

Ammonites at the Cenomanian–Turonian boundary in the Sergipe Basin, Brazil

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Two distinctive ammonite faunas are described from the Cenomanian–Turonian boundary interval in the Sergipe Basin, Brazil. The Jardim 1 section assemblage comprises *Euomphaloceras costatum* Cobban, Hook & Kennedy, 1989, *Burroceras transitorium* Cobban, Hook & Kennedy, 1989, *Pseudaspidoceras pseudonodosoides* Choffat, 1898, and *Vascoceras* cf. *gamai* Choffat, 1898. This same association is found in New Mexico, where it occurs with the upper Cenomanian index fossil *Neocardioceras juddii* (Barrois & Guerne, 1898). On this basis the Sergipe assemblage is referred to the *N. juddii* Zone, and correlated with beds 79–84 of the Pueblo, Colorado section. These lie 1.14–0.63 m below the Global boundary Stratotype Section and Point (GSSP) for the base of the Turonian Stage, the base of bed 86, which corresponds to the first occurrence of the ammonite *Watinoceras devonense* Wright & Kennedy, 1981. The Japarutuba 16 locality in Sergipe yielded an assemblage of *Pachydsmoceras kossmati* Matsumoto, 1987, *Watinoceras coloradoense* (Henderson, 1908), *Pseudaspidoceras flexuosum* Powell, 1963, *Pseudovascoceras nigeriense* (Woods, 1911), *Vascoceras globosum globosum* (Reyment, 1954), *V. simplex* (Barber, 1957), and *Pseudotissotia nigeriensis* (Woods, 1911). The co-occurrence of *W. coloradoense* and *P. flexuosum* is also found in the Pueblo section, in bed 97, 1.65 m above the base of the Turonian.

These ammonite records thus allow the placement of the Cenomanian–Turonian boundary in the Sergipe-Alagoas Basin, and correlation with the Global Boundary Stratotype Section and Point at Pueblo.

Key words: Ammonites, Cretaceous, Cenomanian, Turonian, Sergipe, Brazil.

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The Global boundary Stratotype Section and Point (GSSP) for the base of the Turonian Stage of the Cretaceous System is defined as the base of bed 86 of the Bridge Creek Member of the Greenhorn Limestone at the west end of the Denver and Rio Grande Western Railroad cut near the north boundary of the Pueblo Reservoir State Recreation Area, west of Pueblo, Colorado, USA, where it corresponds to the first occurrence of the ammonite *Watinoceras devonense* Wright & Kennedy, 1981 (Kennedy *et al.* 1995). There are numerous secondary biostratigraphic markers including foraminifera, inoceramid bivalves and ammonites (Kennedy & Cobban 1991; Bengtson 1996; Kennedy *et al.* 2000; Keller & Pardo 2004). The bound-

ary interval lies in the middle of a positive excursion in carbon-13 isotopes that corresponds to Oceanic Anoxic Event II of authors, which has been widely recognised in the marine sedimentary record (Arthur *et al.* 1983; Davey & Jenkyns 1999; Jarvis *et al.* 1988; Jenkyns 1980; Jenkyns *et al.* 1994; Keller *et al.* 2001; Leary & Peryt 1991; Paul *et al.* 1999; Pratt 1985; Pratt & Threlkeld 1984; Tsikos *et al.* (2004). Detailed studies by Gale *et al.* (1993) and Gale *et al.* (2005) have shown that many of the biostratigraphic markers across the boundary interval occur in the same sequence and in the same relative position to the detail of the $\delta^{13}\text{C}$ curve. It was with this detailed information on faunal markers that we have examined

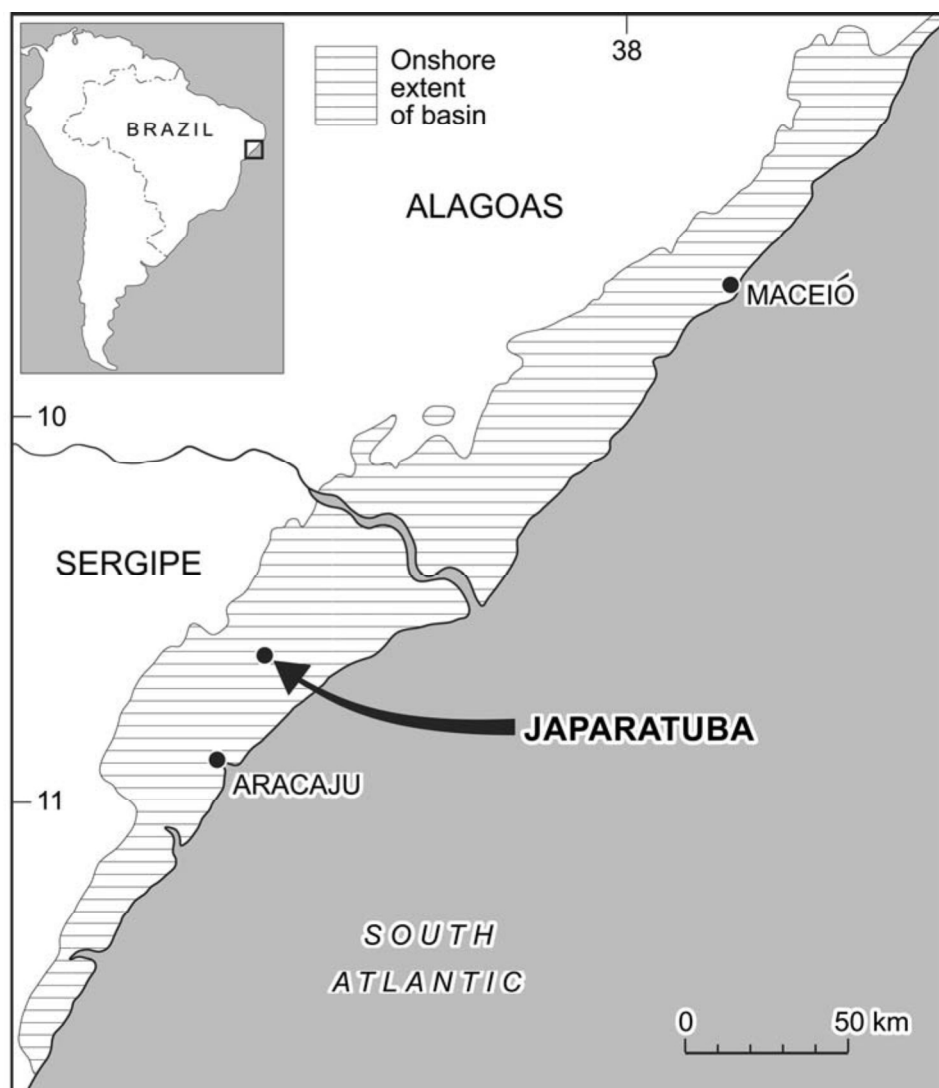


Fig. 1. Location map for the Sergipe Basin.

sections in the Sergipe Basin in northeastern Brazil (Fig. 1), to determine the position of the Cenomanian–Turonian boundary (reviews of the stratigraphy of the Sergipe Basin are to be found in Bengtson 1983, 1996; Koutsoukos 1998; Koutsoukos & Bengtson 1993; Koutsoukos *et al.* 1993; Seeling & Bengtson 2002). Field work was carried out in September 2000 by A.S.G. and P.B.

Geological setting

The Sergipe Basin is located in the coastal and contiguous offshore part of the state of Sergipe in northeastern Brazil (Fig. 1). It is one of the numerous South Atlantic continental margin basins that were formed as a result of rifting and separation of South Ameri-

ca from Africa in late Mesozoic times. Structurally, the basin forms a sub-basin of the Sergipe-Alagoas Basin, which comprises, from north to south, the Cabo, Alagoas, Sergipe and Jacuípe sub-basins (Souza-Lima *et al.* 2002). The sedimentary fill of the Sergipe Basin comprises a basal, Upper Carboniferous to middle Aptian non-marine succession and an Aptian to Miocene marine succession, which together represent one of the most complete Cretaceous successions among those recorded in the South Atlantic marginal basins.

The marine succession consists of the carbonate Riachuelo (Aptian–Albian) and Cotinguiba (Cenomanian–Coniacian) formations and the clastic Calumbi Formation (Santonian–Miocene). The Cenomanian–Turonian boundary interval is well exposed within the Cotinguiba Formation, which is mainly represented by deeper-water, fine-grained carbonates with an

average thickness of c. 200 m (Bengtson 1983) but locally reaching a maximum thickness of up to 800 m (Koutsoukos *et al.* 1993). Biostratigraphically, the formation is subdivided primarily with ammonites, inoceramid bivalves and foraminifers (Bengtson 1983; Kauffman & Bengtson 1985; Koutsoukos 1989; Koutsoukos & Bengtson 1993; Seeling 1999; Andrade *et al.* 2003).

The geological evolution and the stratigraphy of the marine Cretaceous of the Sergipe Basin have been discussed at length by several authors, e.g. Ojeda & Fugita (1976), Ojeda (1982), Bengtson (1983, 1996), Feijó (1995), Koutsoukos (1998), Koutsoukos & Bengtson (1993), Koutsoukos *et al.* (1993), and Souza-Lima *et al.* (2002). The biostratigraphy of the Cenomanian–Turonian boundary interval was discussed more specifically by Seeling (1999), Walter (2000), Seeling & Bengtson (2002), Teodósio & Bengtson (2003) and Walter *et al.* (*in press*).

Locality details

We examined two sections in connection with this study:

- 1) Jardim 1 (Bengtson 1983, p. 65) is a roadcut in the upper Cenomanian of the Cotinguiba Formation on the Japarutuba–Pirambu road, 5.5 km south-east of the town of Japarutuba. The log of the section is shown in Figure 2.
- 2) Japarutuba 16 (Walter *et al.* *in press*) is a shallow quarry in the lower Turonian of the Cotinguiba Formation, 1.5 km south of Japarutuba. The log of the section is shown in Figure 3.

Stratigraphic results

On the basis of ammonites, the Cenomanian–Turonian boundary in Sergipe is currently positioned at the base of the *Pseudotissotia* spp. Zone (Walter *et al.* *in press*). This zone is well represented in the northern Japarutuba area but has not been identified in the southern part of the area (Seeling 1999; Walter *et al.* *in press*).

