THE PALEOECOLOGY OF TENTACULITIDS FROM THE SILURIAN ARISAIG GROUP, NOVA SCOTIA, CANADA

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INTRODUCTION

The Silurian rocks of Nova Scotia record a diverse sedimentologic and paleontologic history. The aim of this research is to understand the paleoecology of portions of the Arisaig Group by studying certain paleoecological indicators associated with tentaculitids. Tentaculitid orientation can yield clues about the local depositional environment. This information may be augmented by taxonomic and petrographic studies of tentaculitid-bearing beds, allowing a better understanding of the Silurian marine environment.

Tentaculitids are annulated, conical, shelled organisms of uncertain biologic affinities that range from the Ordovician to the end of the Devonian (Cornell et al., 2003). The bilateral shells are typically compartmentalized by transverse septa with conical embryonic chambers. They are thought to be related to cephalopods because they have a tapered cone-shaped shell made of calcite; however, they lack a siphuncle. Some have suggested that these organisms are remotely related to pteropods (pelagic gastropods), but most pteropods have a very thin asymmetrical shell and did not emerge until the Tertiary, long after tentaculitids went extinct (Orlov et al., 1976). Because of these uncertainties, tentaculitids have been placed into a separate (probably molluscan) class, the Cricoconarida (Fisher, 1966).

Ten fossiliferous beds from the Arisaig Group (see Lackey et al., Table 1, this volume) contain abundant tentaculitids lying parallel to bedding planes; vertically oriented shells occur rarely. These beds are composed predominantly of shales and siltstones, and contain fossiliferous grainstone lenses that are interpreted to be tempestites (Boucot et al., 1974).

METHODS

Fieldwork was done in Arisaig, Nova Scotia, between July 16 and August 8, 2006. Ten beds that contained abundant tentaculitids (>15) and were exposed along the shoreline were selected for detailed study from the following formations in the Silurian section at Arisaig: Ross Brook Formation (4), Doctors Brook Formation (3), Moydart Formation (3) (Fig. 1). Each bed was measured and described using a Jacobs staff (outfitted with a protractor to account for dip), a meter stick, and a Brunton compass. The strata one meter above and below the selected beds were described and rudimentary stratigraphic columns were constructed. Detailed drawings of the ten fossil beds were made, concentrating on the orientation of tentaculitids in the field. Digital photographs were taken of the fossil beds, the sedimentary beds above and below the fossil beds, and the adjacent stratigraphy.

