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The crinoid *Marsupites* in the Upper Cretaceous Nanaimo Group, British Columbia: Resolution of the Santonian–Campanian boundary in the North Pacific Province

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ABSTRACT

The strongly endemic nature of Late Cretaceous molluscan faunas of the North Pacific region creates challenges for correlation of stratigraphic sections in basins surrounding the proto-Pacific Ocean with European standard successions. A particularly problematic stage boundary in the Pacific region is the Santonian–Campanian boundary, which is poorly defined in the northwest and northeast Pacific regions on the basis of local ammonite and inoceramid bivalve assemblages or poorly constrained magnetostratigraphy. Examples of the crinoid genus *Marsupites* Mantell *in* Miller 1821, considered a marker of the Santonian–Campanian boundary at many places around the globe, have been collected recently from a number of localities of the Upper Cretaceous Nanaimo Group succession of southwestern British Columbia, including the species *M. testudinarius* and *M. lamberti*. Co-occurring specimens of *Marsupites testudinarius* in the Nanaimo Group include both smooth and coarsely ornamented forms which do not show stratigraphic segregation, suggesting that *M. testudinarius* is a morphologically-variable species which includes forms that were attributed to different species by previous workers. The presence of *M. testudinarius* in stratigraphic sections of the Nanaimo Group allows the precise placement of the Santonian–Campanian boundary interval in the Nanaimo Group succession, and correlation of this boundary with the European standard succession. As well, the occurrence of the crinoid allows for revision of the biostratigraphic zonation of the upper Santonian–lower Campanian interval in the Nanaimo Group. Characteristic molluscan assemblages which are found in association with *M. testudinarius* in the Nanaimo Group are known to occur elsewhere along the North American Pacific slope (e.g., northern California, USA), as well as in the northwest Pacific region (Japan, Sakhalin, Koryakia), and thus provide a marker for the Santonian–Campanian boundary in those areas where *Marsupites* has not yet been found.

1. Introduction

Recognition and correlation of Upper Cretaceous stage boundaries in the North Pacific faunal province has been hampered by the tectonically disrupted nature of the strata found in many of the basins of the region, as well as the endemic nature of numerous faunal elements found within them. Many elements of these faunas, which are dominated by ammonites and inoceramid bivalves, are characteristic of the North Pacific region but are unknown in European-based international global standard sections. Thus, correlation of Cretaceous strata in North Pacific basins with the European standard sections presents a continuing challenge.

As with many stage boundaries in the Pacific region, precise placement of the Santonian–Campanian boundary in Upper Cretaceous strata of the basins surrounding the Pacific rim has been especially problematic. In the northwest Pacific region, Jagt-Yazykova (2011, p. 81) has succinctly summarized the boundary correlation problem by stating that "None of the criteria recommended at the Second International Symposium on Cretaceous Stage Boundaries for Santonian/Campanian boundary, that is, the

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extinction of the crinoid genus *Marsupites*, the FAD of the ammonite *Placenticeras bidorsatum* and the belemnite *Gonioteuthis granulataquadrata* (see Hancock and Gale, 1996), is applicable either in Sakhalin, northeast Russia or Japan, because the taxa in question have not been recorded from these areas." Consequently, in Far East Russia (Sakhalin and Koryakia), the boundary is placed at the initial appearance of the bivalve *Inoceramus nagaoi* Matsumoto and Ueda 1962 and the ammonite *Menuites* (*Neopachydiscus*) *naumanni* (Yokoyama, 1890) (see Yazykova, 2002; Jagt-Yazykova, 2011), both of which are restricted to the North Pacific region. In the Japanese Islands, the position of the boundary has been established at the first appearance datum (FAD) of the ammonite *Submortoniceras* cf. *condamyi* (Collignon, 1948) or *Menabites mazenoti* Collignon, 1948, which is noted at nearly the boundary of the bivalve zones of *Inoceramus amakusensis* Nagao and Matsumoto, 1940 and *Inoceramus* (*Platyceramus*) *japonicus* Nagao and Matsumoto, 1940 (Toshimitsu, 1988; Toshimitsu et al., 1995; Toshimitsu and Kikawa, 1997), criteria again based principally on endemic North Pacific taxa. However, Yazykova (2002) reinterpreted this zonal boundary to mark the base of the upper Santonian substage in Sakhalin, rather than its upper boundary, and Hayakawa and Hirano (2013) used carbon isotope stratigraphy to suggest further that the Santonian–Campanian boundary in Hokkaido should actually be placed well down within the *Inoceramus amakusensis* Zone and well below the boundary with the overlying *I.* (*Platyceramus*) *japonicus* Zone.

In the northeast Pacific region, Santonian rocks have not yet been identified in southern Alaska (Jones, 1963), but in the classic Upper Cretaceous succession at Big Chico Creek, California (USA), Matsumoto (1959) placed the Santonian–Campanian boundary at approximately the FAD of the ammonite *Baculites chicoensis* Trask, 1856. Based on his own work in the stratigraphic successions of the Nanaimo Group of southwestern British Columbia and northwest Washington State, Jeletzky (1970) placed the boundary at the FAD of the ammonite *Eupachydiscus haradai* (*sensu* Usher, 1952) in the Nanaimo Group succession of British Columbia and argued that it should also be placed in the California succession at the first occurrence of the ammonite *Submortoniceras chicoense* (Trask, 1856). Subsequently, Ward (1978) placed the boundary within the *Eupachydiscus haradai* Subzone of the *Eubostrychoceras elongatum* Zone in both California and British Columbia, just below the FAD of the inoceramid bivalve *Sphenoceramus schmidti* (Michael, 1899) and the associated ammonite *Canadoceras yokoyamai* (Jimbō, 1894), supported approximately by Ward and Haggart (1981), who studied the classic succession at Sand Creek in northern California. More recently, Ward et al. (2012) have advocated changing the *Sphenoceramus schmidti* zonal name to the *Canadoceras yokoyamai* Zone, as that ammonite has a very similar range to the numerous 'sphenoceramid' taxa that characterize the lower part of the *Sphenoceramus schmidti* Zone.