The section Jardim 1 yielded a rich fauna of poorly preserved ammonites. The fauna comes from a 1.5 m interval of nodular limestones, and is as follows: *Euomphaloceras costatum* Cobban, Hook & Kennedy, 1989, *Burroceras transitorium* Cobban, Hook & Kennedy, 1989, *Pseudaspidoceras pseudonodosoides* (Choffat, 1898), and *Vascoceras* cf. *gamai* Choffat, 1898, be-

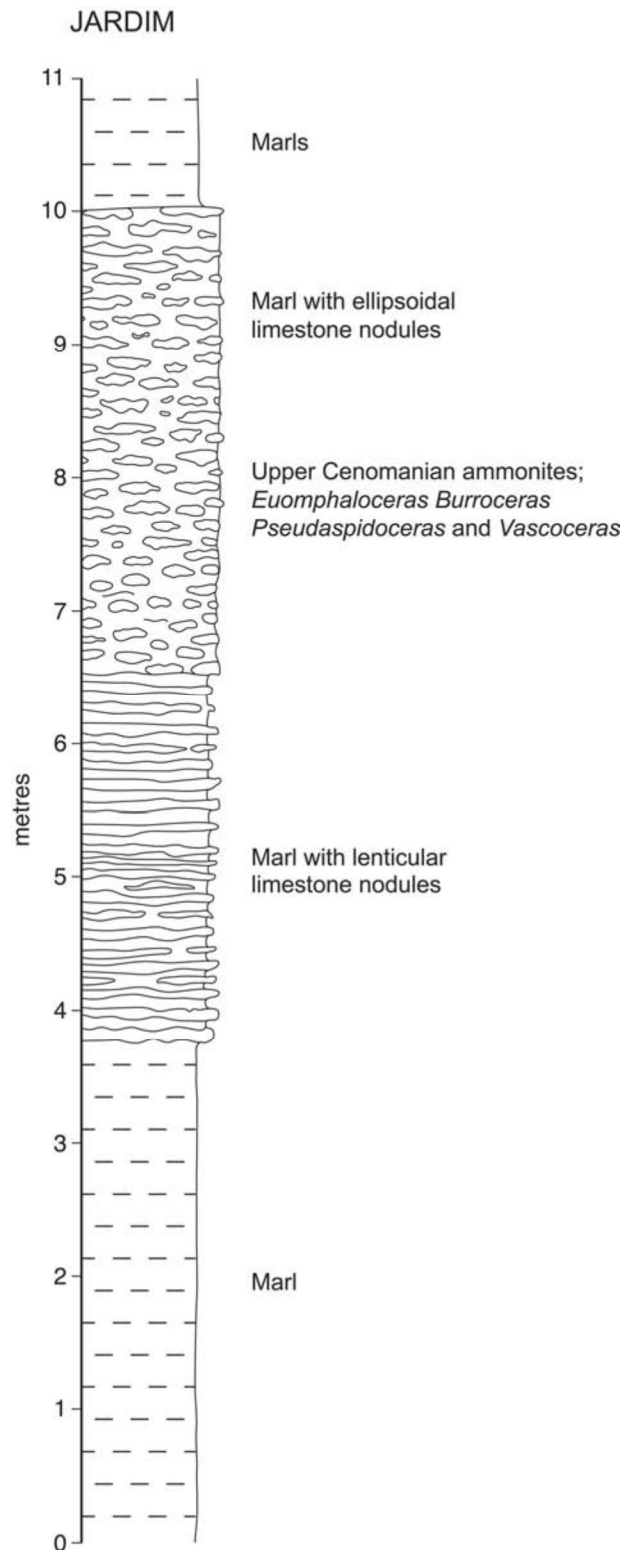


Fig. 2. The upper Cenomanian succession at Jardim 1.

JAPARATUBA 16

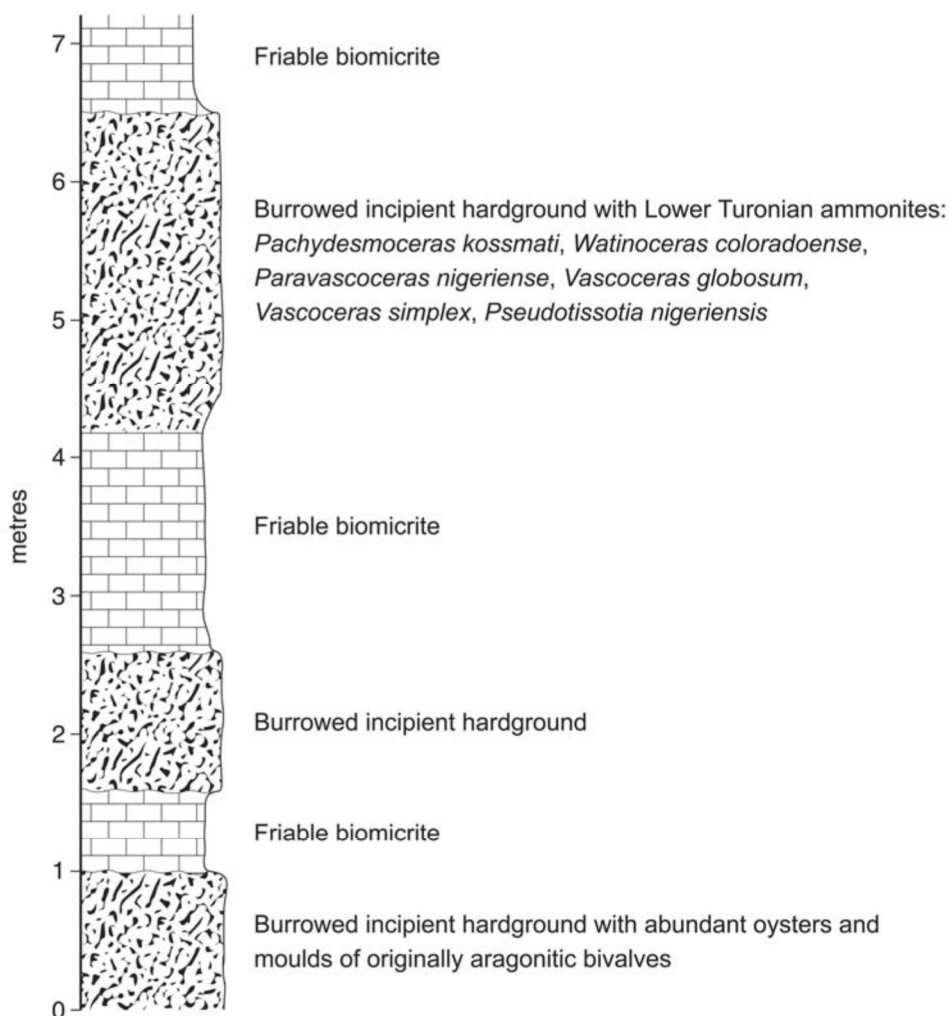


Fig. 3. The lower Turonian succession at Japaratuba 16.

longing to the upper Cenomanian *Euomphaloceras septemseriatum* Zone of Koutsoukos & Bengtson (1993). Elements of this fauna occur widely, from the southern part of the U.S. Western Interior (New Mexico, Arizona), and northern Mexico to southern England, Spain, Portugal, Morocco, Tunisia, Israel, and Egypt. In New Mexico, all species co-occur in association with the index species *Neocardioceras juddii* (Cobban & Hook 1993a, b; Cobban *et al.* 1989), and the present association can be referred to that 'standard' zone, and correlated to beds 79–84 of the Pueblo section (Fig. 2). Beds with Bengtson's (1983) upper Cenomanian 3 fauna with *Eucalycoceras* and other ammonites were formerly exposed 7–8 m below the base of this section.

Japaratuba 16 yielded a rich fauna from a 2 m interval towards the top of the section (Fig. 3): *Pachydesmoceras kossmati* Matsumoto, 1987, *Watinoceras*

coloradoense (Henderson, 1908), *Pseudovascoceras nigeriense* (Woods, 1911, *Pseudaspidoceras flexuosum* Powell, 1963, *Vascoceras globosum globosum* (Reyment, 1954), *V. simplex* (Barber, 1957), and *Pseudotissotia nigeriensis* Woods, 1911. The co-occurrence of *W. coloradoense* and *P. flexuosum* is also found in bed 97 of the Pueblo section (Cobban 1988, p. 9), 1.65 m above the stage boundary. Elements of the Japaratuba 16 fauna occur widely in the southern U.S. Western Interior, northern Mexico, British Columbia, Tunisia, Nigeria, and Madagascar. The Nigerian link is particularly strong: *P. nigeriense*, *P. flexuosum*, *V. globosum globosum*, *V. simplex*, and *P. nigeriensis* are common to both areas. But the co-occurrence geographically is not matched stratigraphically, for *P. nigeriense*, *V. globosum globosum*, and *V. simplex* are said to occur in the upper Cenomanian in Nigeria, as opposed to the lower Turonian in Sergipe. However, the base of

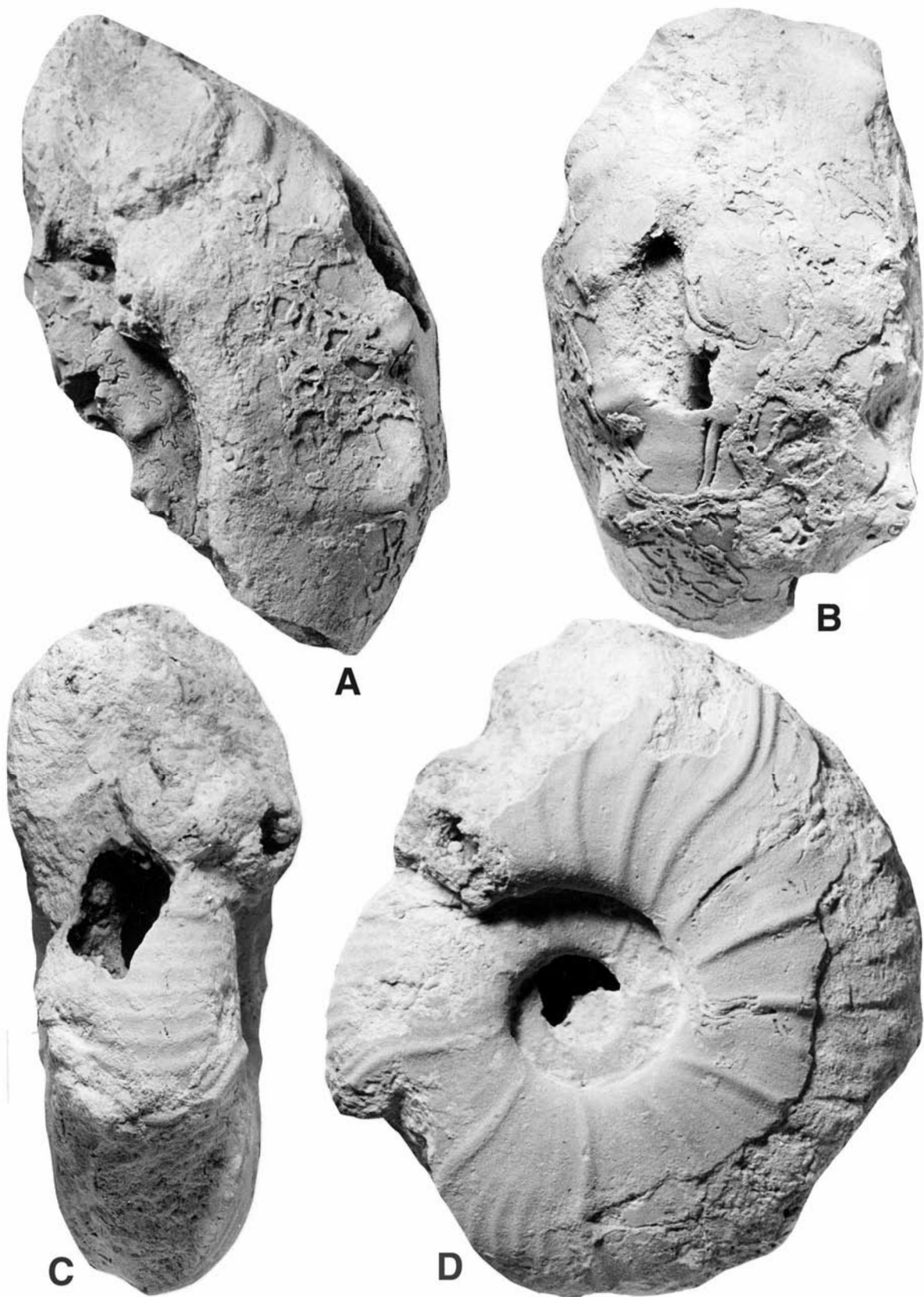


Fig. 4. A, B, *Pseudovascoceras nigeriensis* (Woods, 1911), OUM KU593. C, D, *Pachydesmoceras kossmati* Matsumoto, 1987, OUM KU592. Lower Turonian, Japaratuba 16. All figures are x 1.

the Turonian in Nigeria is placed at the first occurrence of *Pseudaspidoceras flexuosum*, a level which at Pueblo lies clearly above the stage boundary. Thus, it is possible that *P. nigeriense*, *V. globosum globosum*, and *V. simplex* in Nigeria are also Turonian.

Systematic palaeontology

Conventions

All dimensions are given in millimetres. D = diameter, Wb = whorl breadth, Wh = whorl height, U = umbilicus.

Suture terminology is E = external lobe, L = lateral lobe, U = umbilical lobe, I = internal lobe.

