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Onshore–offshore trends in Campanian ammonite facies from the Marambio Group, Antarctica: Implications for ammonite habitats

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Recent biostratigraphic and sedimentologic studies in the lower–mid Campanian ammonite-rich shelf deposits of the James Ross Basin, Antarctica made possible a precise reconstruction of facies tracts along an onshore–offshore transect about 70 km in length. In proximal, inner-shelf settings the Santa Marta Formation include trigoniid-rich coquinas and cross-bedded and massive sandstones. In distal, mid- to outer-shelf settings the age-equivalent Rabot Formation consists of bioturbated mudstones and interbedded inoceramid- and brachiopod-rich tempestites. Each of these sedimentary facies is characterized by a very distinctive ammonite facies, whose characterization along a neritic-oceanic gradient offer clues to ammonite habitats. Ammonite facies of proximal settings are dominated by relatively large and ornate kossmaticeratids, with subordinated heteromorphs, desmoceratids, gaudryceratids and tetragonitids. Taphonomy, size–frequency distribution, and non-lethal injuries attributed to arthropods consistently suggest a shallow habitat and a nektobenthic (demersal) mode of life for the kossmaticeratids. Conversely, in distal settings the ammonite facies is dominated by gaudryceratids, including large *Anagaudryceras* sp., and tetragonitids, with subordinated small kossmaticeratids and large pachydiscids. Restriction to offshore oceanic-influenced facies suggests that these gaudryceratids have a mesopelagic, planktic mode of life. The hamitocone heteromorphs are equally distributed in shallow and deep facies with a high degree of shell fragmentation, particularly in shallow settings. This pattern suggests that hamitocones were exposed to extensive post-mortem drift.

1. Introduction

The interpretation of possible causative relationships between assemblages of ammonite morphotypes and their host sedimentary facies has been controversial. As summarized in Kennedy and Cobban (1976), Westermann (1996) and Lukeneder (2015), two extreme interpretations exist: 1) the host sedimentary facies can be considered as an indicator of the habitat of the living animal or 2) the host sediment is not a reliable indicator of the living organism habitat due to extensive post-mortem transport. The first interpretation is the traditional view of European researchers, which concluded that relatively smooth morphotypes (leiostracans) and relatively ornate morphotypes (trachyostracans) were mostly restricted to deep and shallow marine facies, respectively (See Tanabe, 1979; Marcinowski and Wiedmann, 1985; Westermann, 1996, and the bibliography therein). The second interpretation has some supporting evidence from the known fact that actual *Nautilus* shells can drift hundreds or even thousands of kilometers after death of the organism (Reyment, 1973, 2008).

As with modern cephalopods ammonites are also interpreted as living in the water column, either with a planktic, nektic or nektobenthic mode of life (cf. Westermann, 1996). Accordingly, the ammonite shells can never be preserved *in situ* and there always be some degree of post-mortem transport. Thus the main problem revolves around how to assert whether post-mortem transportation displaced the ammonite shells outside the limits of their original habitat or not. One important line of evidence against the idea of a universal post-mortem superficial drift is based on the concept of a water depth that function as a threshold between surfacing and never surfacing dead shells (Chamberlain et al., 1981; Maeda and

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Seilacher, 1996). Hydrostatic pressure below this boundary will rapidly flood the phragmocone chambers causing the shell to sink. Small shells and those with large siphuncle diameter will flood the phragmocone chambers quickly and so they will sink at lower water depths than larger shells (see Wani and Gupta, 2015, and the bibliography therein). Nonetheless, dead cephalopod shells sinking below the never surfacing threshold depth can still be transported by bottom currents (Maeda, 1991; Maeda and Seilacher, 1996; Olivero, 2007; Wani and Gupta, 2015), which can move them outside their original habitat complicating paleoecological interpretations.

Relative changes of water depth in sedimentary basins can be detected using sedimentologic criteria. When these changes are analyzed in connection to quantitative data on ammonite faunal spectra from proximal to distal sedimentary facies, the join analysis can offer important independent evidence to evaluate if a given faunal spectrum represents original ammonite habitats or post mortem dispersal. Extensive post-mortem drift of ammonite shells will result in lack of coherence between sedimentary and ammonite facies, whereas close relationships between sedimentary facies and ammonite groups will reflect minimal post-mortem dispersal of ammonite shells (Kennedy and Cobban, 1976; Westermann, 1996; Lukeneder, 2015). In this study, we present an analysis of ammonite spectra, including the distribution of morphotypes and shell sizes, in the lower to mid Campanian of the Marambio Group, James Ross Basin, Antarctica. We restrict the analysis to a relatively short time spanning the Ammonite Association 6 (Olivero, 2012a, 2012b), with the finding that the ammonite assemblages of the shallower northwestern deposits of the upper Beta Member of the Santa Marta Formation are significantly different, both in terms of relative frequency of ammonite morphotypes and individual shell size, from that of the deeper, contemporaneous southeastern deposits of the Rabot Formation. Interestingly, the distribution patterns of Campanian ammonites facies from the Marambio Group shares many features in common with the Turonian ammonite facies of the Yezo Group in Japan (cf. Tanabe, 1979; Wani, 2007). Thus, the main objectives of this paper are to document onshore–offshore trends in ammonite facies from the Campanian of the Marambio Group, Antarctica; to discuss the implications of the segregation of particular ammonite assemblages to sedimentary facies; and to make some generalizations on the habitat of certain Antarctic ammonite groups, particularly kossmaticeratid and gaudryceratid groups.

