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Most post-Paleozoic crinoids were benthic as adults and, thus, have always been considered rather poor stratigraphic indicators. Nevertheless, when standard macro- and microfossil data are lacking (zonal-index markers such as ammonoids, belemnites, brachiopods, echinoids, rudist bivalves, or inoceramids) or simply ineffective (long-range or facies-dependent groups like some vertebrates, bivalves, benthic large agglutinated, or small hyaline calcareous foraminifers), crinoids have been successfully used in local and regional correlations. For instance, in the Middle Triassic, five crinoid biozones (*Dadocrinus*, *Holocrinus acutangulus*, *H. dubius*, *Silesiacrinus*, and *Encrinus liliiformis*) are distinguished from the well-recognized stratigraphic ranges of these Middle Triassic (Anisian) crinoids in the Polish sector of the Germanic Basin (HAGDORN & GŁUCHOWSKI, 1993; HAGDORN, 1999) (Fig. 1). Somewhat earlier, HILDEBRANDT (1926), PIA (1930), and KOZUR (1974) also used *Dadocrinus* to correlate the central and eastern parts of the Germanic Basin to the Alpine area. The stratigraphic scheme proposed by HAGDORN and GŁUCHOWSKI (1993) has also been successfully used in Hungary, the Mecsek Mountains and the Balaton Highland (HAGDORN, KONRÁD, & TÖRÖK, 1997, HAGDORN & VELLEDITS, 2006); in southern Poland, the Tatra Mountains (NIEDŹWIEDZKI & SALAMON, 2006); in other areas of the Germanic Basin, such as the margin of the Holy Cross Mountains, southern Poland (see SALAMON, 2003; SALAMON & NIEDŹWIEDZKI, 2005); and in the North Sudetic Basin, Poland (see SALAMON, NIEDŹWIEDZKI, & WALTER, 2003; GŁUCHOWSKI & SALAMON, 2005). HAGDORN (1995) had hoped to frame a biozonal scheme based on crinoids for the greater part of the Triassic in Asia and for the Lower and Upper Triassic of the Alps, where index fossils are rare. Indeed, as stressed by SALAMON and NIEDŹWIEDZKI (2005), the degree of endemism of Triassic stalked crinoids is much lower than that of any other benthic macrofauna.

Stalkless roveacrinids are also of value in Triassic biostratigraphy. KRISTAN-TOLLMANN (1970, 1977, 1988a, 1990), MOSTLER (1972), and DONOFRIO and MOSTLER (1975) documented several roveacrinid species displaying short stratigraphic ranges. Additionally, HAGDORN (1995) stressed that these pelagic crinoids were widespread and abundant in the Upper Triassic all over the Tethys realm and can be potential candidates for index fossils. Nevertheless, most of the Triassic roveacrinids described by KRISTAN-TOLLMANN (e.g., 1980, 1988a, 1988b, 1990) are represented by dissociated ossicles that were retrieved from washing residues of claystones or acid-etched limestones; some of them possess bizarre morphology and are of uncertain systematic affinities.

In contrast, the use of crinoids in the biostratigraphy of Jurassic deposits is more complicated. Although there are some species with narrow stratigraphic ranges (mainly belonging to Millericrinida), they display a high degree of endemism. For instance, *Ailsacrinus* TAYLOR, 1983 has only been reported from the Bathonian of

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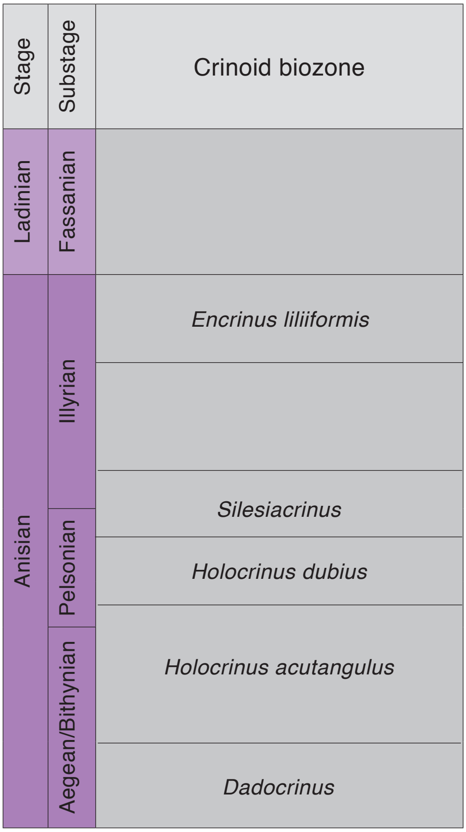