Repositories of specimens are indicated as follows:
OUM: Oxford University Museum of Natural History

TMM: Texas Memorial Museum, Austin

USNM: US National Museum of Natural History, Washington D.C.

Order Ammonoidea Zittel, 1884

Suborder Ammonitina Hyatt, 1889

Superfamily Desmoceratoidea Zittel, 1895

Family Desmoceratidae Zittel, 1895

Subfamily Puzosiinae Spath, 1922

Genus *Pachydesmoceras* Spath, 1922

Type species – *Ammonites denisonianus* Stoliczka, 1865, p. 133, pl. 65, fig. 4; pls 66, 66a.

Pachydesmoceras kossmati Matsumoto, 1987

Fig. 4C, D

1987 *Pachydesmoceras kossmati* Matsumoto, p. 6, fig. 1.

1988 *Pachydesmoceras kossmati* Matsumoto - Matsumoto, Kera, Takahashi, Kawashita & Muramoto in Matsumoto 1987, p. 116, figs 50–54.

Holotype. The holotype, by original designation, is the specimen in the Warth Collection, now housed in the collections of the Geological Survey of India, the original of Kossmat, 1898, pl. 14(20), fig. 6; pl. 15(21), figs 5a, b, from the Utatur Group of Odium, South India.

Material. One specimen (OUM KU592) from Japaratuba 16, Sergipe Basin, Brazil.

Description. The specimen OUM KU592 (Fig. 4C, D) is a phragmocone 120 mm in diameter, with extensive areas of well-preserved replaced shell. Coiling is moderately involute, with 62% of the previous whorl covered. The umbilicus comprises 28% of the diameter, and is shallow, with a low, flattened umbilical wall, and narrowly rounded umbilical shoulder. The whorl section is slightly depressed, the inner flanks flattened, the outer flanks flattened and convergent, the ventrolateral shoulders and venter broadly rounded. The inner flanks of the penultimate whorl bear narrow, delicate prorsiradiate ribs, five on the adapertural half whorl. The adapical half of the outer whorl bears six narrow, widely separated primary ribs. These arise as mere striae on the umbilical wall, and strengthen progressively across the flanks. They are prorsiradiate, straight on the inner flank, flexing back and feebly convex at mid-flank, concave on the outer flank, sweep forwards over the ventrolateral shoulders, and cross the venter in a broad convexity. There are three to five intercalated ribs between the primaries. These arise as mere prorsiradiate striae on the inner flank, but strengthen on the outer flank, where they are markedly concave, sweeping forwards and crossing the venter in a broad convexity; they are always weaker than the primary ribs. On the adapertural half of the outer whorl, the primary ribs number 10, and become increasingly closely spaced as size increases, the number of intercalated ribs decreasing. At this growth stage, one of the primary ribs has an associated adapical constriction on the ventrolateral shoulders and venter, flanked by a narrow adapical rib.

Occurrence. Lower Turonian of South India, Japan and Sergipe, Brazil.

Superfamily Acanthoceratoidea de Grossouvre, 1894

Family Acanthoceratidae de Grossouvre, 1894

Subfamily Acanthoceratinae de Grossouvre, 1894

Genus *Watinoceras* Warren, 1930

Type species. *Watinoceras reesidei* Warren, 1930, p. 67, pl. 3, fig. 2; pl. 4, figs 9–12, by original designation by Warren 1930, p. 66.

Watinoceras coloradoense (Henderson, 1908)

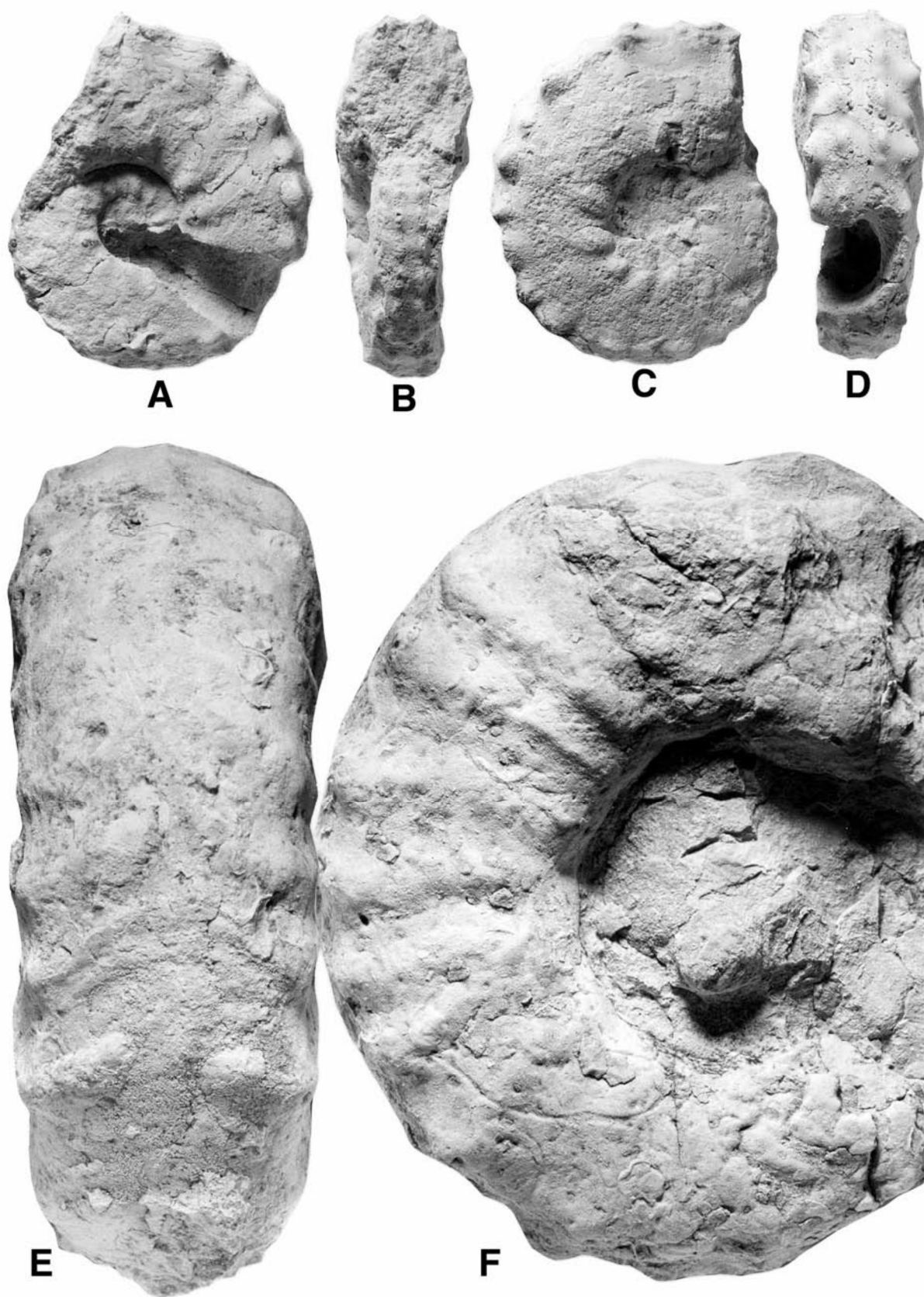


Fig. 5. A–D, *Watinoceras coloradoense* (Henderson, 1908), OUM KU591. Lower Turonian, Japarutuba 16. E, F, *Burroceras transitorium* Cobban, Hook & Kennedy, 1989, OUM KU575, upper Cenomanian, Jardim 1. All figures are x 1.

Fig. 5A–D

- 1908 *Acanthoceras coloradoensis* Henderson, p. 259, pl. 13, figs 10, 11.
1988 *Watinoceras coloradoense* (Henderson) - Cobban, p. 7, pl. 2, figs 1–23; pl. 3, figs 4, 5; text-fig. 4 (with full synonymy).
1994 *Watinoceras coloradoense* (Henderson, 1908) – Chancellor *et al.*, p. 24, pl. 2, figs 2, 3.
1996 *Watinoceras coloradoense* (Henderson, 1908) - Kirkland, p. 83, pl. 33, figs a, c, d.

Holotype. The holotype is USNM 30877, the original of Henderson, 1908, p. 259, pl. 13, figs 10, 11, from the Greenhorn Limestone near Lyons, Colorado, USA.

Material. One specimen (OUMKU591a) from Japarutuba 16, Sergipe Basin, Brazil.

Description. The specimen OUM KU591a (Fig. 5A–D) is a phragmocone 61 mm in diameter. Coiling is moderately involute, with 68% of the previous whorl being covered. The shallow umbilicus comprises 27% of the diameter, with a low, feebly convex wall and more narrowly rounded umbilical shoulder. The whorl section is compressed trapezoidal in intercostal section, with a costal whorl breadth to height ratio of 0.86, the greatest breadth at the umbilical bullae. Ornament on the fragmentary penultimate whorl comprises an estimated eight umbilical bullae per half whorl that give rise to strongly prorsiradiate ribs. There are 13–14 primary ribs on the outer whorl. They arise at the umbilical seam, are strong on the umbilical wall, and develop into crowded blunt bullae, perched on the umbilical shoulder. These give rise to low, broad, strongly prorsiradiate ribs that broaden and weaken at mid-flank. Intercalated ribs arise on the outer flank, and all ribs bear inner ventrolateral clavi, some but not all of those on the intercalated ribs weaker than on the primary ribs. There are 24–26 inner ventrolateral tubercles on the outer whorl, linked by a broad feebly prorsiradiate rib to strong outer ventrolateral clavi, of uniform strength on both primary and intercalated ribs. The venter is markedly concave between the outer ventrolateral clavi. The suture is poorly preserved, with a broad E/L.

Discussion. Ontogeny and variation in *Watinoceras coloradoense* is described by Cobban & Scott (1972) and Cobban (1988). The present specimen shows a tendency to an alternation of strong and weak inner ventrolateral tubercles on primary and intercalated ribs, as is shown by some North American specimens

(see for instance Cobban & Scott 1972, pl. 28, figs 1, 3).

Occurrence. Lower Turonian *Pseudaspidoceras flexuosum* Zone, Bed 97 of the Greenhorn Limestone at Pueblo, Colorado, and correlatives elsewhere in Colorado and western Kansas, USA. Also recorded from western Alberta, British Columbia (Canada), Turkmenistan, and Sergipe, Brazil.

Genus *Pseudovascoceras* Zaborski, 1996

Type species. *Vascoceras nigeriense* Woods, 1911, p. 281, pl. 21, fig. 6; pl. 22, figs 2, 3, by original designation by Zaborski 1996, p. 67.

Pseudovascoceras nigeriense (Woods, 1911)
Fig. 4A, B

- 1911 *Vascoceras nigeriense* Woods, p. 281, pl. 21, fig. 6; pl. 22, figs 2, 3.
1996 *Pseudovascoceras nigeriense* (Woods, 1911) - Zaborski, p. 68, figs 14–24, 36, 37 (with full synonymy).

Type. Lectotype, by the subsequent designation of Berthou, Chancellor & Lauverjat 1985, p. 69, is no. B3237 in the collections of the Sedgwick Museum, Cambridge, from Kunini in northeastern Nigeria. There is a further paralectotype in the same collections.

Material. One specimen (OUM KU593), from Japarutuba 16, Sergipe Basin, Brazil.