2. Stratigraphic and paleoenvironmental settings

The James Ross Basin is a back arc basin located to the east of the Antarctic Peninsula (Fig. 1A). The basin fill includes two major Cretaceous stratigraphic units: the deep-water Aptian–Coniacian Gustav Group (Ineson, 1989) and the shelfal Santonian–Danian Marambio Group (Rinaldi et al., 1978). The Marambio Group is highly fossiliferous throughout its 3-km-thick clastic succession of mainly fine-grained sandstone and mudstone, with subordinate conglomerate and coquina (Crame et al., 1996, 2004; Pirrie et al., 1997; Olivero and Medina, 2000; Olivero et al., 2008; Olivero, 2012a).

During deposition of the Marambio Group, clastic provenance was located along the Antarctic Peninsula towards the west; clastic particles were transported to the east–southeast and east–northeast; and the shelf prograded for more than 100 km into the proto-Weddell Sea. The expansion of the shelf was punctuated by three major sedimentary cycles (Olivero and Medina, 2000; Olivero, 2012a): the N (Santonian–early Campanian); NG (late Campanian–early Maastrichtian); and MG (early Maastrichtian–Danian) sequences (Fig. 1B). The N Sequence includes the Santa Marta and Rabot formations; the NG Sequence includes the Snow Hill Island Formation and Haslum Crag Sandstone and the MG Sequence consists of the López de Bertodano Formation. These formations were correlated across the basin by means of 15 Santonian–Maastrichtian ammonite assemblages (see Olivero and Medina, 2000; Olivero et al., 2008; Olivero, 2012a, 2012b; and the bibliography therein).

The studied sections (Fig. 1) comprise the upper Beta Member (Scasso et al., 1991) of the Santa Marta Formation exposed in the Brandy Bay area, NW James Ross Island (Brandy Bay Section, Fig. 2) and the Rabot Formation (Lirio et al., 1989; Marenssi et al., 1992) exposed in Hamilton Norte and Redonda points, in SE James Ross Island (Hamilton and Redonda Points Sections, Fig. 2). In the Brandy Bay Section, six successive ammonite assemblages (Figs. 1B, 2) are recognized in the Alpha and Beta members of the Santa Marta Formation. The lowest, Santonian Ammonite Assemblage 1 (*Baculites* cf. *kirki*) lacks kossmaticeratids (Olivero, 1992), but the bases of the following early Campanian ammonite assemblages 2–6 were defined at the first occurrence of a particular kossmaticeratid genus and/or species. The stratigraphic interval that contains the Ammonite Assemblage 6 in Brandy Bay can be continued in a down-dip direction across the basin to the south east of James Ross Island (Fig. 2, Olivero, 1992; 2012a, 2012b; Raffi and Olivero, 2016).

In SE James Ross Island, the Ammonite Assemblage 6 in the Rabot Formation (Fig. 2, Olivero and Medina, 2000; Olivero, 2012a, 2012b) is characterized by abundant *Natalites* cf. *hauthali* associated with *Parasolenoceras* sp., *Antarcticeramus rabotensis* and abundant *Gaudryceras rabotense* Raffi and Olivero and two relatively large species of *Anagaudryceras* (Olivero, 2012b; Raffi and Olivero, 2016). The succeeding mudstones and intercalated fine-grained sandstones of the Ammonite Assemblage 7 bear abundant specimens of *Neokossmaticeras redondensis*, *Polyptychoceras* sp., *Gaudryceras rabotense*, *Anagaudryceras* spp., *Tetragonites* spp. and *A. rabotensis*, with rare records of *Metaplacenticeras subtilistriatum* and *Hoplitoplacenticeras* sp. (Olivero, 2012b; Raffi and Olivero, 2016).

The top of the Santa Marta and Rabot formations is defined by an unconformity, which defines a notable, marked change in the Antarctic kossmaticeratid fauna. Below the unconformity, the N (for *Natalites*) Sequence records a relatively diverse fauna dominated by species of *Natalites*. Above the unconformity, the *Natalites* fauna is replaced in the NG (for *Neograhamites* and *Gunnarites*) Sequence by a low-diversity fauna dominated by abundant specimens of these two kossmaticeratid genera (Olivero and Medina, 2000). Erosion associated with this unconformity eliminated most of the stratigraphic interval encompassing Ammonite Assemblage 7 (*Neokossmaticeras redondensis*) and part of Ammonite Assemblage 8–1 (*Neograhamites primus*) in the basin (Fig. 1B).

At Brandy Bay, the Alpha and Beta Members of the Santa Marta Formation consist of four vertically stacked intergrading facies associations interpreted as prodelta-basin plain; base of slope depositional lobes; delta slope channel complexes; and delta plain–inner shelf depositional settings, respectively (Fig. 2A–C) that represent a regressive, deep-water delta sequence (Scasso et al., 1991; Olivero, 2007). The uppermost facies association (subaqueous delta plain–inner shelf), dominated by coquinas with abundant shells of *Pterotrigonia*, *Cuccullaea* and *Aporrhais* (Fig. 2C), will be fully described in section 4. Nonetheless, we note here that in this facies association ornate kossmaticeratid and compressed desmoceratid shells dominate the ammonite fauna, with a relative frequency of more than 60%. In SE James Ross Island, the Rabot Formation comprises more than 300 m of storm dominated deposits, with a characteristic inoceramid–bachiopod biofacies, interpreted as originated in mid-outer shelf settings (Fig. 2, Hamilton–Redonda Point sections; Martinioni, 1992; Olivero, 2012a).

3. Methodology

Quantitative data on relative abundance of different morphotypes and/or species of ammonite were obtained partly in the field