EARLY CAMBRIAN PHOSPHATIZED ARCHAEOCYATHANS AND SMALL SHELLY FOSSILS (SSFS) OF SOUTHWESTERN MONGOLIA

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INTRODUCTION

Before the Phanerozoic era, microbial and abiotic fabrics were the main components of carbonate reefs (e.g., Grotzinger and James, 2010), but during the Cambrian Period, archaeocyathans appeared as the first animals that secreted thick carbonate skeletons and built reefs (e.g., Rowland and Gangloff, 1988; Zhuravlev, 1989; Kruse, 1990), and much remains to be explained about their life mode and ecological preferences (Wood et al., 1992). Archaeocyathans are difficult to extract because they have the same calcitic mineralogy as their host rock, which limits the study of their internal structures (Rigby and Gangloff, 1987). However, a few phosphatized archaeocyathans have been found in Siberia (Dzik, 1994), Greenland (Skovsted, 2006), Antarctica (Wrona, 2004; Myrow, 2002), China (Wang et al., 2010), and now in the Zavkhan Basin of southwestern Mongolia **(Figure 1)**. The discovery of phosphatized archaeocyathans in Mongolia has provided an exciting opportunity to examine their exceptional preservation **(Figure 2)**. This type of preservation reveals important aspects of their morphology as well as the environmental conditions that led to phosphatic preservation.

STUDY AREA

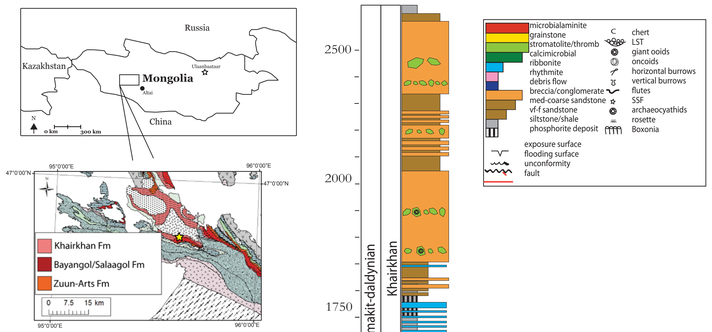

Figure 1. *Map showing location of phosphatized fossils in southwestern Mongolia. Yellow star marks Orolgiin Gol locality (E1221). Modified from Smith et al., in prep.*

Figure 2. *Field photo of Orolgiin Gorge. Large talus block with calcified archaeocyathans (pink) and phosphatized horizons (dark brown). Cover lens for scale. Photo courtesy of E. Smith.*

Figure 3. *Stratigraphic column of Orolgiin Gol section. The phosphatized fossils are found at the contact of these two units in the upper Salaagol Formation. Modified fred from Smith et al., in prep.*

The upper Salaagol Formation is a carbonate limestone facies with partially phosphatized archaeocyathans and SSFs (Smith et al., in prep). The Khairkhan Formation is composed of conglomerate, black shale, and sandstone (Macdonald et al., 2009; Khomentovsky and Gibsher, 1996) **(Figure 3)**.

METHODS

Twenty-five samples (E1221) were collected from talus at Orolgiin Gorge. Eight limestones were selected because they contained the most fossils in hand sample. The 8 samples were cut to about the size of half a fist and were each dissolved in 10% buffered acetic acid. 2 extractions were preformed and sieved into five size fractions: >840µm, 420µm – 840µm, 250µm – 420µm, and 160µm – 250 µm and <160µm. All residues were examined under the light microscope, but residues >840µm and 420µm – 840µm were picked for fossils with different morphologies. As an initial screening process, the 10 best-preserved and most representative fossils from each extraction were photographed under the light microscope and the Scanning Electron Microscope (SEM) **(Figure 4)**. To understand the nature of preservation, the petrographic microscope was used to analyze thin sections **(Figure 5)**. For residue and thin section, qualitative observations about diversity and preservation were noted for each sample. For residue sample E1221.3A2, four fossils were selected to do Energy Dispersive Spectroscopy (EDS) analysis for the most common preservation modes of fossils **(Figure 6)**.