Description. The specimen OUM KU593 (Fig. 4A, B) is a 120° sector of body chamber with a maximum preserved whorl height of 50 mm, with parts of the preceding two whorls present. There are traces of replaced shell. Coiling appears to have been evolute, and of moderate depth, with a feebly convex wall and very narrowly rounded umbilical shoulder. The whorl section is depressed, trapezoidal with a whorl breadth to height ratio of 1.57 on the penultimate whorl, and 1.68 on the body chamber. The greatest breadth is at the umbilical bullae/shoulder. The flanks are feebly convex and convergent in intercostal section, with broadly rounded ventrolateral shoulders, and a very broad, feebly convex venter. The penultimate whorl fragment bears three coarse umbilical bullae, but little else of the ornament is visible. On the body chamber fragment, there are traces of two near-effaced umbilical bullae. There is a

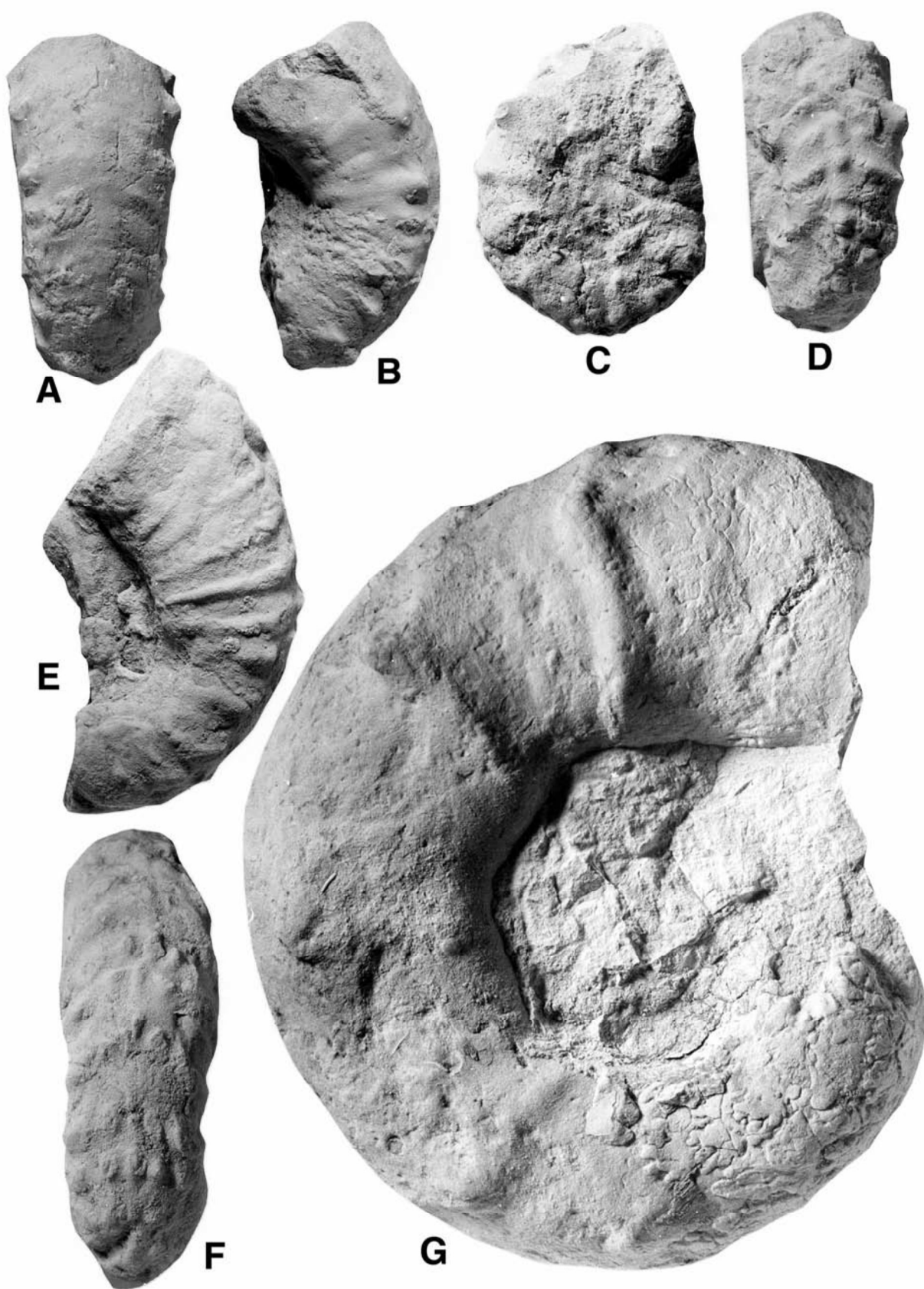


Fig. 6. A, B, *Burroceras transitorium* Cobban, Hook & Kennedy, 1989, OUM KU573. C–F, *Euomphaloceras costatum* Cobban, Hook & Kennedy, 1989; C, D, OUM KU577; E, F, OUM KU576. G, *Pseudaspidoceras pseudonodosoides* (Choffat, 1898), OUM KU587. All specimens are from the upper Cenomanian of Jardim 1. All figures are x 1.

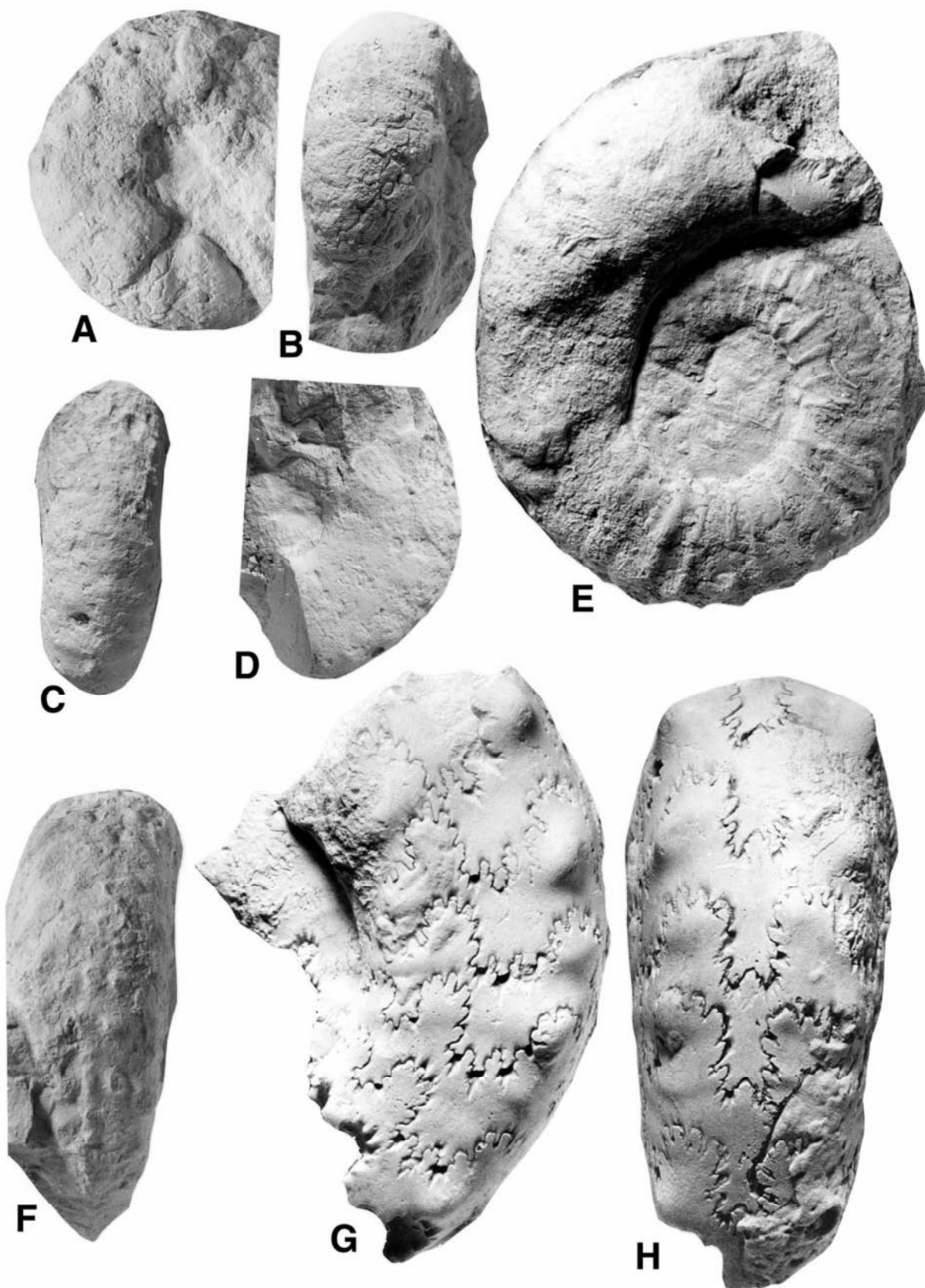


Fig. 7. A–D, *Vascoceras* cf. *gamai* Choffat, 1898; A, B, OUM KU581; C, D, OUM KU580. E, F, *Euomphaloceras costatum* Cobban, Hook & Kennedy, 1989, OUM KU578. G, H, *Pseudaspidoceras flexuosum* Powell, 1963, OUM KU594. A–F are from the upper Cenomanian of Jardim 1; G, H, are from the lower Turonian of Japaratuba 16. All figures are x 1.

strong, pinched ventrolateral clavus at the adapical end of the fragment, succeeded by three rows of progressively weakening ventrolateral bullae (the adapertural one near-effaced). Feeble prorsiradiate ribs link these tubercles to the effaced umbilical bullae, and effaced ribs, growth lines and striae link the tubercles over the venter. Ornament modifies and effaces towards the adapertural end of the fragment, indicating maturity.

Discussion. Zaborski (1996) introduced *Pseudovascoceras*, with *V. nigeriense* Woods, 1911, for the diverse tuberculate 'vascoceratids' from Nigeria, placing a range of 'Nigericeras', 'Vascoceras', 'Paravascoceras' and 'Paramammmites' species described by Schneegans (1943), Reyment (1954a, b, 1955), Barber (1957), Meister (1989), and others in synonymy. The present large fragment corresponds closely to the holotype of 'Paramammmites' *tuberculatus* Barber, 1957, p. 31, pl. 12, fig. 1.

Occurrence. Uppermost Cenomanian, Nigeria; lower Turonian, Sergipe, Brazil.

Subfamily Euomphaloceratinae Cooper, 1978

Genus *Euomphaloceras* Spath, 1923

Type species. *Ammonites euomphalus* Sharpe, 1855, p. 31, pl. 13, fig. 4a–c, by monotypy.

Euomphaloceras costatum Cobban, Hook & Kennedy, 1989
Figs 6C–F, 7E, F

1989 *Euomphaloceras costatum* Cobban, Hook & Kennedy, p. 37, figs. 37, 77s–ee, 78a–h.

Types. The holotype is USNM 419966, the original of Cobban *et al.*, 1989, fig. 77v–x, from the Colorado Formation in the Cookes Range, Luna County, New Mexico. Paratypes are USNM 419967–74, 425244–47.

Material. Three specimens (OUM KU576–578) from Jardim 1, Sergipe Basin, Brazil.

Description. Specimens range from 85 to 95 mm in diameter. OUM KU578 (Fig. 7E, F), preserved to a diameter of 93 mm, has ornament well-preserved to 70 mm diameter. Coiling is very evolute, approaching serpentine, the wide umbilicus comprising 40% of the diameter, the whorls subcircular. There are an

estimated 14 primary ribs per half whorl at a diameter of 70 mm. These arise at the umbilical seam and strengthen across the umbilical wall, developing into a long, narrow bulla on the inner flank. The ribs are narrow, widely separated, straight and prorsiradiate across the flanks, with delicate riblets and striae between. All bear an oblique inner ventrolateral bulla linked by a straight, markedly prorsiradiate rib to an outer ventrolateral clavus. Short ribs intercalate on the ventrolateral shoulder, and bear an outer ventrolateral clavus only. There is a marked siphonal ridge with well-developed siphonal clavi, equal in number to the outer ventrolateral clavi.

Discussion. OUM KU578 has ornament very much like that of the holotype (Cobban *et al.* 1989, pl. 77, figs v–x) and paratype USNM 419967 (loc. cit. pl. 77, fig. AA).

Occurrence. Upper Cenomanian *Neocardioceras juddii* Zone of New Mexico, USA, and southern England; upper Cenomanian of Sergipe, Brazil.