FIG. 1. Middle Triassic crinoid biozones (adapted from HAGDORN, 1999, fig. 178; note that the upper limit of the *Encrinus liliiformis* LAMARCK, 1801 zone is uncertain; for instance, according to SALAMON & NIEDŹWIEDZKI [2005], *E. liliiformis* occurs also in the Ladinian of the Holy Cross Mountains of Poland).

southwestern England (TAYLOR, 1983; SIMMS, 1999). It should be emphasized that the occurrence of complete specimens of millericrinids, allowing precise taxonomic assignations, are rare. These crinoids are preserved mostly as isolated, non-diagnostic, columnals. The same applies to balanocrinids (Balanocrinidae; Isocrinida). Balanocrinid isolated columnals are abundant in Jurassic deposits, but complete or nearly complete specimens are mostly known from the Early Jurassic of the UK (SIMMS, 1989). The descriptions of many Middle to Late Jurassic balanocrinid species are based solely on isolated stalk remains.

Although the parataxonomy of columnals confuses the issue of their genuine biological affinity, columnal taxa may be relevant for stratigraphic purposes. BROADHEAD (1980) stressed that it is important to avoid incorporating possible homeomorphic forms in erecting crinoid-based biostratigraphic schemes and to establish them based on a high level of confidence in recognition of both complete specimens and disarticulated ossicles. Actually, *Balanocrinus berchteni* HESS & PUGIN, 1983; *B. gillieroni* (DE LORIOL, 1879); *B. hessi* SALAMON & ZATOŃ, 2006; *B. pentagonalis* (GOLDFUSS 1833); and many others described from the Jurassic of central Europe, are indeed very similar to *B. subteres* (MÜNSTER in GOLDFUSS, 1831) or *B. brachiospina* HESS, 2014a (compare, for example, GŁUCHOWSKI, 1987; KLIKUSHIN, 1992; SALAMON & ZATOŃ, 2007; SALAMON, 2008a, 2008b, 2008c; ZATOŃ, SALAMON, & KAŹMIERCZAK, 2008; HESS, 2014a, 2014b). Although HESS (2014a, 2014b) indicated that it is possible to distinguish balanocrinid species based on columnals only, it is applicable to only a few species. KLIKUSHIN (1992) highlighted the uselessness of Jurassic–Cretaceous isocrinids for biostratigraphy, considering that some isocrinid species occur diachronously in Russia and former Soviet republics. RASMUSSEN (1961) mentioned that due to the fact that arm articulations remain unknown in many isocrinid species, their biological taxonomic assignations are uncertain, thus hampering their use in biostratigraphy. However, this did not preclude these authors from presenting a biostratigraphic scheme for the UK, based on the Isocrinidae, with *Isocrinus annulatus* (ROEMER, 1836) as the oldest Early Cretaceous species and *Isselicrinus buchii* (ROEMER, 1840 as the youngest Late Cretaceous (Maastrichtian) one. Nevertheless, this scheme is not applicable to other regions because the species involved in this scheme either display strong endemism or have different stratigraphic ranges in other parts of Europe or Asia (compare KLIKUSHIN, 1992, and literature cited therein).