Ward et al. (1983) and Verosub et al. (1989) utilized magnetostratigraphic analysis to define the Santonian–Campanian boundary in the California succession better, arguing that the base of Chron 33r, presumed to be at the base of the Campanian in the classic succession at Gubbio, Italy, could be recognized in California just above the base of the *Baculites chicoensis* Zone and associated occurrences of *Submortoniceras chicoense* Trask. This resulted in placement of the *Eubostrychoceras elongatum* (Whiteaves, 1903) and *Sphenoceramus schmidti* zones of California and British Columbia into the Santonian. Chron 33r was subsequently identified in southern California (Fry et al., 1985) and then in the northwest Pacific (Toshimitsu and Kikawa, 1997; Kodama et al., 2000), and has thus served as an indicator of the Santonian–Campanian boundary interval in those areas, although Japanese workers noted that the endemic nature of the Japanese faunas made it challenging to recognize the boundary outside of drilled magnetostratigraphic localities. Other workers, however, have since argued that Chron 33r may actually be younger than the base of the Campanian (e.g., Lillegraven, 1991; Cande and Kent, 1992), while still more recent work has suggested that the base of the chron is actually found within the uppermost Santonian, below the Santonian–Campanian boundary (e.g. Gale et al., 1995; Ward et al., 2012). Clearly, much work still needs to be done to establish firmly the precise relationship between biostratigraphic and magnetostratigraphic data around the boundary interval.

Most recently, Zakharov et al. (2013) have assessed oxygen and carbon stable isotope trends in the Nanaimo Group. Using molluscan fossils collected from specific outcrops, but not stratigraphic sections, these workers were able to recognize overall trends in isotopic data, including a positive $\delta^{13}C$ excursion which they correlated with the Santonian–Campanian Boundary Event (SCBE). Unfortunately, the study of Zakharov et al. (2013) was not stratigraphically based and so cannot be used to identify the Santonian–Campanian boundary in the Nanaimo Group succession. Nevertheless, their study provides a useful tool for establishing that the boundary is present on other criteria than biochronology.

As can be seen from the above discussion, the generally endemic nature of the Late Cretaceous ammonite and inoceramid faunas of the Pacific basin (see Yazykova, 2002), as well as challenges in establishing precise magnetostratigraphic chronostratigraphy in this region (see Ward et al., 2012), particularly in the mudstone facies which characterize the Santonian and Campanian parts of the succession, have precluded establishment of a basin-wide biostratigraphic zonation, and correlations with the international stratotype stages in Europe have been, for the most part, only weakly established.

Outside of the North Pacific region, the highest occurrence of the crinoid *Marsupites* Mantell *in* Miller, 1821 has been recognized as a marker of the uppermost part of the Santonian Stage in the European type sections, and has long been suggested as an indicator for the Santonian–Campanian stage boundary (de Grossouvre, 1901; Ernst, 1963; Naidin, 1979; Bailey et al., 1984; Birkelund et al., 1984; Schulz et al., 1984; Gale et al., 1995, 2008). *Marsupites* has a generally global distribution, with records from northern Europe (Sherlock and Noble, 1922; Sieverts, 1927; Löser, 1985; Salamon and Gorzelak, 2010, 2011; Lach, 2016; Lach and Salamon, 2016); North Africa (Peron, 1898; Gallemí and Abdallah, 2010), eastern Europe and central Asia (Klikushin, 1983; Pechersky et al., 1983), Madagascar and India (Stoliczka, 1873; Besairie, 1936; Walaszczyk et al., 2013), Australia (Withers, 1926; Clarke and Teichert, 1948; Feldtmann, 1963), and the United States Western Interior and Gulf Coast regions (Stephenson and Monroe, 1940; Marks, 1952; Cobban, 1962, 1964, 1995). In many of these regions, examples of *Marsupites* are found to overlie those of the allied crinoid *Uintacrinus* Grinnell 1876, and the former is considered to form a zone suprajacent to the latter. Although *Uintacrinus* was described from the Pacific coast Cretaceous of Canada by Whiteaves (1904), the precise geographic location and stratigraphic level of those specimens were poorly known, and *Marsupites* was not known to occur with this material. An example of *Marsupites* was illustrated more recently in a popular guide to the west coast fossils of British Columbia (Ludvigsen and Beard, 1998), but there was insufficient information on this specimen to assess its stratigraphic significance. Indeed, outside of this occurrence, the genus *Marsupites* has not been recognized previously anywhere on the Pacific slope of North America, or anywhere else in the North Pacific region.

We have recently identified specimens of *Marsupites* spp. from several localities in strata of the Upper Cretaceous Nanaimo Group of Vancouver Island, British Columbia (Figs. 1–2) and summarize the stratigraphy of these new finds in the present contribution.

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