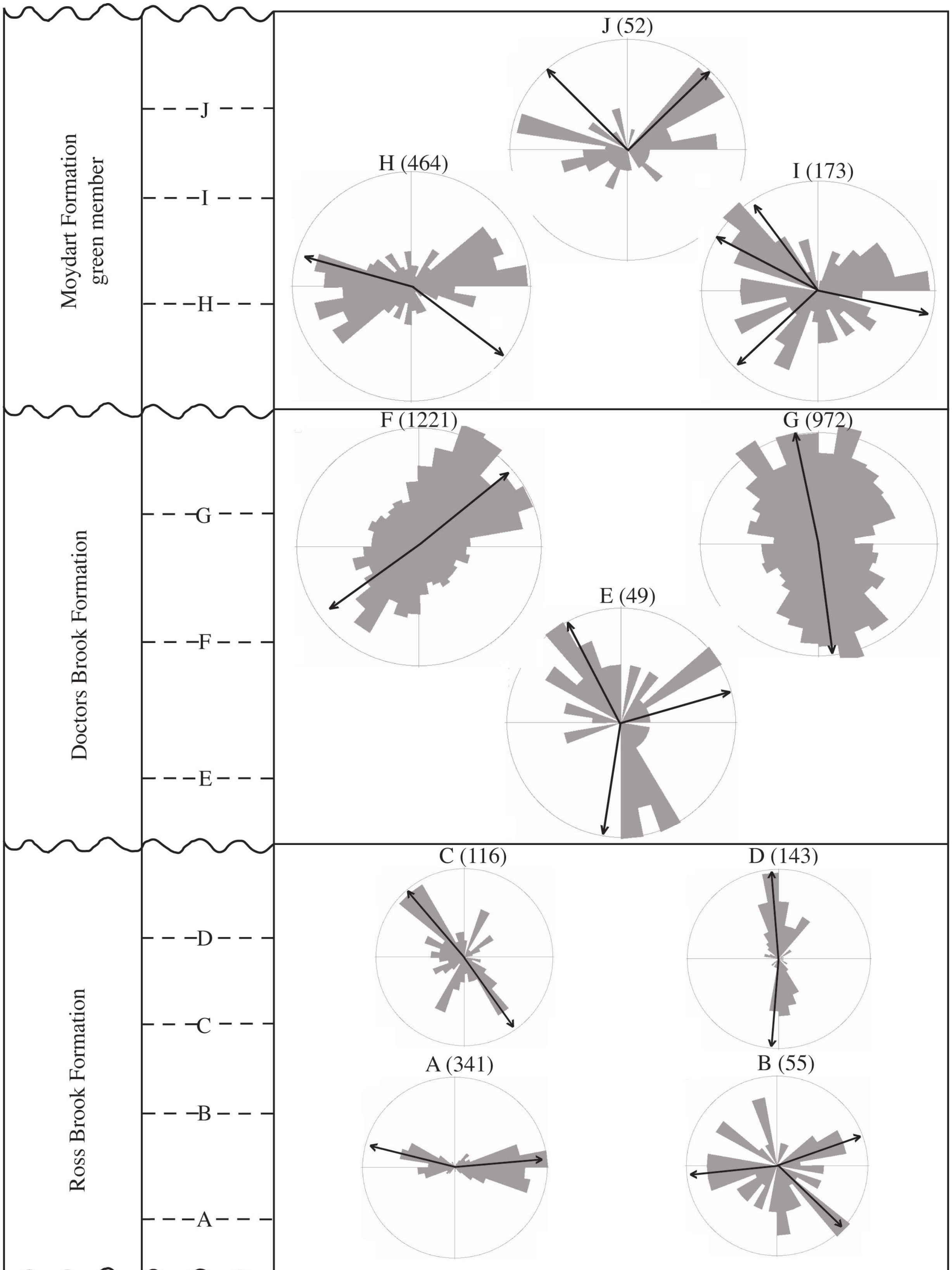


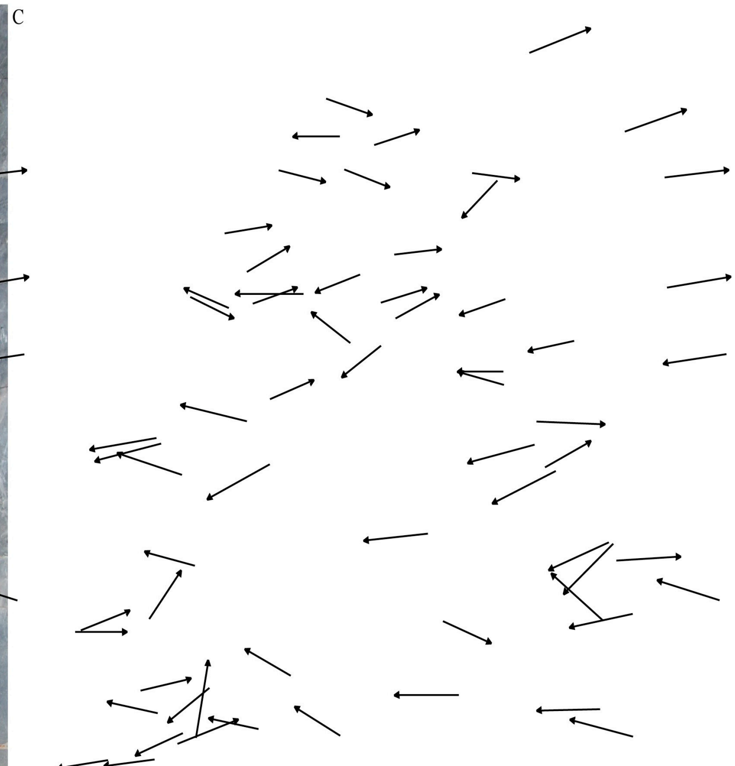
Figure 1**.** Equal-area rose diagrams of the orientation of tentaculitid apices in 10 beds of the Arisaig succession. Complete composition of Arisaig Group not shown, and only relative positions of beds (A-J) are indicated. Number of tentaculitids measured indicated in parentheses. Selected modes (arrows) have been corrected for tilt.