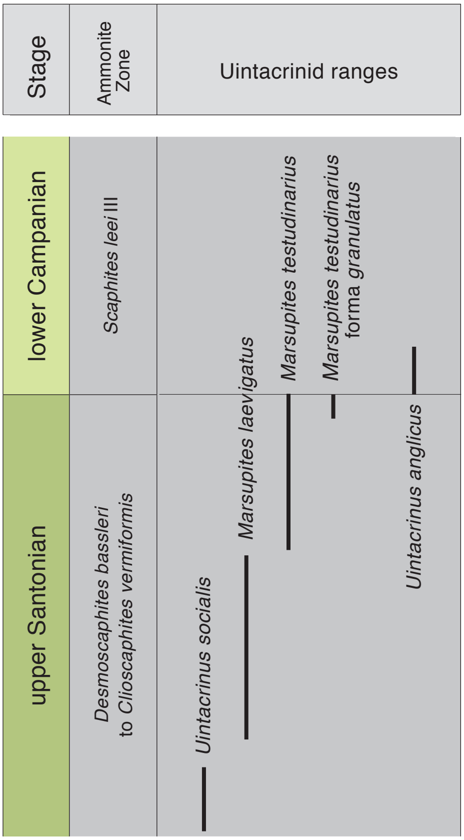

FIG. 2. Santonian–Campanian uintacrinoid crinoids ranges (adapted from GALE & others, 2008, fig. 12; ammonite zonation adapted from OGG, OGG, & GRADSTEIN, 2016, fig. 13,*4*).

Thiolliericrinids are potentially promising for local biostratigraphy of the Jurassic (Oxfordian)–Cretaceous (Hauterivian) sedimentary rocks. These crinoids, represented by several recognizable species, have been described from many regions, such as Czech Republic, France, Germany, Portugal, Switzerland, and Crimea, and display narrow stratigraphic ranges (e.g., ÉTALLON, 1859; DE LORIOL, 1891; JAEKEL, 1918; RASMUSSEN, 1961; KLIKUSHIN, 1987; HESS & SPICHIGER, 2001).

As for Cretaceous uintacrinoids (Uintacrinoidea), they are among the best-known crinoids widely used for biostratigraphic purposes. These epibenthic crinoids (GORZELAK & others, 2017), likely with a long-term planktonic larval stage, have widespread distribution during a short time interval. Their usefulness in correlations has been highlighted by many researchers (RASMUSSEN, 1961; MILSOM, SIMS, & GALE, 1994; MITCHELL, 1995, 2009, 2018; HANCOCK & GALE, 1996; JAGT, 1999; GALE & others, 2008). Around the Santonian/Campanian boundary, five successive uintacrinoid species or subspecies can be recognized (GALE & others, 2008) (Fig. 2). According to these latter authors, each of them was short-lived with a mean duration of ~200 kyr. The oldest uintacrinoid species, *Uintacrinus socialis* GRINNELL, 1876 is recorded in the lower upper Santonian. A somewhat younger, late Santonian species is *Marsupites laevigatus* FORBES, 1850, with a smooth external surface to the calyx and arms, and displaying a semicircular, cryptosyzygial radial facet. The latest late Santonian species is *Marsupites testudinarius* (VON SCHLOTHEIM, 1820). This species, with near-global distribution (e.g., RASMUSSEN, 1961, 1978; GALE & others, 1995, and literature cited therein; ŁUKOWIAK & GORZELAK, 2006; HAGGART & GRAHAM, 2018) possesses a basal/radial articulation lacking large, central crypto-syzygial articulations. Noticeably, the extinction level of this species occurs synchronously on a global scale and is widely considered as the boundary marker for the base of the Campanian stage. In some regions (Kazakhstan, Australia, UK, France, and USA), additional latest Santonian subspecies can be distinguished, such as *M. testudinarius* forma *granulatus* GALE, 2008 in GALE & others, 2008. This species displays sculpture on the radials in the form of fine, commonly sparse granulation. The youngest uintacrinoid species is the earliest Campanian *Uintacrinus anglicus* RASMUSSEN, 1961 recorded in Australia, Europe (mostly England), and North America (USA) (MITCHELL, 1995; GALE & others, 2008). It is characterized by corrugated outer surfaces on the basals, radials, and proximal brachials (for more details see RASMUSSEN, 1961). It should be noted that HANCOCK (1989, p. 571, fig. 7) considered *U. socialis* a middle Santonian