Genus *Burroceras* Cobban, Hook & Kennedy, 1989

Type species. *Burroceras clydense* Cobban, Hook & Kennedy, 1989, p. 38, figs 38; 79d–j, n–t, by original designation.

Burroceras transitorium Cobban, Hook & Kennedy, 1989
Figs 5E, F, 6A, B, 8A, 12C, D

1989 *Burroceras transitorium* Cobban, Hook & Kennedy, p. 39, figs 40, 79a–c, 80d–r.

Types. The holotype is USNM 425258, the original of Cobban, Hook & Kennedy, 1989, fig. 80n–p, from the Colorado Formation in the Little Burro Mountains, Grant County, New Mexico, USA. Paratypes are USNM 425259–66.

Material. Three specimens (OUM KU573, KU575, KU585) from Jardim 1, Sergipe Basin, Brazil.

Description. OUM KU573 (Figs 6A–B, 8A) is a 120° sector of whorl with a maximum preserved whorl height of 28.9 mm. Coiling appears to have been relatively evolute, the umbilicus deep, with a feebly convex outward-inclined wall. The whorl section is as wide as high, with flattened subparallel flanks, and a broad, feebly convex venter. Blunt umbilical bullae give rise to one or two low, broad, straight

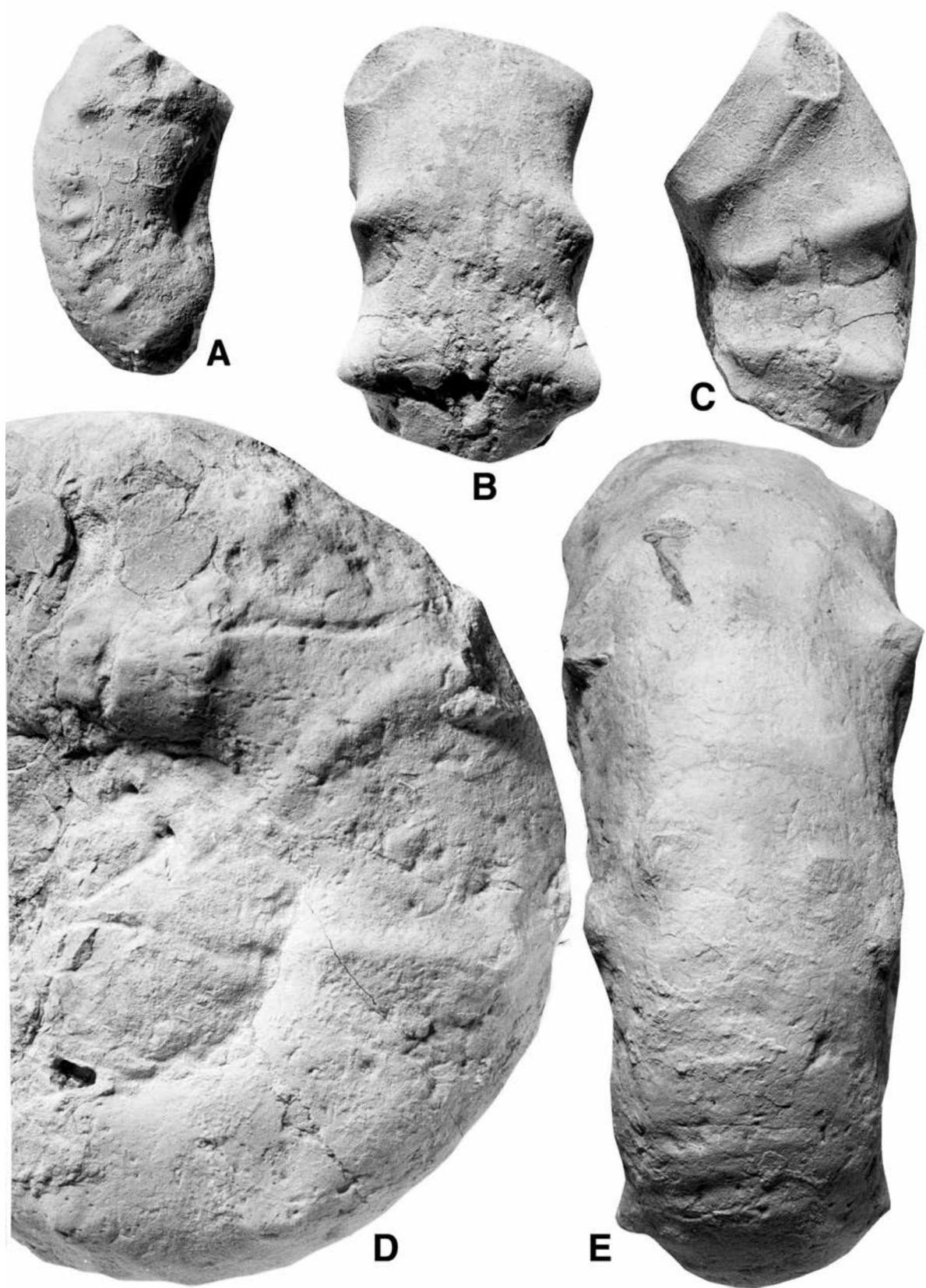


Fig. 8. A, *Burroceras transitorium* Cobban, Hook & Kennedy, 1989, OUM KU573. B–E, *Pseudaspidoceras pseudonodosoides* (Choffat, 1898); B, C, OUM KU589; D, E, OUM KU587. All specimens are from the upper Cenomanian of Jardim 1. All figures are x 1.

primary ribs, which bear inner ventral tubercles which vary from feeble bullae to strong and conical; a few lack tubercles altogether. These tubercles give rise to one or more feeble prorsiradiate ribs that, with additional intercalated ribs, form an obtuse ventral chevron with very feeble oblique outer ventrolateral bullae poorly developed. There is a feeble siphonal ridge, with traces of very feeble tubercles. OUM KU577 (Fig. 6C, D) is interpreted as a coarsely ornamented juvenile of the species. It is 48 mm in diameter, with distant prorsiradiate primary ribs arising from well-developed umbilical bullae. These link to inner ventrolateral tubercles that vary from feeble oblique bullae to strong conical nodes. Strong oblique prorsiradiate ribs link to oblique outer ventrolateral bullae. There are well-developed if irregular siphonal tubercles. OUM KU585 (Fig. 12C, D) is an adult 110 mm in diameter, with 180° of body chamber preserved. Coiling is evolute, eccentric on the adapertural part of the body chamber, where the umbilicus comprises 34% of the diameter, shallow, with a flattened, outward-inclined wall and narrowly rounded umbilical shoulder. The whorl section is compressed (whorl breadth to height ratio 0.84), with flattened, subparallel flanks, broadly rounded ventrolateral shoulders, and a very feebly convex venter. There are 10 umbilical bullae at a diameter of 92 mm. They are of variable strength and give rise to straight to feebly flexuous prorsiradiate ribs that efface on the inner flank, and strengthen on the outer flank. There are occasional long intercalated ribs. All ribs bear weak to strong inner ventrolateral tubercles, conical when strong, and bullate when weak. A broad prorsiradiate rib links to blunt outer ventrolateral clavi with additional nontuberculate ribs between. There is a low siphonal ridge, with traces of obscure siphonal tubercles.

OUM KU575 (Fig. 5E, F) is a somewhat corroded adult 140 mm in diameter, with 240° of body chamber preserved. Ornament is of predominantly primary ribs, which arise either singly or in pairs at the umbilical shoulder. They are narrow, straight, distant, and recti- to feebly rursiradiate. They all bear blunt inner ventrolateral tubercles, linked by a broad, coarsely prorsiradiate rib to a blunt rounded-clavate outer ventrolateral tubercle that gives rise to a weakening prorsiradiate rib that forms an obtuse chevron. Interspaces bear delicate ventral ribs but no tubercles. There is a low siphonal ridge, with numerous irregular blunt clavi and transverse ribs.

Discussion. This variable suite of specimens combine the flat-sided whorl section of *Pseudaspidoceras* with obsolete to strong siphonal tuberculation, as is seen in the equally variable type material of *Burroceras*

transitorium. OUM KU573 finds a match in paratype USNM 425264 (Cobban *et al.* 1989, pl. 80, figs q, r); OUM KU577 in USNM 424259 (Cobban *et al.* 1989, pl. 79, figs. a, b), and OUM KU585 shows similarities to paratype USNM 425255 (Cobban *et al.* 1989, pl. 79, fig. q). OUM KU585, a small adult, may represent the microconch of these species, KU575 may be the macroconch.

Occurrence. Upper Cenomanian *Neocardioceras juddii* Zone in New Mexico, USA; upper Cenomanian of Sergipe, Brazil.

Genus *Pseudaspidoceras* Hyatt, 1903

Type species. *Ammonites footeanus* Stoliczka, 1864, 101, pl. 52, figs 1, 2, by original designation by Hyatt, 1903, 106.

Pseudaspidoceras pseudonodosoides (Choffat, 1898)
Figs 6G, 8B–E

- 1898 *Acanthoceras* (?) *pseudonodosoides* Choffat, p. 65, pl. 16, figs 5–8; pl. 22, figs 32, 33.
- 1989 *Pseudaspidoceras pseudonodosoides* (Choffat) – Cobban *et al.*, p. 40, figs 41, 81–83 (with synonymy).
- 1995 *Pseudaspidoceras pseudonodosoides* (Choffat) – Zaborski, p. 57, figs 2, 5, 8, 14 (with additional synonymy).

Type. The lectotype, by the subsequent designation of Cobban *et al.* 1989, p. 40 is the original of Choffat 1898, p. 65, pl. 16, fig. 5, from Costa d'Arnes, Portugal.

Material. Five specimens (OUM KU582, 586–589) from Jardim 1, Sergipe Basin, Brazil.

Description. OUM KU582, 586 and 589 are incomplete juveniles with whorl heights of up to 40 mm. Coiling is very evolute, with a broad umbilicus of moderate depth, the umbilical wall flattened and outward-inclined. The whorl section is slightly depressed and rectangular in costal section, the flanks and venter broadly rounded in intercostal section. Sparse coarse bullae perch on the umbilical shoulder, and give rise to low, broad, straight prorsiradiate ribs, weakened at mid-flank, but strengthening into a coarse ventrolateral horn, that gives rise to a low, broad, feebly prorsiradiate rib that forms a very obtuse rounded chevron on the venter, with feeble blunt outer ventrolateral clavi on the phragmocone, but these are lost

on OUM KU589 (Fig. 8B, C), a fragment of adapertural phragmocone and adapical body chamber. OUM KU587 (Fig. 6G) is an adult 148 mm in diameter, with 240° of body chamber preserved. The broad umbilicus comprises 37% of the diameter. Phragmocone ornament is poorly preserved. There are four very distant primary ribs on the body chamber. They arise at the umbilical seam, and strengthen into coarse bullae at the adapical end; these bullae efface progressively, and are lost by the adapertural end of the body chamber. The ribs are strong and bar-like, straight and feebly prorsiradiate on the flanks, and linking to strong conical to subspinose inner ventrolateral tubercles. A low, broad, prorsiradiate rib links to a coarse outer ventrolateral tubercle, the opposed outer ventrolateral tubercles linked over the venter by a low, broad rib. Interspaces between the very distant ribs bear irregular low broad riblets, most conspicuous on the venter, where irregular shallow constrictions develop. Larger still is OUM KU588, a body chamber from an individual with an original estimated diameter of 170 mm, and similar ornament.

Discussion. The best-preserved fragment, OUM KU589, has ornament and whorl section close to that of the lectotype (Choffat, 1898, pl. 16, fig. 5), and specimens from New Mexico (Hook & Cobban 1981, pl. 2, figs 9–11). The larger specimens agree well with comparably sized specimens figured by Cobban *et al.* (1989, pl. 83, figs i, j).

