 5 m level (and possibly at 1.3 m) in the WalMart section, above the FO of *D. asymetrica*. These occurrences are in agreement with those in the Elles and El Kef region in Tunisia (EL AMRI & ZAGHBIB-TURKI 2005) and the Olazagutía section in Spain (LAMOLDA & *al*. 2007) where the FO of *C. pilula* is in the lower part of the *D. asymetrica* Zone. Such a sequence of events was also observed on the Exmouth Plateau (southern Indian Ocean, western Australia; PETRIZZO 2000).

2) The appearance of *Heterohelix papula*, slightly above the FO of *D. asymetrica,* at the 5 m level (and possibly at 1.3 m) in the WalMart section. In contrast, its first occurrence is recorded below the FO of *D. asymetrica* in the Southern Ocean (PETRIZZO 2003). However, this bioevent appears to be coeval with the FO of large heterohelicids (*Sigalia* group and ventilabrellids) that at low latitudes slightly precedes the appearance of *D. asymetrica* (SIGAL 1977; PREMOLI SILVA & SLITER 1995; ROBASZYNSKI & CARON 1995). Based on these data, *H. papula* is confirmed to first occur close to the appearance of *D. asymetrica*, although further investigations are needed to establish its validity over distance as a proxy boundary marker.

3) The extinction of the *Whiteinella* group, which falls at the 11.7 m level in the WalMart section, above the FO of *D. asymetrica*, is in agreement with the record observed at Bottaccione in Italy (PREMOLI SILVA & SLITER 1994) and in the

Kalaat Senan region in central Tunisia (ROBASZYNSKI & *al.* 2000). In contrast, LAMOLDA & *al.* (2007) showed this group to range to the top of their studied interval at Olazagutía. A local palaeoecological control cannot be excluded. It should be noted that the sequence of planktonic foraminiferal events recognised here is significantly different from that in a recently published study of the three candidate GSSP sections (Olazgutía, Seaford Head, and Ten Mile Creek) by HOWE & *al.* (2007). For example, the FO of *D. asymetrica* is shown as being above the FO of *Cl. undulatoplicatus* by these authors. Furthermore, they did not not recognise *D. asymetrica* (see Text-fig. 20.10-20.12), *Contusotruncana fornicata* (Text-fig. 20.4-20.6), or *Costellagerina* (Text-fig. 21.13-21.18) in the Ten Mile Creek section.

CARBON STABLE ISOTOPES (A.S. GALE)

Carbon isotope data, expressed as $\delta^{13}C$, are a powerful correlation tool in Late Cretaceous successions, because of the relatively large, rapid and effectively contemporaneous global variance in $\delta^{13}C$ values (e.g. JENKYNS & *al*. 1994; JARVIS & *al*. 2006). The carbon isotope stratigraphy of the Coniacian-Santonian interval has recently been described in detail on the basis of the chalk successions of southern England (JARVIS & *al*. 2006). This study revealed numerous distinctive isotopic events, including a mid- to Late Coniacian positive excursion. Many of these excursions have also been described from Gubbio, Italy (JENKYNS & *al*. 1994).

Accordingly, we have investigated the carbon isotope stratigraphy of a number of exposures of the Austin Chalk in the Dallas area, including those documented in detail here, and derived a composite curve that can be compared with the succession in southern England (Text-fig. 23) using known common biostratigraphic markers as an independent control. This in turn provides a broad context to the detailed carbon isotope stratigraphy of the composite Nazarene-WalMart-Arbor Park succession (Text-fig. 24).

The stable carbon isotope record for the lower part of the Austin Chalk has been derived from the Bluff View and Clark Road (Jacobson 1 and 2) sections (LARSON & *al*. 1991, p. 41; HANCOCK & WALASZCZYK 2004). The latter authors placed the base of the Coniacian 0.4 m above the base of the Atco Member, at the first occurrence of *Cremnoceramus erectus*. The carbon isotope curve from the Bluff View section displays striking fluctuations of approximately 1 ppt $\delta^{13}C$. These are correlated with the Navigation (negative) and Beeding carbon stable isotope Events (positive) in the chalk of southern England (JARVIS & *al.* 2006). The Clark Road section (LARSON & *al*. 1991, p. 49) continues the succession upwards, and displays a stepped positive excursion of nearly 1 ppt $\delta^{13}C$, reaching values of almost 2.3 ppt, including peaks tentatively identified as the correlatives of the Light Point, East Cliff and White Fall Events. The correlation is supported by the identical positions of the first occurrence of the inoceramid *Volviceramus involutus* in both southern England and Texas, which is coincident with the maximum peak of the White Fall Event.