RESULTS

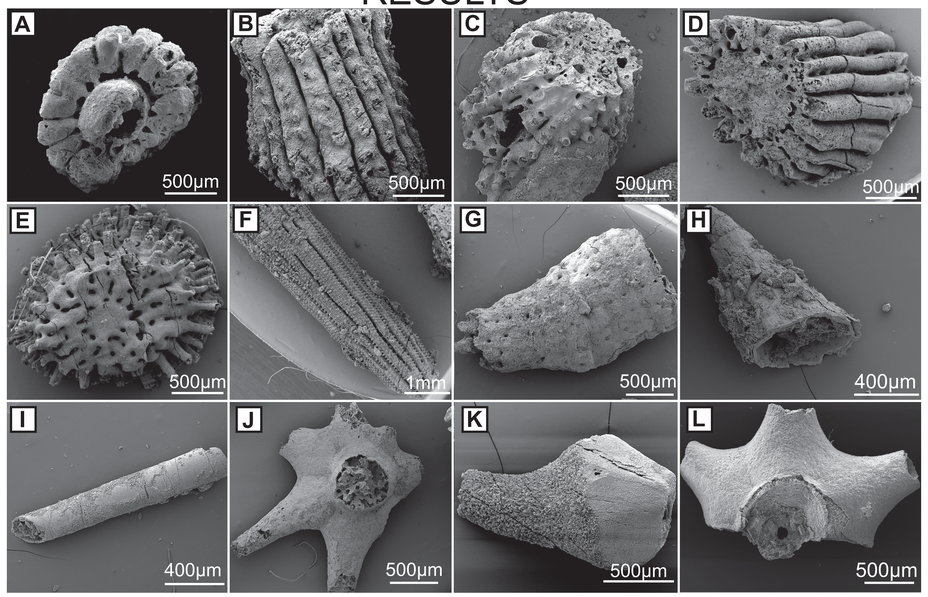

Figure 4. *Fossil SEM images.*
A–F. Phosphate fills in an archaeocyathan's central cavity, intersepta, and pores.
G. External surface of a phosphatized archaeocyathan's outer wall and pores
H–I. Phosphatized hyolith.
J, L. Phosphatized chancelloriid with a center ray and lateral rays.
K. Phosphatized chancelloriid ray.

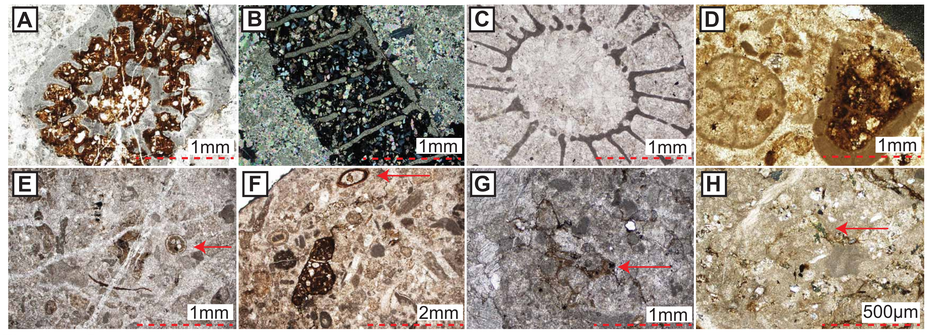

Figure 5. *Petrographic images.*
A. Various mineral and phosphate fill in an archaeocyathan's central cavity and intersepta. The inner wall, outer wall, and septa are calcified and surround the phosphate and other minerals.
B. Various mineral and phosphate fill in an archaeocyathan's intersepta. The septa are calcified (XPL).
C. Calcified archaeocyathan with central cavity, septa, and intersepta.
D. Calcified archaeocyathan (left) and an archaeocyathan with its outer skeleton calcified and its internal structure filled in with phosphate (right).
E. Chancelloriid (red arrow).
F. Hyolith (red arrow).
G. Phosphatic Cement (red arrow).
H. Glauconite Cement (XPL, red arrow).

