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Paleontology and tectono-stratigraphic setting of the Lower Permian Johnston Canyon Formation, Banff National Park: Was it a sponge-rich estuary?

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Summary

The Permian Johnston Canyon and Ranger Canyon formations of western Canada represent persistently thin sequences occurring between thick Carboniferous and Lower Triassic successions. The Johnston Canyon Formation (JCF) at the Tunnel Mountain section comprises twenty-two metres of relatively complete rhythmic sedimentation from mid-Asselian to mid-Artinskian. Metre-scale rhythms include recessive phosphatic dolo-siltstone and resistant silty dolostone with chert nodules after evaporite. Pelagic fossils in the siltstone include conodonts and various fish remains. Benthic fossils include rare lingulid brachiopods, *Zoophycos* and *Thalassinoides* burrows, and abundant siliceous sponge spicules. Thriving siliceous sponge communities in the fossil record are traditionally interpreted to indicate cool, deep-water environments. Sedimentologic data indicate that the conditions required for sponges to flourish (including high nutrients, low turbidity, and low energy) can also be found in shallow nearshore embayments or estuarine settings, the proposed depositional setting for the JCF.

Introduction

The JCF is Early Permian in age (~295-290 Ma) and was deposited along a narrow embayment on the northwest margin of Pangea at a paleolatitude near 20°N, herein named the McGugan Embayment (Fig. 1). The embayment was controlled by southward extension of fault-bounded structures related to the Peace River Embayment. The presence of a volcanic arc located far offshore of the back-arc Slide Mountain Ocean (Fig. 1) indicates that subsidence rates were likely low in the McGugan Embayment. Today, the JCF outcrops at several locations within the Rocky Mountains of western Canada. The formation is enigmatic for two reasons, including 1) the presence of seemingly contradictory rhythmic lithologies (i.e. phosphatic dolo-siltstone and silty dolostone containing chert nodules after evaporites), and 2) the abundance of giant siliceous sponge spicules in the absence of nearly any other macrofossils. A highly specialized set of conditions would have been required to deposit this distinct combination of lithologies and this low diversity sponge community. The aims of this study are two-fold: 1) to interpret the climatic conditions and depositional environment of the JCF, and 2) to describe the characteristics of the giant siliceous sponge community and determine optimal environmental conditions for it to thrive.

Previous Work

The stratigraphy of the Ishbel Group was first described in the 1960's. The JCF was named by McGugan and Rapson (1964). Early depositional interpretations suggested transgression along a low-gradient shelf setting with low rates of deposition (McGugan, 1965) to account for this persistently thin stratigraphic unit. Early studies also noted problematic burrow-like structures and the conspicuous lack of macrofossils besides sponge spicules and rare lingulid brachiopod fragments (McGugan, 1977). Other work included conodont biostratigraphic studies to refine the age of the strata (Henderson and McGugan, 1986).

Methods

The research presented here focuses on a JCF outcrop located on the road-cut at Surprise Corner on Tunnel Mountain, near the Banff townsite (51.16751°N; 115.55965°W). Fieldwork at this location included sample collection for geochemical analysis, conodont biostratigraphy, and lithology, as well as gamma-ray logging using a hand-held scintillometer. Thin-sections to characterize lithology and identify spicules were prepared in the petrographic laboratory at the Department of Geoscience. Large dolostone samples were etched to release siliceous spicules and other bioclasts. Conodonts were recovered using a combination of standard dissolution and disaggregation techniques and photographed using a SEM. Additional conodonts from legacy collections were sent to Nanjing, China for oxygen-isotopic analysis. Several samples were sent to Beijing for Rock-eval analysis to determine TOC. Trace element analysis for redox and productivity proxies were performed using a tabletop X-50 mobile XRF system by InnovXsystems.

Age of the Johnston Canyon Formation

The timing of deposition is determined by conodont biostratigraphy as well as the characteristic stratigraphic stacking pattern associated with the late stages of the Late Paleozoic Ice Age (LPIA). The characteristic deposits during the LPIA include Milankovitch-scale cyclothems associated with glacial eustacy (late Asselian). This pattern accounts for the first 7.5 metres of the outcrop with the top of this interval marking a maximum flooding surface (MFS) and the base of the Sakmarian stage (Fig. 1). The late Asselian age is supported by the occurrence of *Sweetognathus* aff. *merrilli* and *Mesogondolella dentiseparata*. The significant reduction of continental ice volume means that subsequent deposition was influenced primarily by climatic variation and not glacial-eustacy. The Sakmarian age of the succession from 7.5 to 20.5 metres is supported by the occurrence of *M. monstra*, *Sw. binodosus*, *Sw. anceps* and *Sw. obliquidentatus* (Henderson, 2018). A late Sakmarian transgressive surface is marked by a firmground with *Thalassinoides* burrows filled by sponge spicules – the same “problematic burrows” noted by McGugan (1977).

Lithologic Characteristics

The JCF is divided into two dominant lithofacies including 1) resistant silty dolostone, with many beds having layers or clusters of chert and phosphate nodules, and 2) recessive dolomitic shaly siltstone layers, including phosphatic nodules (Fraser, 2021). Both lithofacies include variable amounts of quartz silt to very-fine grained sand floating within a dolomite matrix, which is interpreted to be wind-blown from inland desert dunes. The only sedimentary structures present are indistinct parallel laminations, interpreted to be formed through suspension deposition in a protected, shallow-water setting. The chert nodules within the dolostone beds are interpreted as diagenetic replacements of evaporite nodules, based on the occasional preservation of gypsum in nodule cores. Other nodules are phosphatic and occur within the dolomitic shaly siltstone units.