Photographs of the beds were imported into *Adobe Illustrator 10* to trace and measure the orientation of tentaculitids (Fig. 2). Data were then transferred to *Stereonet* for construction of rose diagrams using 10° intervals on equal-area plots. Because the beds typically dipped, true orientations of tentaculitids were determined via stereonet analysis.

RESULTS

Ross Brook Formation

The orientation of the tentaculitid shells from the upper Ross Brook Formation (beds A-D) display bimodal and polymodal distributions (Fig. 1). Beds A, C, and D are bimodal, with modes at 80° and 280° (A), 150° and 320° (C), and 180° and 350° (D). Bed B has a polymodal distribution with modes at 70°, 150°, and 270°. Bed C has a relatively weaker orientation at 30° and 210°, yielding a quadrimodal distribution.



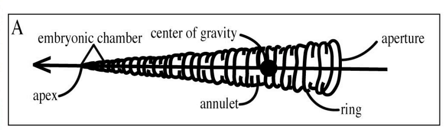


Figure 2. A) Typical Arisaig tentaculitid showing important features; apex may point downcurrent or upcurrent (see text). B) Oriented tentaculitids (arrow points in same direction as apex, as in part A), Ross Brook Formation. C) Same as part B, showing alignment arrows only (n=64).

Doctors Brook Formation
Bed E exhibits a nearly trimodal pattern with modes of 50°, 170°, and 320° (Fig. 1). Beds F and G are bimodal, with modes at 30° and 220° (F) and 170° and 350° (G).

Moydart Formation
In the green member of the formation beds H and J show a dominant bimodal distribution with modes at 90° and 250° (H) and 50° and 280° (J) (Fig. 1). Bed I exhibits a polymodal distribution, with modes at 90°, 190°, 270°, and 320°.

TENTACULITID SYSTEMATICS

According to McLearn (1924) and Flower (1943), tentaculitid fossils in the Arisaig Group belong to *Tentaculites canadensis* Ami, 1894. On the basis of more recent and detailed studies of Fisher (1966) and Larsson (1979), I believe that the diversity of Arisaig tentaculitids is much greater. Preliminary taxonomic analysis yields four genera and at least five species in the study area. Taxonomic characters of tentaculitids include the size of the shell, spacing and shape of the rings, shape of the embryonic chamber, and cross-sectional morphology of the inner wall (Fig. 2A). Below are brief descriptions of the tentaculitids examined in the Arisaig Group.

Class Cricoconarida Lyashenko, 1957

Order Tentaculitida Lyashenko, 1955
Family Tentaculitidae Walcott, 1886
Genus *Tentaculites* von Schlotheim, 1820
Tentaculites canadensis Ami, 1894

Description: Length 6-23 mm, width 0.5-4.5 mm. The embryonic chamber is narrow with a blunt point and the internal wall undulates slightly. Ornamentation consists of evenly spaced primary rings that are lipped, giving a stacked cup appearance (Fig. 3).

Occurrence: Upper Ross Brook Formation (Hurst and Pickerill, 1986).