Values of $\delta^{13}C$ remained high through the succession exposed in the Jacobsen 1 and Jacobsen 2 sections on Clark Road (Text-fig. 23) (LARSON & *al*. 1991, p. 50), and represent the mid-Late Coniacian excursion identified in southern England and elsewhere. The excursion includes small minor excursions tentatively identified as the correlatives of the j1 and j2 events in southern England (JARVIS & *al.* 2006). The succession continues in the basal Nazarene 1 section on Ten Mile Creek (the Williams 9 section of LARSON & *al*. 1991, p. 54) (Text-fig. 23), and a positive excursion found between the 3 and 6 m level in this section represents the Kingsdown Event of JARVIS & *al*. (2006). Above this level, $\delta^{13}C$ values follow a declining trend through to the top of the WalMart section. This declining curve includes a number of short positive and negative excursions of less than 0.5 ppt $\delta^{13}C$. These are correlated with the K1, K2, Michel Dean and Bedwell Events in the southern England. The candidate GSSP in the WalMart section, the FO of *Cladoceramus undulatoplicatus* thus falls 3.5 m below the correlative of the Michel Dean Event in southern England, and coincides with a minor negative event. The higher *Cl. undulatoplicatus* concentration identified in the Nazarene 2 and Arbor Park sections coincide with a minor positive $\delta^{13}C$ excursion that corresponds to the Bedwell Event in southern England (JARVIS & *al.* 2006), where it is also associated with a second, higher concentration of *Cl. undulatoplicatus*.

It will be seen (Text-fig. 23) that there is a close correspondence between the $\delta^{13}C$ curves for the

