Correlating Early Cambrian archaeocyathan-built reefs across North America and China: Stratigraphy of the Xiannudong Formation

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Abstract

Archaeocyathan reefs diversified and radiated rapidly throughout the Early Cambrian. By late Early Cambrian, archaeocyathan reefs were in decline and disappeared by the end of the Early Cambrian. Several global climatic changes are hypothesized to have influenced the decline of archaeocyathan reefs. These climatic variables are rising CO_2, rising sea surface temperatures, and changing seawater chemistry (Rowland and Shapiro, 2002). A high-resolution study of coeval reefs from China and Nevada that span peak reef growth (mid-Early Cambrian) to decline (late-Early Cambrian) will provide information regarding the speed of decline and its record, if any signs of decline are documented.

One month of fieldwork in China provided several sections of archaeocyath-bearing beds in two different formations, Xiannudong (mid-Early Cambrian) and the Tianheban (late-Early Cambrian). The Fucheng section described herein contains numerous archaeocyathan bearing/microbial intervals that cycle with unfossiliferous siliciclastic intervals. These cycles suggest fluctuating sea levels from reef-bearing, shallow water to deeper water silts and muds.

Introduction

Reefs have existed since the Archean Eon. Archean and Proterozoic reefs were built exclusively by microbes and calcimicrobes. However, in the Early Cambrian, the appearance of archaeocyaths ushered in the beginnings of metazoan-calcimicrobial-built reefs. Archaeocyaths are a class of calcareous sponges within the Phylum Porifera and are divided into two informal groups, ‘Regulares’ and ‘Irregulares’. These two groups evolved at the same time and are often found inhabiting the same reefs (Debrenne and Zhuravlev, 1992). Irregulars are distinguished from regulars by their more complex morphologies and their placement of living tissue within the skeleton (Debrenne and Zhuravlev, 1992; Debrenne et al., 2002). Both irregulars and regulars are solitary and modular ("branching colonies").

Archaeocyathan reefs first appeared on the Siberian platform from which they rapidly diversified and globally radiated until their peak diversity in the mid-Early Cambrian. In the late-Early Cambrian, archaeocyaths, although still globally dispersed, declined and finally disappeared by the end of the Early Cambrian. Only two instances of Middle and Upper Cambrian archaeocyaths are documented and both are in Antarctica (Wood, 1999).

Several physicochemical and biological variables are proposed to have influenced archaeocyathan demise and promoted the resurgence of microbialite reefs. These variables are (1) rising atmospheric CO_2, (2) rising surface seawater temperatures, (3) changing Mg/Ca ratio in seawater, (4) post-extinction lag time, (5) photosymbiosis recovery lag time, and (6) lack of other metazoans to fill archaeocyath niche (Rowland and Shapiro, 2002).

In order to understand the effects of global climate change on reef ecosystems, reefs that are globally distributed must be correlated, compared and contrasted. One aspect of this study is to correlate strata from Nevada (Laurentia) and China. During the summer of 2002, one month of fieldwork was completed in China.

Geological Background

Several different localities from Nevada and China are used in this research (Figure 1). The Nevadan localities include two formations in Esmeralda County, Nevada that range from the *Nevadalla* to middle *Bonnia-Olenellus* trilobite zones (Figure 2). These trilobite zones occur in the Lower Poleta Formation through the Upper Harkless Formation and span from the mid-Early Cambrian to the late-Early Cambrian, respectively. Both formations contain a number of archaeocyathan reefs, which are well studied with respect to paleoecology and taxonomy (Rowland, 1978; Rowland and Gangloff, 1988; Hicks, 2001).

The archaeocyathan reefs studied in China occur on the Yangtze platform in the south Shaanxi province and Hubei province. Four sections were analyzed for this study, Fucheng, Shatan, Xinchao, and Wangjiaping. The Xiannudong Formation is exposed at the Fucheng, Shatan, and Xinchao localities, while the Tianheban Formation is exposed at the Wangjiaping locality (Figure 2). Each Chinese section was preliminarily investigated (Qin and Yuan, 1984; Gandin and Luchinina, 1993; Zhang and Yuan, 1994; Ye et al., 1997; Yuan et al., 2001) but none have been studied in detail. The Shatan Section in the Shaanxi province is the stratotype for the Xiannudong Formation, which is hypothesized to be coeval with the Poleta Formation in Nevada. Here, the Xiannudong contains only one instance of *in situ* archaeocyaths as a bafflestone, otherwise, archaeocyaths occur as grainstone and as the nuclei of oncoids.