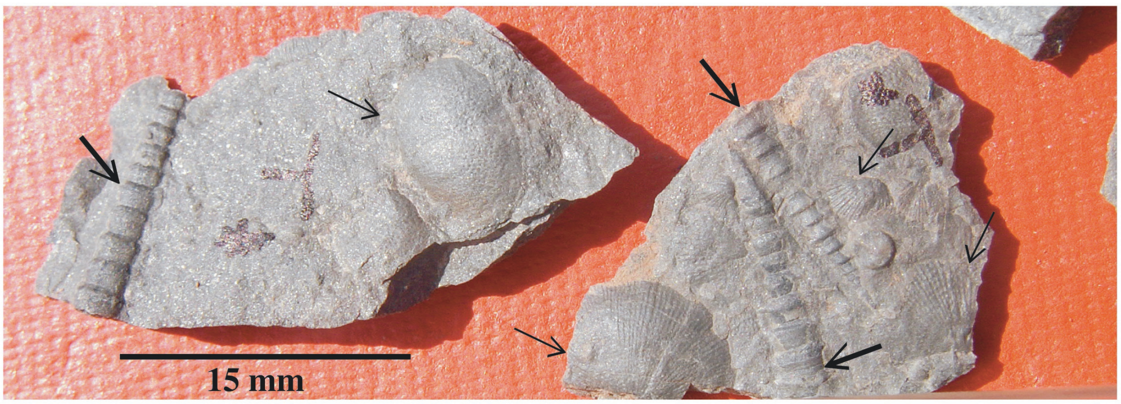


Figure 3. *Tentaculites canadensis* (thick arrow) and the common Arisaig brachiopod *Eocoelia* (thin arrow), bed B, Ross Brook Formation.

Tentaculites sp.
Description: Length 3-9 mm, width 0.5-1 mm (Doctors Brook Formation). Length 9-12 mm, width <1-3 mm (Moydart Formation). Embryonic chamber is narrow with a blunt point. The inner wall undulates slightly and the external ornamentation consists of evenly spaced and lipped primary rings. This species overlaps in size with *T. canadensis*, but is typically significantly smaller.

Occurrence: Doctors Brook Formation (phosphatized), Moydart Formation (pyritized and phosphatized).

Family Rossiitidae Lyashenko, 1969
Genus *Dicricoconus* Fisher, 1962
Dicricoconus sp.

Description: Length 8-12 mm, width 0.5-1 mm. Embryonic chamber has a narrow blunt point and the internal wall is smooth. This genus has uniformly spaced primary rings separated by secondary rings that are lipped.

Occurrence: Doctors Brook Formation.

Family Volynitidae Lyashenko, 1969
Genus *Odessites* Lyashenko, 1969
Odessites sp.

Description: Length 2.5-9 mm, width 0.5-0.8 mm. The shape of the embryonic chamber has a blunt point with an irregular inner wall. Ornamentation consists of annulations that alternate with widely and equally spaced rings.

Occurrence: Moydart Formation.

Genus *Podolites* Lyashenko, 1969
Podolites sp.

Description: Length 2.5-9 mm, width 0.5-0.8 mm. The embryonic chamber has a blunt point. Shells are straight with primary and secondary rings that contain curved annulets. The inner wall is irregular and lacks correspondence with the primary rings, secondary rings, and annulets on the outer wall of the shell.

Occurrence: Moydart Formation.

DISCUSSION

Orientation Analysis

Tentaculitid orientation is dependent upon at least three variables: nature of the flow (e.g., unidirectional, bidirectional/oscillatory), shell hydrodynamics, and position of the center of gravity of the shell (Lindholm, 1987). Unidirectional flow typically gives rise to a strong alignment of tentaculitids along their long axes (Flower, 1943; Fisher, 1966; Cornell et al., 2003). But the shell apex points downcurrent in relatively rapid flow, and upcurrent in relatively slow flow (Nagle, 1967; Allen, 1984). During waning stages of storms, wave action may produce oscillatory flow, causing high-spired shells (such as tentaculitids) to orient parallel to the wave crests (see Myrow and Southard, 1996). Around half of the apices point in one direction and the other half point in the opposite direction, yielding bimodal paleocurrent roses. Differential filling of a shell may cause the center of gravity to migrate; in this case, unidirectional flow might result in a bimodal pattern. Furthermore, the biology of tentaculitids is unknown, and may play a part in shell alignment. The interpretation of rose diagrams based on tentaculitid orientation is thus complex.