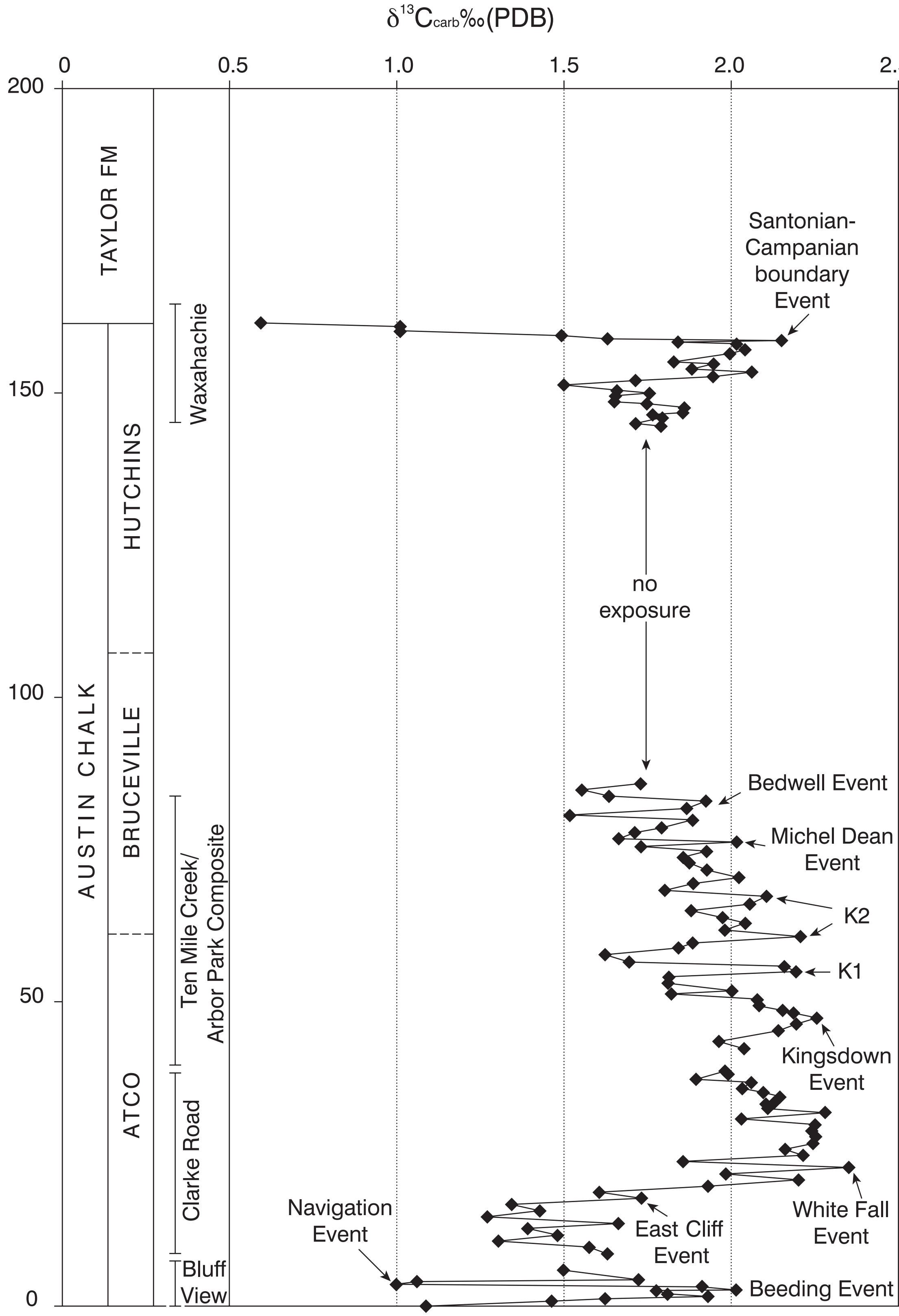

Fig. 23. The partial stable carbon isotope curve for the Austin Chalk in the Dallas area, with the position of events in the English Chalk as recognised by JARVIS & *al*. (2006) indicated

Early Coniacian to Early Santonian part of the Austin Chalk in the Dallas area of Texas and the corresponding interval in southern England, both in overall trends, and the relative position and magnitudes of minor excursions. The identity and correlation of individual events can be confirmed using high-resolution inoceramid stratigraphy. A combination of carbon isotope stratigraphy and biostratigraphy enables transatlantic correlations in Coniacian and Santonian chalks at a resolution of one to several metres. This demonstrates that in both areas the first occurrence of *Cl. undulatoplicatus*, the boundary marker for the base of the Santonian Stage, corresponds to the minor negative excursion between the K2 and Mitchel Dean Events of JARVIS & *al.* (2006) and their Texan correlative.

CONCLUSIONS

The detailed analyses above show that the WalMart section is an excellent candidate Global boundary Stratotype Section for the base of the Santonian Stage, the boundary marker being the first occurrence of the distinctive inoceramid bivalve *Cladoceramus undulatoplicatus* (ROEMER, 1852).

There is exposure over an interval of 23 metres, and the section can be integrated into a composite section of over 60 metres on the basis of detailed bed-by-bed correlation. Within this composite section, the candidate GSSP can be shown to lie within the UC11c nannofossil Zone of BURNETT (1998), within the *Dicarinella asymetrica* planktonic foram Zone, within a *Texanites gallicus* ammonite Zone,