Occurrence. Upper Cenomanian *Neocardioceras juddii* Zone and correlatives, Portugal, Tunisia, Israel; Arizona, New Mexico and Trans-Pecos, USA; upper Cenomanian, Sergipe, Brazil.

Pseudaspidoceras flexuosum Powell, 1963
Fig. 7G, H

- 1963 *Pseudaspidoceras flexuosum* Powell, p. 318, pl. 32, figs 1, 9, 10; text-figs 2a-c, f, g.
1995 *Pseudaspidoceras flexuosum* Powell, 1963 - Zaboriski, p. 63, figs 11-13, 17, 18, 20, 21 (with full synonymy).

Holotype. The holotype is TMM 30842, the original of Powell, 1963, pl. 32, figs 1, 9, from the Ojinaga Formation of Calvert Canyon, Hudspeth County, Texas, USA.

Material. One specimen (OUM KU594) from Japarutuba 16, Sergipe Basin, Brazil.

Description. The specimen OUM KU594 (Fig. 7G, H)

is a well-preserved 120° sector of two successive whorls; the maximum preserved whorl height is 47 mm. Coiling appears to have been evolute, the umbilicus of moderate depth, with a feebly convex, outward-inclined wall. The costal whorl section is slightly depressed, with a whorl breadth to height ratio of 1.16, the greatest breadth at the umbilical bullae. The umbilical shoulder is broadly rounded, the flanks flattened and convergent, the venter broad, and feebly convex intercostally. The inner flank region of the penultimate whorl bears delicate flexuous ribs of variable strength, and convex on the surviving mid-flank region. The outer whorl has six bullae of very variable strength perched on the umbilical shoulder. These give rise to one or more low, flexuous prorsiradiate ribs. Four strong conical inner ventrolateral tubercles are present on the fragment. At the adapical end, successive tubercles are separated by two feeble ribs, one of which bears a feeble ventrolateral bulla. The succeeding pair are separated by a single rib with a well developed bulla. Variably developed inner ventrolateral clavi are associated with some but not all of the much stronger outer ventrolateral tubercles. The well-preserved suture line comprises a narrow E, broader E/L, L broader and E/L, and narrower L/U₂, with all elements only moderately incised.

Discussion. This fragment, with feebly flexuous ribbing resembles both topotype material, and the paralectotype of *Kamerunoceras (Ampakabites) auriculatum* Collignon, 1965 (a synonym), as illustrated by Kennedy *et al.* (1987), although lacking the convex rib linking outer ventrolateral tubercles shown by some specimens, including the holotype (Powell, 1963, pl. 32, figs 1, 9).

Occurrence. Lower Turonian *Pseudaspidoceras flexuosum* Zone and correlatives, Colorado, New Mexico and Texas in the United States, northern Mexico, Tunisia, Nigeria and Madagascar; lower Turonian of Sergipe, Brazil.

Family Vascoceratidae H. Douvillé, 1912

Genus *Vascoceras* Choffat, 1898

Type species. *Vascoceras gamai* Choffat, 1898, p. 54, pl. 7, figs 1-4; pl. 8, fig. 1; pl. 10, fig. 2; pl. 21, figs 1-5.

Vascoceras cf. gamai Choffat, 1898

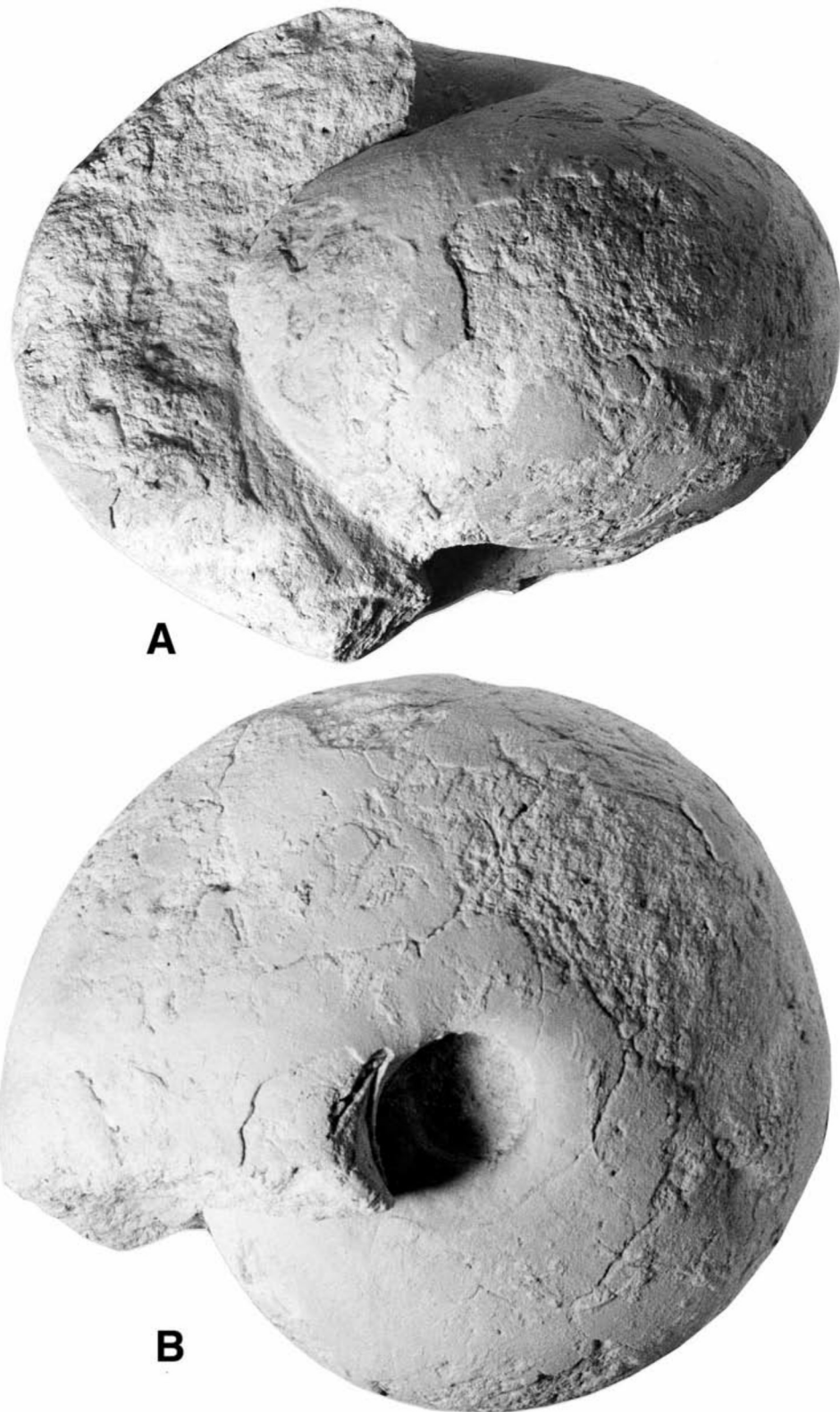


Fig. 9. *Vascoceras globosum globosum* Reyment, 1954, OUM KU605. Lower Turonian, Japarutuba 16. Figures are $\times 1$.

Fig. 7A–D

1989 *Vascoceras* cf. *gamai* Choffat – Cobban *et al.*, p. 45, figs 44, 87w–aa, ee–rr.

Material. Two specimens (OUM KU580, KU581) from Jardim 1, Sergipe Basin, Brazil.

Description and Discussion. OUM KU580 (Fig. 7C, D) is a corroded half whorl of a specimen with an original estimated diameter of 53 mm. The small umbilicus comprises an estimated 25% of the diameter, and is shallow, with a flattened wall and narrowly rounded umbilical shoulder. The whorl section is compressed, with a whorl breadth to height ratio of 0.7–0.8, the flanks feebly convex, subparallel, the ventrolateral shoulders and venter broadly and evenly rounded. Prorsiradiate ribs are weak on the flanks, but strengthen on the ventrolateral shoulders and venter, where additional ribs intercalate to give an ornament of low, blunt, feebly prorsiradiate ribs that strengthen over the venter, which they cross in a very feeble convexity. This specimen closely resembles the feebly ornamented variants of *Vascoceras* cf. *gamai* of Cobban *et al.* (1989, fig. 87ee, ff, oo, pp). OUM KU581 (Fig. 7A, B) is 49 mm in diameter, the umbilicus comprising an estimated 25–29% of the diameter. Four coarse bullae perch on the umbilical shoulder of the adapertural half whorl of the specimen, and give rise to one or two coarse prorsiradiate primary ribs, while additional ribs intercalate on the outer flank, to give ventrolateral shoulders and venter ornamented by blunt, even ribs. This specimen corresponds to the coarsely ornamented variant of *Vascoceras* cf. *gamai* described by Cobban *et al.* (1989, fig. 87ii–kk, qq–rr).

Occurrence. *Vascoceras* cf. *gamai* occurs in the upper Cenomanian zones of *Burroceras clydense* and *Neocardioceras juddii* in New Mexico (Cobban *et al.* 1989); the present specimens are from the upper Cenomanian of Jardim 1, Sergipe Basin, Brazil. *V. gamai* ranges from the upper Cenomanian *Metoicoceras geslinianum* Zone to the *Neocardioceras juddii* Zone according to Callapez Tonicher (1998). The geographic range of *V. gamai* is Portugal, Spain, Morocco, Algeria and Egypt, according to Berthou *et al.* (1985), who also note that records from France, Yugoslavia, and Madagascar are based on mis-identification.

Vascoceras globosum globosum (Reyment, 1954)
Fig. 9
1954a *Pachyvascoceras globosum* Reyment, p. 259, pl.

3, fig. 3; pl. 5, fig. 4; text-figs 3e, 7.
1996 *Vascoceras globosum globosum* (Reyment, 1954b) – Zaborski, p. 79, figs 51, 52 (with full synonymy).

Holotype. The holotype is BMNH C47408, the original of Reyment, 1954a, pl. 3, fig. 3; pl. 5, fig. 4; text-figs 3e, 7) from Gombe, Nigeria.

Material. One specimen (OUM KU605) from Japaratu-ba 16, Sergipe Basin, Brazil.

Dimensions.

	<i>D</i>	<i>Wb</i>	<i>Wh</i>	<i>Wb:Wh</i>	<i>U</i>
OUM KU605	124(100)	92(0.74)	66(53)	1.39	23.5(18.9)

Description. The specimen OUM KU605 (Fig. 9) is a well-preserved individual 124 mm in diameter, with extensive areas of replaced shell preserved. It is part body chamber, but the position of the last septum cannot be determined. Coiling is very involute, with 76% of the previous whorl covered. The umbilicus is small (18.9% of the diameter), very deep, with a flattened, inwards-inclined wall, and relatively narrowly rounded umbilical shoulder. The whorl section is very depressed, reniform, with a whorl breadth to height ratio of 1.39. Where the surface of the replaced shell is preserved, there is a very subdued ornament of growth lines and striae, concave and prorsiradiate on umbilical shoulder and inner flank, sweeping forwards on the outer flank and ventrolateral shoulder, and crossing the venter in a broad convexity.

Discussion. The specific name *Vascoceras harttii* was introduced for depressed cadicone ammonites from the Sergipe-Alagoas Basin by Hyatt (1870), first illustrated by White (1887, pl. 19, figs 1, 2) (see Chancellor 1982; Howarth, 1985; Zaborski 1996). It remains uncertain as to which of the other smooth cadicone *Vascoceras* described are specifically distinct. The present specimen is referred to *V. globosum globosum* on the basis of its smaller umbilicus (18.9% of diameter versus 37% in White's figure, 28–29% in specimens described by Howarth (1985, p. 100)), and a rounded, undercut umbilical wall, rather than flat and outward-inclined.

Occurrence. Uppermost Cenomanian of Nigeria; lower Turonian of Sergipe, Brazil. Closely related forms (*V. harttii* Hyatt, 1870; *V. durandi* (Thomas & Peron in Peron 1889) (see Chancellor *et al.* 1994, p. 48) range into the lower Turonian.