Ross Brook Formation

Tentaculitid orientations within beds A-D display bimodal distributions, but the predominant modes vary from 80° and 280° to 180° and 350°. According to Beck and Strother (2001), the upper Ross Brook Formation demonstrates a middle to inner shelf environment where storm waves commonly occur; the bimodal rose diagrams support this interpretation (Boggs, 2006). Within the shaly siltstones (above and below the tempestites), local evidence of tidal and other nearshore processes occur, including flame structures, flaser bedding, ripple marks, and bioturbated beds. Some of the tentaculitids that show preferred alignment within this formation were found perpendicular to ripple marks, further supporting an inner shelf environment. The polymodal distribution in bed B could be due to bioturbation, which would alter the original orientation of the shells.

Tentaculites canadensis specimens are preserved as complete shells or external molds; broken shells are rare, suggesting only modest transport. The associated fauna includes the brachiopod *Camarotoechia rossonia* (Hurst and Pickerill, 1986) and trilobite fragments.

Doctors Brook Formation
Specimens of *Tentaculites* and *Dicricoconus* from beds E (even though trimodal) and G display similar paleocurrents (northwest-southeast), whereas bed F differs (northeast-southwest). These varied bimodal directions could indicate that the current shifted in direction over time. Beck and Strother (2001) found that the Doctors Brook Formation represents a time of high sea level where the tentaculitid shells were deposited in a middle to outer shelf environment. In the outer shelf, storm currents have a large effect on the orientation of shells; perhaps the trimodal pattern in bed E is due to a combination of the effects of fair weather and storm winds. Other factors, such as shell hydrodynamics and the position of the center of gravity, may have played roles in generating this pattern.

The tentaculitids in the Doctors Brook are commonly replaced by phosphate or pyrite, making identification difficult. Incomplete specimens (broken internal and external molds) dominate the siltstones; associated fauna includes brachiopods, echinoderms, mollusks, and trilobites. Fragmented shells and telescoped tentaculitids might be due to storm-induced collisions, and thus this assemblage does not represent a fossil community (Hladil et al., 1996).

Moydart Formation
During the time of deposition of *Tentaculites, Odessites,* and *Podolites*, sea level was lowering in an inner shelf/shoal environment (Beck and Strother, 2001). The three tentaculitid-bearing beds show similar orientations (northeast-southwest). Beds H and J have similar bimodal distributions; even polymodal bed I has a similar trend. These beds could show a nearshore environment where the tentaculitids were deposited.

Vertically oriented tentaculitids occur in association with *in situ* crinoid columns; perhaps these tentaculitids have been preserved in life positions (e.g., Cornell et al., 2003). The tentaculitids are pyritized, and occur within green cross-laminated siltstones and shales. Associated fossils include echinoderms, brachiopods, bryozoans, mollusks, and trilobites. Bioturbation is prevalent and could account for polymodal orientations of tentaculitids (bed I).

CONCLUSION

Tentaculitid fossils and their orientations yield important paleoecologic information about the sedimentary succession near Arisaig, Nova Scotia. During the Silurian, fluctuations in sea level caused migration of the shoreline and migration of facies representing outer shelf to inner shelf environments. The bimodal roses may reflect 1) tentaculitid response to oscillatory waves by orienting parallel with the shoreline; 2) tentaculitid hydrodynamics (apex downcurrent or apex upcurrent, depending on water velocity); 3) variation in the position of the center of gravity of individual tentaculitid shells; or 4) a combination of these possibilities. Because the beds studied here have been documented to be tempestites, oscillatory flow during the declining phases of a storm are considered to be the best interpretation for the bimodal orientations of the tentaculitids. Finally, the diversity of these enigmatic fossils at Arisaig is greater than previously reported.

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