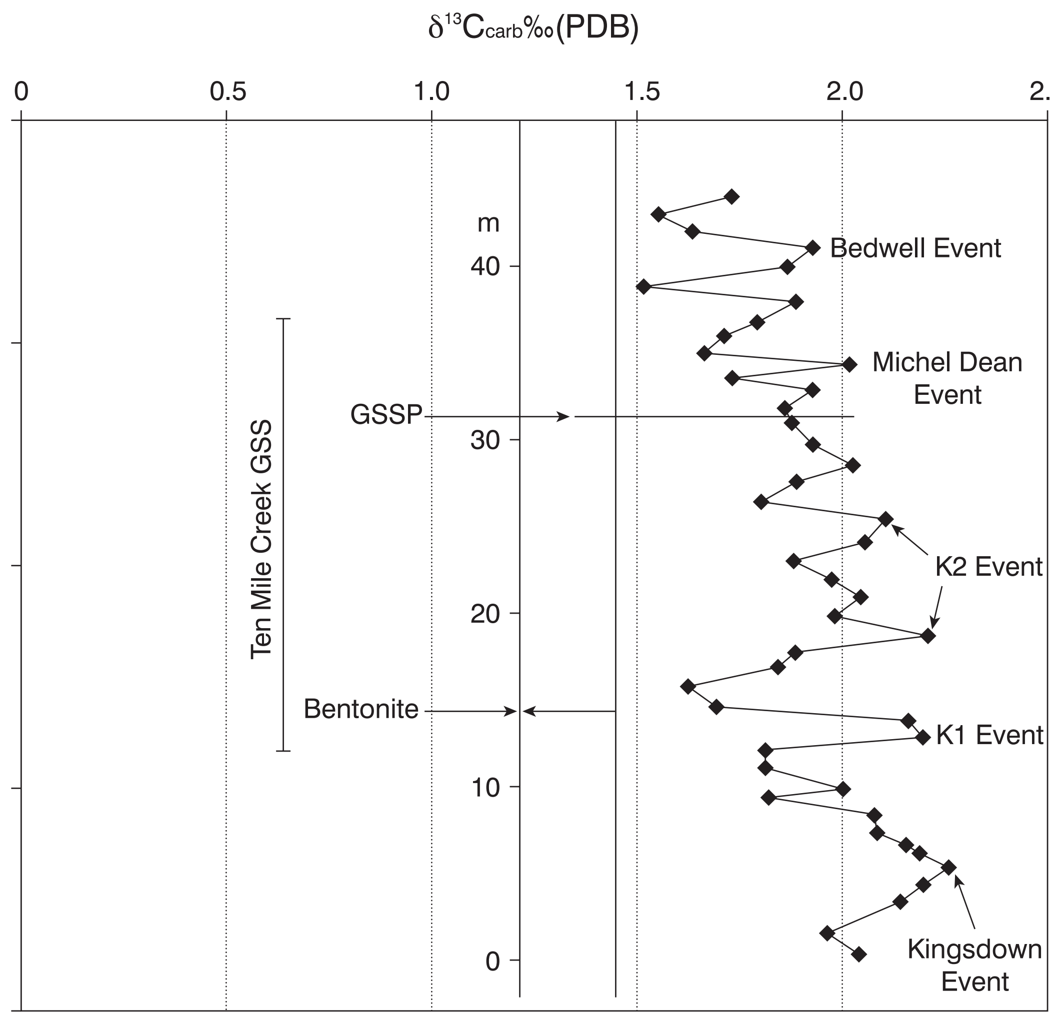

Fig. 24. The stable carbon isotope curve for the composite Ten Mile Creek and Arbor Park sections, with the WalMart candidate Global Stratotype Section and Point indicated. The stable isotope events in the English Chalk recognised by JARVIS & *al*. (2006) are also indicated