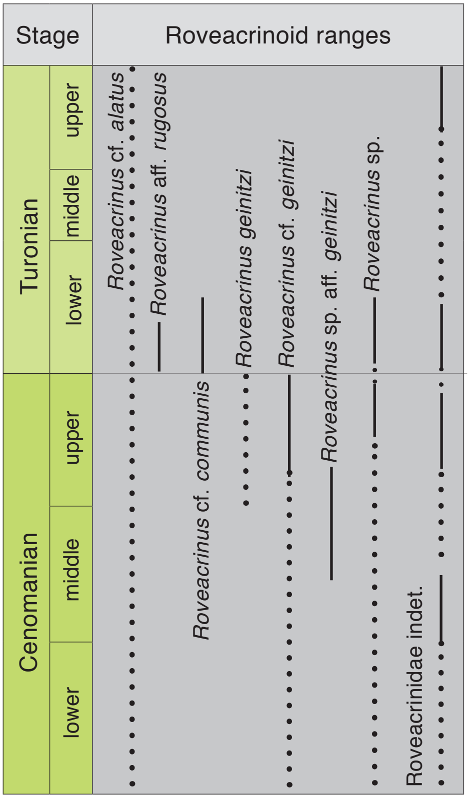

Fig. 3. Cenomanian–Turonian roveacrinoid ranges in the Sergipe Basin (Brazil), solid line denotes taxon documented within the shown range, dotted line indicates taxon documented before and after the considered time range but without grounded evidence within (adapted from Ferré, Berthou, & Bengtson, 1996, fig. 2).

species; his opinion is not shared by other biostratigraphers. Likewise, *M. testudinarius* was mentioned from the Campanian of Madagascar by Besairie (1936). However, Milsom, Simms, and Gale (1994) concluded that this occurrence appears to be improbable with regard to its late Santonian age elsewhere.

During the Cretaceous, another group of benthic crinoids, bourgueticrinids (Bourgueticrinidae), were common. Wright and Smith (1987) stressed that bourgueticrinids from the white chalk facies of southern England could be used as zonal indicators. Nevertheless, these crinoids have a rather limited value in biostratigraphy at the supra-regional scale due to their patchy distributions, relatively long ranges, and difficulties in classification (e.g., Jagt & Odin, 2001; Jagt & Salamon, 2007, table 1). For instance, Maastrichtian and early Paleogene species such as *Bourgueticrinus bruennichinielseni* Jessen & Ødum, 1923; *B. constrictus* (von Hagenown in Quenstedt,1876); *B. danicus* Nielsen, 1913; *Democrinus dubius* (Nielsen, 1915); *D. maximus* (Nielsen, 1915); and *D. gisleni* Rasmussen 1961 are difficult to distinguish from each other. Indeed, Kjaer and Thomsen (1999) stated that *B. bruennichinielseni*, *D. gisleni*, and *D. dubius* may represent juvenile representatives of *B. constrictus* and *B. danicus* and pointed out that the taxonomic status of *B. constrictus*, *B. danicus*, and *D. maximus* is far from unequivocal. *Dunnicrinus* Moore, 1967 is among the few, if not the only bourgueticrinid genus, occurring on both sides of the Atlantic Ocean during only the Maastrichtian, and it may be used in correlation of these deposits (Jagt & others, 1998; Jagt, 1999).

In our present understanding, pelagic roveacrinids (Roveacrinida) seem to be the most promising group to be used in the biostratigraphy of Cretaceous strata. Although formal supra-regional biostratigraphic schemes are not available yet, some local biozonations have been proposed, for example for the Sergipe Basin (Brazil) (Ferré & others, 1996) and southern England (Gale, 2016, 2018). Moreover, Gale (2018) added that some changes in the roveacrinid faunas, especially through the lower Campanian, are evolutionary transitions and, therefore, represent fundamental morphological shifts that have considerable potential even for interregional correlation (e.g., transitions between *Costatocrinus laevis* Gale, 2018 and *C. brydonei* Gale, 2018; and *Stellacrinus hughesae* forma *cristatus* Gale, 2018 and *S. hughesae* forma *hughesae* Gale, 2018). For further transition details see Gale, 2018, p. 315, 317, plus fig. 17) (Fig. 3–4).