Oceanographic and Climatic Setting

The two lithofacies are rhythmically bedded and interpreted to be the product of climate changes. The number of rhythms suggest that they may be related to 100 Kyr short-eccentricity

Milankovitch forcing. Surface water temperatures were 24.5 to 27.4°C based on conodont oxygen isotopes, with one sample in the most distal section at Johnston Canyon indicating 15.8°C, suggesting the possibility of a thermocline. These data indicate the JCF was deposited in a protected, warm, shallow-water embayment or estuary (Fig. 1). Redox proxy trace element analysis (U, V) reveal an oxic-suboxic oscillation, with oxic conditions being prevalent (Schoepfer *et al*., 2013). Despite these oxic conditions, productivity proxies (Ba, Zn, Ni) are enriched, indicating productivity was high enough to overcome suboptimal preservation conditions (Wiebe, 2018). Eolian loess deposition provided ample silica input to the embayment. The dolostone units were probably the product of warm, arid intervals and anti-estuarine circulation in which a plume of hypersaline water flows along the sea floor; this may have prohibited development of a benthic community, but later provided a substrate for benthos when estuarine circulation began. During cooler, humid conditions, estuarine circulation allowed nutrient-rich normal marine water to flow along the sea floor and led to the deposition of shaly siltstone units.

Sponge Biology

Sponges are benthic, fixosessile organisms, and the majority live in normal marine environments, although a few varieties are adapted to live in fresh or brackish water. Most sponges do not need to be in the photic zone to survive and can be highly resilient to low oxygen conditions, but not anoxia (Mills *et al*., 2014). Most genera of sponges also display a wide range of temperature tolerance, but do require a consolidated substrate on which to anchor (Finks *et al*., 2009). Sponges are highly susceptible to elevated water turbidity and high sediment input rates, which are detrimental to their filtering and pumping processes. Siliceous sponge size and abundance is also positively correlated with nutrient supply and dissolved silica concentration.

Siliceous Sponge Community

The JCF contains the fossils of an abundant, low-diversity giant sponge community (Hyslop, 2018). This thriving community is recognized by horizons of abundant, predominantly monaxon siliceous spicules of unusually large size, reaching up to 2 cm in length and 0.8 mm in diameter. These sponge spicules are some of the largest ever documented and the sponge bodies, though not preserved, were likely abnormally large as well. The vast majority (~95%) of the spicules are demosponge monaxons. Occasional branching forms were observed in thin section, and sample etching yielded a single hexaxon spicule. The sponge spicules are not observed continuously throughout the Tunnel Mountain section, but appear to be concentrated at specific stratigraphic intervals, and particularly above 14 metres. Bacterial mats are recorded at 12.75 m. Other benthic fossils are conspicuous only in their absence – the only other organisms present in the benthic community appear to be phosphate-based lingulid brachiopods. Additional pelagic microfossils indicate that conodonts, ray-finned fish and sharks were present in the water column above.

Analogues

Reid *et al*. (2008) described a modern analogue for a biosiliceous, cooler, more humid estuary at Bathurst Harbour, southwest Tasmania. Here, the harbour system displayed a halocline separating tannin-rich, low salinity surface waters from clear water below. The tannins limited the photic zone, resulting in the mixing of subphotic biota including soft corals, bryozoans and sponges with other more typical shallow-water biota (echinoderms) living close to the shoreline. At the same time, organic-rich sediments in protected embayments generated few bioclasts, but included transported spicules. The organic-rich, slightly acidic sediments lead to the dissolution of calcareous biota and preferential preservation of the siliceous spicules. However, in the McGugan Embayment there was no evidence of transport, nor any ghosts of fossils in thin-section, leading the authors to interpret a paucity of $CaCO_3$ organisms, rather than a preservation bias. Gammon *et al*. (2000) described shallow-water, biosiliceous deposits from the Eocene of southern Western Australia. The inner shelf setting was protected by islands in a structurally controlled embayment, similar to the McGugan Embayment, where sponges outcompeted calcareous biota because of high levels of land-derived nutrients and dissolved silica in a low energy setting. Open marine bryozoan-rich carbonate mudstone is found offshore. They conclude that neither water temperature, nor depth are critical factors for abundant sponge communities, and instead highlight the importance of elevated silica, high nutrient levels, and tranquil settings.

Conclusions

This study represents the first description of a low-diversity giant sponge community in the JCF. Geochemical and lithological evidence suggest a high productivity and low turbidity setting, with rhythmic lithofacies resulting from climatic cycles. Eolian-delivered silt provided a source of dissolved silica, and estuarine circulation delivered nutrient-rich sea water. These conditions, combined with occasional firmgrounds and the sheltered, low energy setting of the McGugan Embayment provided an ideal setting for siliceous sponges, which likely outcompeted most other benthic organisms to form a thriving giant sponge community.

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Figure 1. Paleogeographic setting for Lower Permian Johnston Canyon Formation and McGugan Embayment (modified from Zubin-Stathopoulos et al., 2013). Inset is a litholog and age correlation from Fraser (2021).