Vascoceras simplex (Barber, 1957)

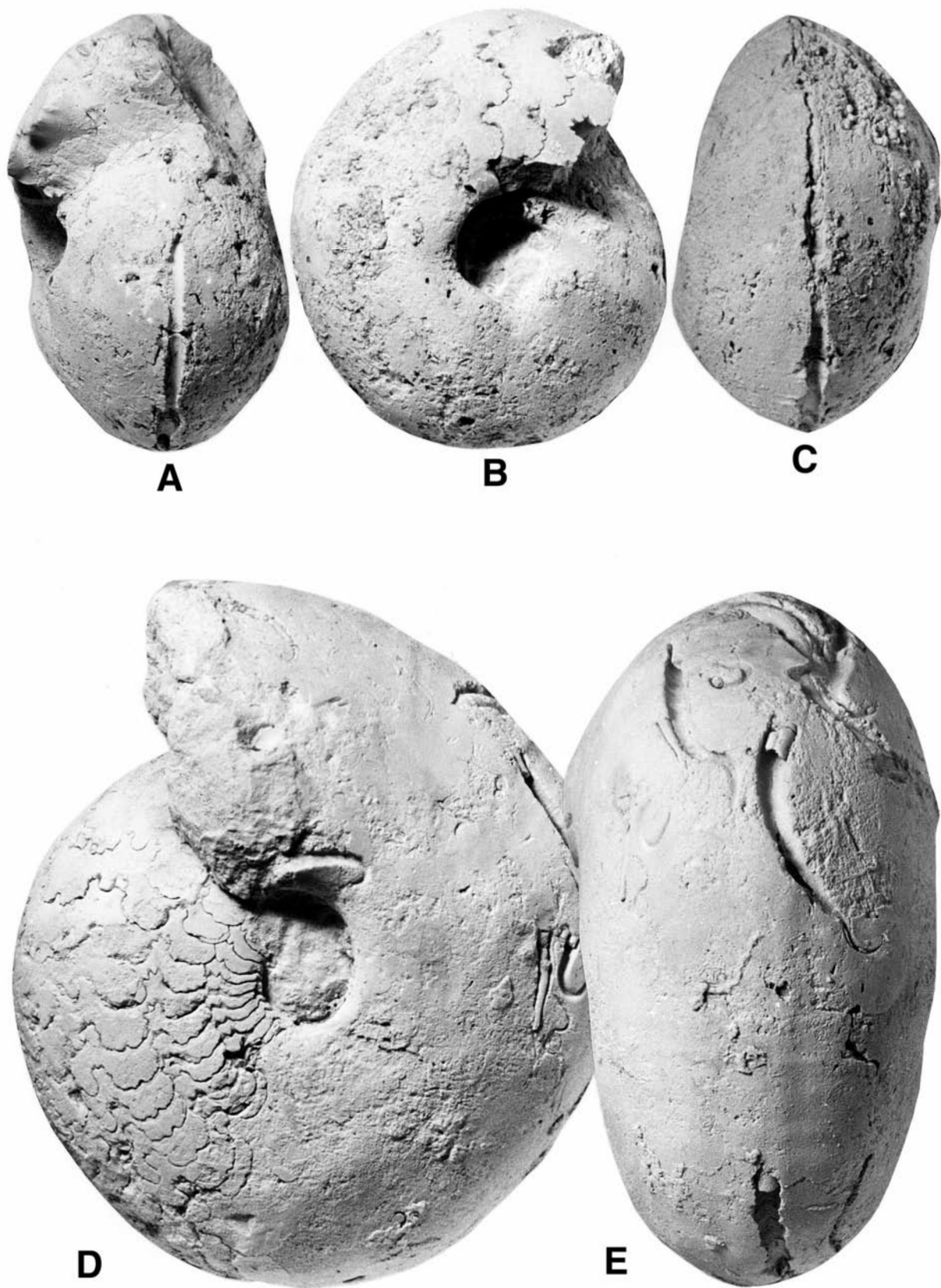


Fig. 10. A–C, *Vascoceras simplex* (Barber, 1957). OUM KU590. D, E, *Pseudotissotia nigeriensis* (Woods, 1911), OUM KU597. Both specimens are from the lower Turonian of Japaratuba 16. All figures are x 1.

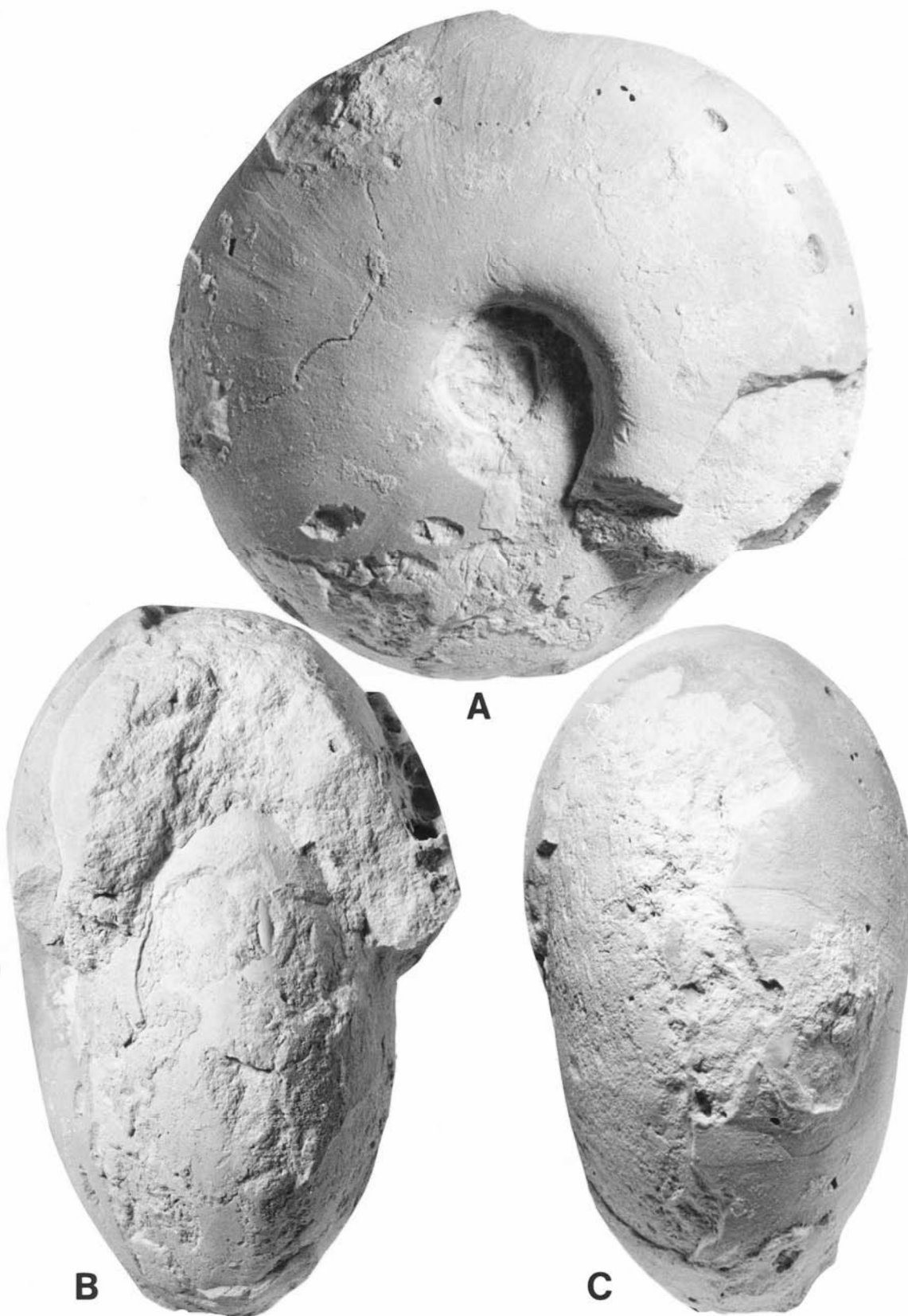


Fig. 11. A–C, *Vascoceras simplex* (Barber, 1957), OUM KU596. Lower Turonian, Japaratuba 16. All figures are x 1.

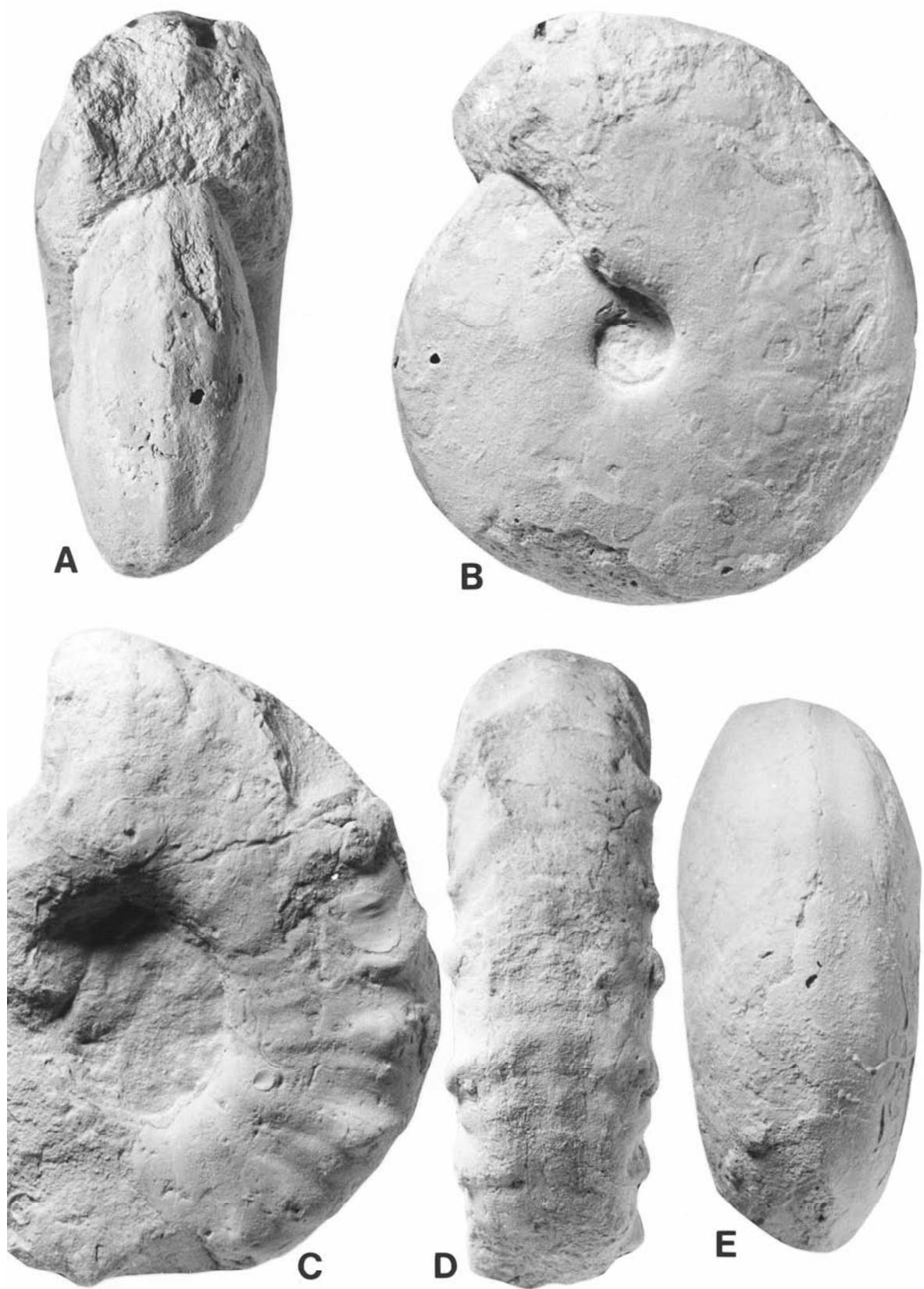


Fig. 12. A, B, E, *Pseudotissotia nigeriensis* (Woods, 1911), OUM KU601. C, D, *Burroceras transitorium* Cobban, Hook & Kennedy, 1989, OUM KU585. A, B, E is from the lower Turonian of Japarutuba 16. C, D, is from the upper Cenomanian of Jardim 1. All figures are $\times 1$.