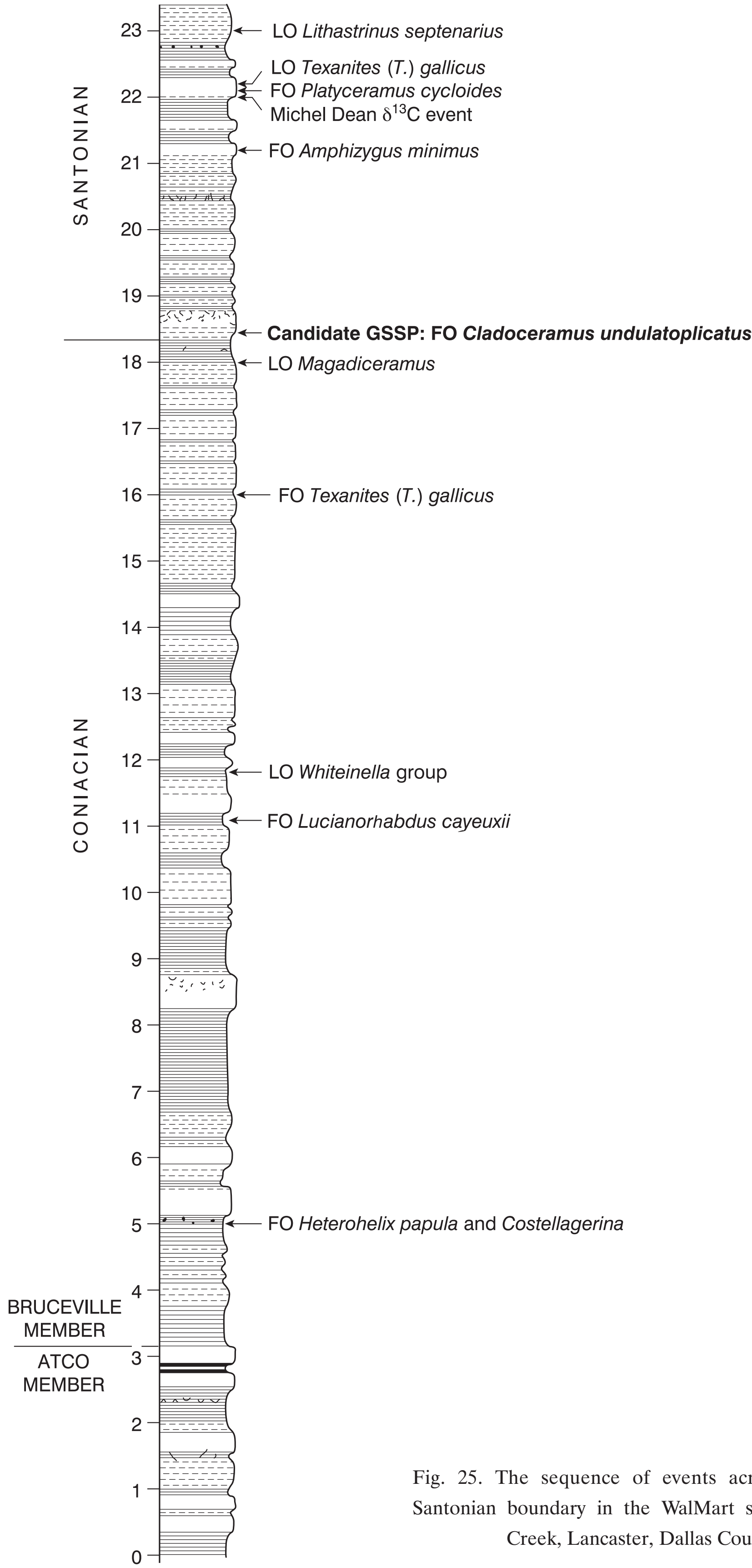

Fig. 25. The sequence of events across the Coniacian-Santonian boundary in the WalMart section on Ten Mile Creek, Lancaster, Dallas County, Texas

and within the interval of declining δ^{13}C between the K2 and Michel Dean events of JARVIS & *al.* (2006). Within the WalMart section, the candidate GSSP can be located within a series of ancillary marker events. From oldest to youngest, these are as follows (Text-fig. 25)

1. The first occurrence of the planktonic foraminiferan *Heterohelix papula* at the 5 m level (and possibly at the 1.3 m level).
2. The first occurrence of the planktonic foraminiferan *Costellagerina* at the 5 m level (and possibly at the 1.3 m level).
3. The first occurrence of the nannofossil *Lucianorhabdus cayeuxii* at the 11 m level.
4. The last occurrence of planktonic foraminifera of the *Whiteinella* group at the 11.7 m level.
5. The first occurrence of the ammonite *Texanites* (*T.*) *gallicus* at the 16 m level.
6. The last occurrence of the inoceramid bivalve *Magadiceramus* at the 18 m level.
7. **The candidate GSSP: the first occurrence of the inoceramid bivalve *Cladoceramus undulatoplicatus* at the 18.4 m level.**
8. The Michel Dean δ^{13}C stable carbon isotope event at the 21.9 m level.
9. The first occurrence of the inoceramid bivalve *Platyceramus cycloides* at the 22 m level.
10. The last occurrence of the ammonite *Texanites* (*T.*) *gallicus* at the 22.1 m level.
11. The last occurrence of the nannofossil *Lithastrinus septenarius* at the 23.0 m level.

In terms of other criteria required of a GSSP (REMANE & *al*. 1996, p. 9) the WalMart section:

- displays continuous sedimentation over the boundary interval;
- has a rate of sedimentation that is sufficiently high that the sequence of ancillary marker events are clearly separated;
- shows no sedimentary or tectonic disturbance of the boundary interval;
- has suffered neither metamorphism nor tectonic deformation;
- yields common fossils of diverse groups;
- shows no significant facies changes across the boundary;
- displays distinctive Milankovitch cyclicity, and is amenable to cyclostratigraphic analysis and long distance cyclostratigraphic correlation;
- yields a well-preserved carbon and oxygen stable isotope record;
- contains skeletal elements and chalks that are amenable to strontium isotope analysis;
- includes clays that are reported to be bentonitic, and thus are potentially datable by radiometric analysis;
- is made up of chalks that are amenable to palaeomagnetic analysis.

The section is at present freely accessible via a tarmac road, and there is no hinderance to visitors. If adopted as a GSSP for the base of the Santonian Stage, there will be a need to clarify ownership of the section, guarantee access rights, and preserve the section for future reference.

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