Actually, many roveacrinid species display narrow stratigraphic ranges and are widely

Stage	E and b zones	Campanian roveacrinoid (CaR) zones	Definition of respective roveacrinoid biozones
upper Campanian	*Belemnitella mucronata*	CaR11	FO of *Stellacrinus pannosus* (upper limit is not defined)
lower Campanian	*Gonioteuthis quadrata*	CaR10	LO of *Costatocrinus brydonei, Lucernacrinus woodi, Saggitacrinus torpedo* to FO of *Stellacrinus pannosus*
		CaR9	AO of *Hessicrinus filigree and Platelicrinus campaniensis* to LO of *Costatocrinus brydonei*
		CaR8	LO of *Cultellacrinus gladius* to AO of *Hessicrinus filigree* and *Platelicrinus campaniensis*
		CaR7	LO of *Saggitacrinus longirostris* to LO of *Cultellacrinus gladius*
		CaR6	FO of *Assericrinus portusadernensis, Saggitacrinus longirostris, Applinocrinus cretaceus* forma *spinifer, Stellacrinus hughesae* forma *lineatus, Platelicrinus campaniensis* to LO of *Saggitacrinus longirostris* at the top and FLO of *Cultellacrinus gladius* at the base
		CaR5	FO of *Platelicrinus longispinus* to FO of *Platelicrinus campaniensis, Assericrinus portusadernensis, Saggitacrinus longirostris*
		CaR4	FO of *Hessicrinus filigree to* FO of *Platelicrinus longispinus*
		CaR3	LO of *Cultellacrinus gladius* to FO of *Hessicrinus filigree*
	Offaster pilula	CaR2	FLO of *Stellacrinus hughesae* forma *cristatus* to FO of *Cultellacrinus gladius*
		CaR1	LO of *Uintracrinus anglicus* to FO of *Stellacrinus hughesae* forma *cristatus*

FIG. 4. Lower–upper Campanian microcrinoid biozones (adapted and simplified from GALE, 2018, fig.17). Echinoid (*E*) and belemnite (*b*) zonation adapted from GALE, 2018. *FO*, first occurrence, *LO*, last occurrence, *FLO*, flood occurrence, *AO*, acme occurrence.

distributed (JAGT, 1992, 1999, 2005; GALE, 2016, 2018; GALE, SADORF, & JAGT, 2018). For instance, the upper Cenomanian species *Roveacrinus geinitzi* SCHNEIDER, 1989 is widely distributed over Boreal Europe, the Iberian plate, northern Africa, the Arabian plate, and both Americas (SCHNEIDER, 1989; FERRÉ, WALTER, & BENGTSON, 1997; FERRÉ & GRANIER, 2000; FERRÉ & others, 2018; NIEBUHR & FERRÉ, 2016). The genus *Orthogonocrinus* PECK, 1943 (upper Cenomanian–lower Coniacian) is represented by upper Cenomanian–lowermost (?) Turonian *Orthogonocrinus apertus* PECK, 1943 (FERRÉ, 1995; HESS, 2015); lower–middle Turonian undescribed specimens; and uppermost Turonian–lower Coniacian *O. janeti* (Valette, 1917) (see Ferré, 1995). Whereas knowledge of full biostratigraphic range of respective roveacrinid taxa is still in its infancy (Žítt & others, 2018), the most promising is within the event stratigraphy of roveacrinid mass occurrences, especially at anoxic/hypoxic time intervals (OAE) such as the Albian (OAE1) (e.g., Destombes, 1985; Hess, 2015); Cenomanian/Turonian boundary (C/TBE, OAE2) (Ferré, 1995; Ferré & others, 2017); Santonian/Campanian boundary (Gale, 2016, 2018); and the Campanian/Maastrichtian boundary (Jagt, 1999).

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