Figs 10A-C, 11, 13C, D

1957 *Fagesia simplex* Barber, p. 27, pl. 8, fig. 1; pl. 29, figs 4, 5.

1994 *Fagesia simplex* Barber – Chancellor *et al.*, p. 60.

Material. Three specimens (OUM KU590, 596, 599) from Japarutuba 16, Sergipe Basin, Brazil.

Holotype. The holotype is BMNH C47621, from Pindiga, Nigeria, the original of Barber, 1957, pl. 8, fig. 1; pl. 29, figs 4, 5.

Dimensions.

	D	Wb
Wh	Wb:Wh	U
OUM KU590	78.2 (100)	- (-)
35.4 (45.3)	-	19.2 (24.6)
at	68.6 (100)	46.2 (67.3)
34.9 (50.9)	1.32	16.6 (24.2)
OUM KU599	110.9 (100)	61.3 (55.3)
45.5 (41.0)	1.35	26.8 (24.1)
OUM KU596	120.2 (100)	72.3 (60.3)
53.9 (44.8)	1.34	24.0 (20.0)

Description. OUM KU590 (Fig. 10A-C) is a phragmocone 78.2 mm in diameter. Coiling is involute, with 80% of the previous whorl covered, the umbilicus deep, with a flattened, undercut wall and narrowly rounded umbilical shoulder. The whorl section is depressed, with a whorl breadth to height ratio of 1.32. The flanks are feebly convex, and converge to a fastigiate venter. Four coarse blunt bullae perch on the umbilical shoulder; there are no ribs. Suture imperfectly preserved, with broad, little-incised lobes and saddles.

OUM KU599 (Fig. 13C, D) is a larger individual, 111 mm in diameter, with coarse umbilical bullae on the penultimate whorl, that are lost on the outer whorl. There is a marked siphonal ridge on the septate part of the outer whorl, marking the position of, and partially housing the siphuncle. There are traces of irregular ribs on ventrolateral shoulders and venter of the body chamber at the largest preserved diameter. OUM KU596 (Fig. 11) is 120 mm in diameter, with a 240° sector of adult body chamber pre-

served. A siphonal ridge is flanked by shallow grooves, producing a feebly expressed bisulcate-tricarinate appearance to the venter. Replaced shell is well-preserved. The flanks are ornamented by crowded growth lirae and striae, which strengthen into feeble irregular ridges and folds on ventrolateral shoulders and venter. The sutures are imperfectly preserved on OUM KU590 and 596, and have broad, little-incised lobes and saddles.

OUM KU590 differs in no significant respects from the holotype, the other specimens allow description of the adult stage, where umbilical tuberculation is lost. The simple suture suggests *Vascoceras* rather than *Fagesia*, as indicated by Chancellor *et al.* (1999, p. 62).

Occurrence. Barber (1957) did not give the age of the holotype. The present specimens are from the lower Turonian of Sergipe, Brazil.

Family Pseudotissotiidae Hyatt, 1903

Genus *Pseudotissotia* Peron, 1897

Type species. *Ammonites galliennei* d'Orbigny, 1850, p. 190, by the subsequent designation of Pervinquière 1907, p. 349.

Pseudotissotia nigeriensis (Woods, 1911)

Figs 10D-E, 12A-B, E, 13A-B

1911 *Hoplitoides nigeriensis* Woods, p. 284, pl. 23, fig. 3; pl. 24, figs 15; text-fig. 1.

1983 *Pseudotissotia nigeriensis* (Woods, 1911) - Hirano, p. 46, pl. 1, figs 1-10; pl. 2, figs 1-10; pl. 3, figs 1-18; pl. 4, figs 1-6 (with synonymy).

1996 *Pseudotissotia nigeriensis* (Woods, 1911) - Amédéo, p. 217, figs 19-22 (with additional synonymy).

Type. Reyment (1954b, p. 158) referred to the original of Wood's (1911), p. 23, fig. 3; pl. 24, figs 1, 4), as the holotype, and to the original of Woods' pl. 24,

Dimensions.

	D	Wb	Wh	Wb:Wh	U
OUM KU602	99.6 (100)	53.4 (53.6)	49.9 (50.1)	1.01	15.3 (15.4)
OUM KU601	103.1 (100)	45.8 (44.4)	49.6 (48.1)	0.92	16.5 (16.0)
OUM KU600	109.9 (100)	50.1 (45.6)	52.1 (47.4)	0.96	14.7 (13.4)
OUM KU597	124.8 (100)	64.7 (51.8)	57.5 (46.1)	1.13	23.6 (19.0)
OUM KU595	146.6 (100)	71.3 (48.6)	70.8 (48.3)	1.01	26.6 (18.1)

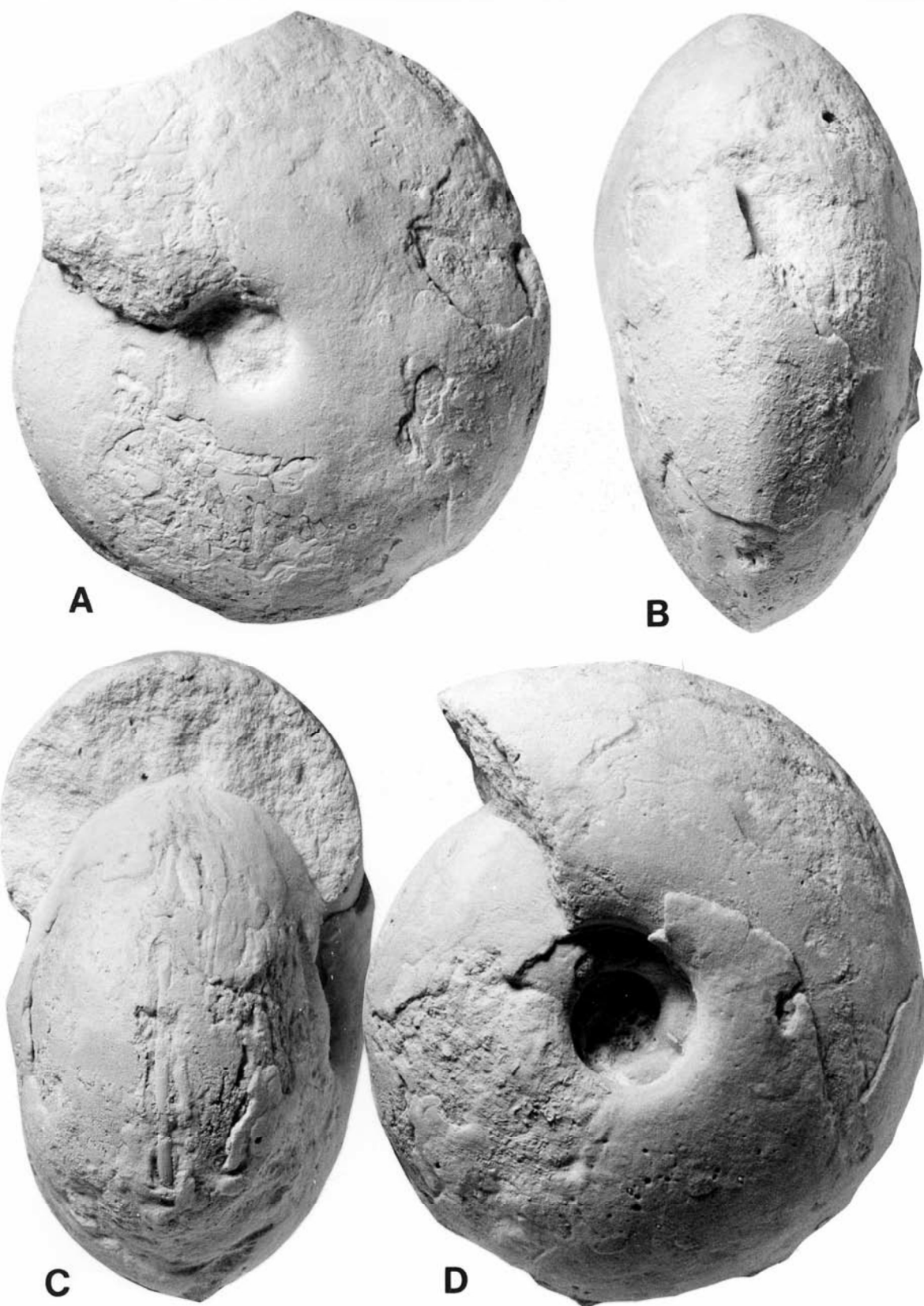


Fig. 13. A, B, *Pseudotissotia nigeriensis* (Woods, 1911), OUM KU602. C, D, *Vascoceras simplex* (Barber, 1957), OUM KU599. Both specimens are from the lower Turonian of Japaratuba 16.

figs 2, 3, 5 as paratype. Woods' pl. 23, fig. 3 and pl. 24, fig. 4 represent the same specimen, but his pl. 23, fig. 4 is a second specimen. Accordingly no. B3249 in the collections of the Sedgwick Museum Cambridge is here designated lectotype of the species; it is the original of Wood's (1911, pl. 23, fig. 3; pl. 24, fig. 1; text-fig. 1g.) and is from Gongila, Nigeria.

Material. Eight specimens (OUM KU595, 597, 598, 600–604) from Japaratuba 16, Sergipe Basin, Brazil.

Description. Eight specimens are referred to the species: OUM KU595, 597, 598, 600–604. Specimens vary from 99–147 mm in diameter, many retaining replaced shell, and all have part or all of the body chamber preserved, which extends to up to 240°. Coiling is involute, with up to 80% of the previous whorl covered. The most compressed specimen is OUM KU603, with a whorl breadth to height ratio of 0.8. The inner flanks are very broadly convex, the outer flanks converging to the narrow venter. There is no flank ornament. The venter bears two shallow grooves, producing a bisulcate-tricarinate appearance. The lateral keels that define the ventrolateral shoulder are lower than the central keel, producing a distinctive fastigate appearance. All of the keels are blunt, and rounded. With increasing inflation, the whorl breadth to height ratio increases to up to 1.13 (in OUM KU597: Fig. 10D, E), the flanks becoming broadly rounded, converging to a bluntly fastigate rounded venter on the phragmocone, with siphonal keel coarse, and higher than the lateral ones. The venter rounds on the adult body chamber and the lateral keels efface. These may be ornamented by low, weak, irregular ribs and folds on outer flank and venter. OUM KU602 (Fig. 13A, B) is a particularly distinctive individual, with trigonal whorl section. The suture is well-exposed in OUM KU597 (Fig. 10D), E/L is broad and little-incised; L is smaller and bifid, with a prominent median element; L/U₂ is broad and plump with minor incisions. The saddles close to the umbilicus are near-entire.

Discussion. This variable assemblage is characterised by the complete absence of tubercles on the ventrolateral keels, and lack of flank ornament on the outer whorl, while the fastigate venter, with siphonal keel higher than the lateral, is distinctive. The range of whorl section corresponds to that shown by the Pindiga assemblage described by Barber (1957) and Hirano (1983), but whereas the siphonal keel is higher than the lateral ones in all of the Brazilian material, the three keels are of the same relative height in some compressed individuals in the Nigerian assemblage. The present material lacks any trace of tuber-

culution on the keels, a feature of a few Nigerian examples of similar size to our smallest specimens.

Occurrence. Lower Turonian of Nigeria, southern Algeria, Israel, and northern Mexico. The present specimens are from the lower Turonian of Sergipe, Brazil.

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