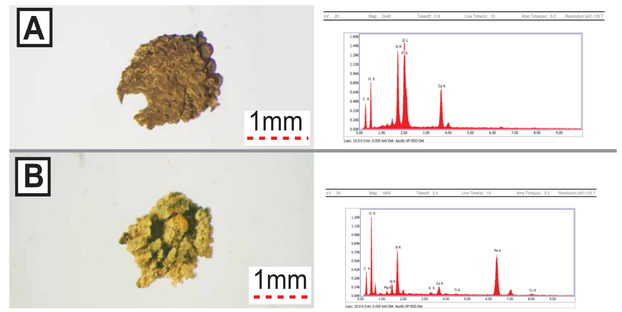

Figure 6. *EDS analysis. By using EDS, the chemical composition was determined. XRD analysis would be required to confirm these identifications, but it appears these archaeocyathans were preserved as an apatite and glauconite internal mold.*

A. Fossil 3A2.20.11 had a brown color similar to other fossils observed. The chemical composition was determined to be C, O, Si, P, and Ca which is consistent with apatite. Even though the majority mineral constituting fossils was apatite, other minerals were observed. Zr was detected because a zircon was found among apatite.

B. Fossil 5A2.20.3 looked unique underneath the light microscope because it had a green color. The chemical composition was determined to be O, Mg, Al, Si, K, Ca, and Fe which is consistent with the glauconite.

DISCUSSION

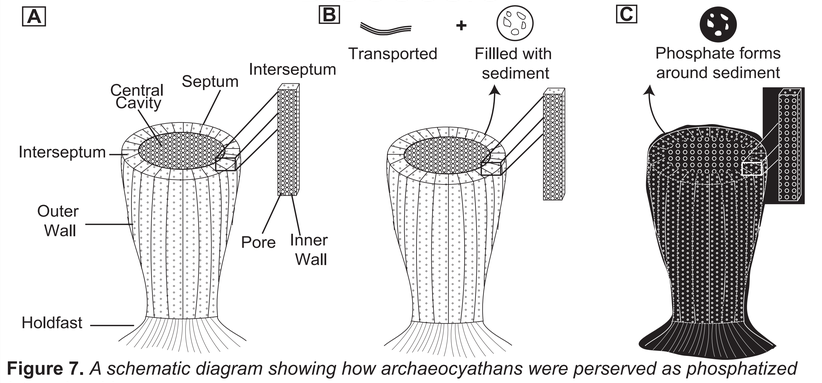

Figure 7. *A schematic diagram showing how archaeocyathans were perserved as phosphatized internal molds.*
A. In-situ Ajacicyathus' (Regularia) Archaeocyathan.
B. Transported from peri-reefal environment to a deeper marine setting that filled with sediment.
C. Soft tissue decays in anoxic and ferriginous conditions. This combination creates an optimal site for apatite to grow. Phosphatic internal molds form.

In residue, phosphatic internal molds archaeocyathans, one archaeocyathan replaced by phosphate, one possible glauconite archaeocyathan, and phosphatized SSFs were found. In thin section, the internal structures of archaeocyathans were phosphatized, creating internal molds that were extracted in residue. In thin section, calcified and phosphatized examples of SSFs were observed. There is a difference in diversity between residue and thin section because only >840µm and 420µm to 840µm was observed under the light microscope and SEM, while under the petrographic microscope all fossil sizes were observed.

In the Salaagol Formation, family Ajacicyathus (Regularia) archaeocyathans dominated these samples (Wood et al., 1993). The Orolgiin Gorge archaeocyathans are identified as Ajacicyathus (Regularia) based on their simple wall and large pore structure that form longitudinal rows. Ajacicyathus archaeocyathans settled on soft bottom environments usually at reef peripheries (Debrenne and Reitner, 2001).

The nature of phosphatization and the redox conditions that fostered it remain a mysterious process. Ferrguinous and anoxic conditions appear to contribute to the secondary growth of apatite (Creveling et al., 2014). In these settings, apatite was likely created *in situ* based on the presence of phosphatic internal molds and apatite cement. Ajacicyathus archaeocyathans are known to have intersepta filled with soft-tissue (Wood et al., 1992). The areas where soft tissue would have decayed are areas where phosphate is prevalent, including the intersepta and pores of the inner wall. After the archaeocyathans were transported and sediment filled their cavities, phosphate grew in the empty spaces around the mineral grains. As the archaeocyathans died, the fleshy organic material decayed and may have created a site for apatite nucleation along with possible anoxic and ferruginous conditions in this deeper water setting **(Figure 7)**.

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