The Fucheng section in south Shaanxi province near the village of Fucheng contains six archaeocyathan-bearing units in the Xiannudong Formation. These six archaeocyathan-bearing units show close associations between archaeocyaths and

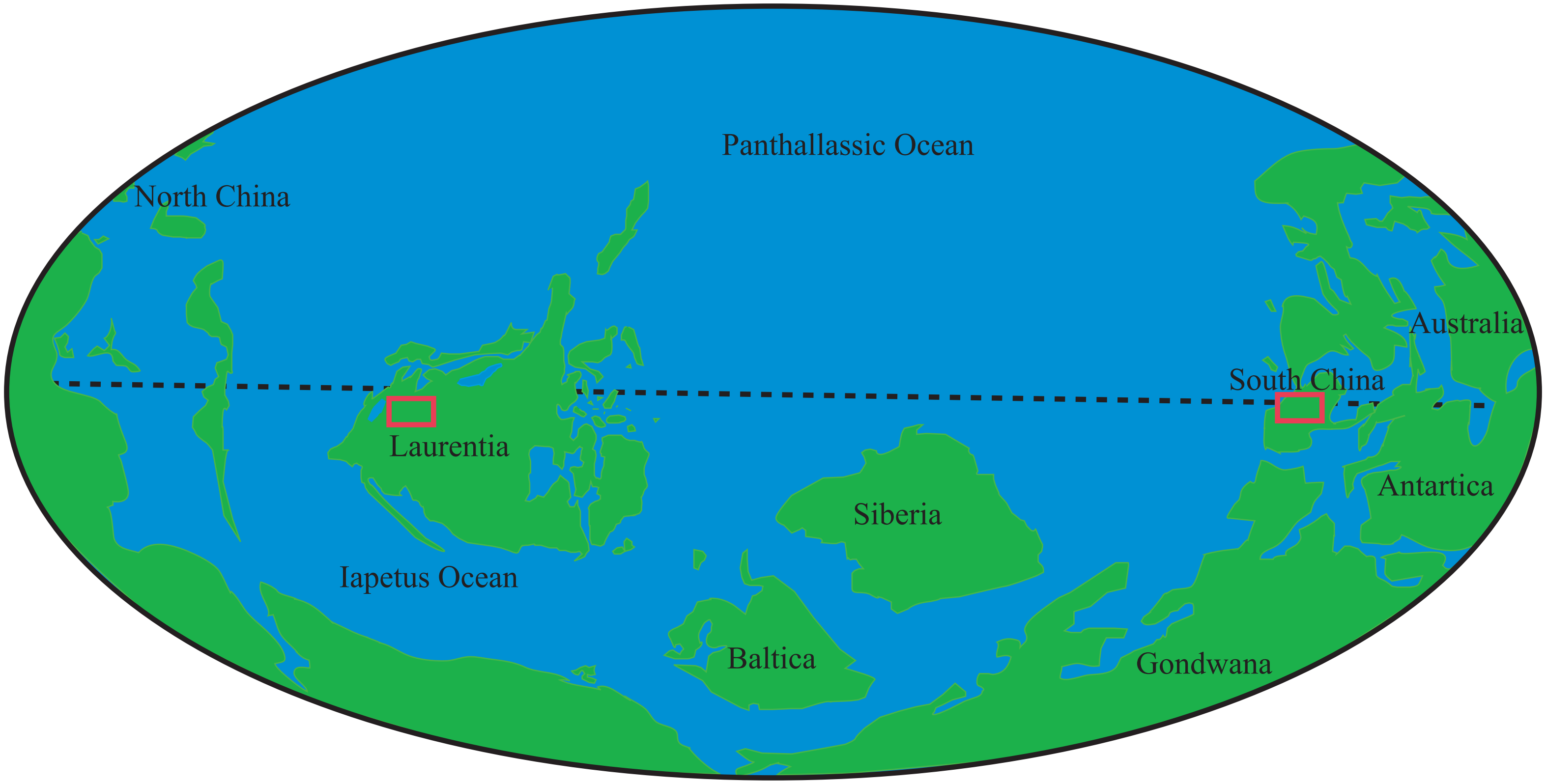

Figure 1. Reconstruction of the Early Cambrian Earth [modified from Smith, 2001]. Red boxes indictate field areas for this study.

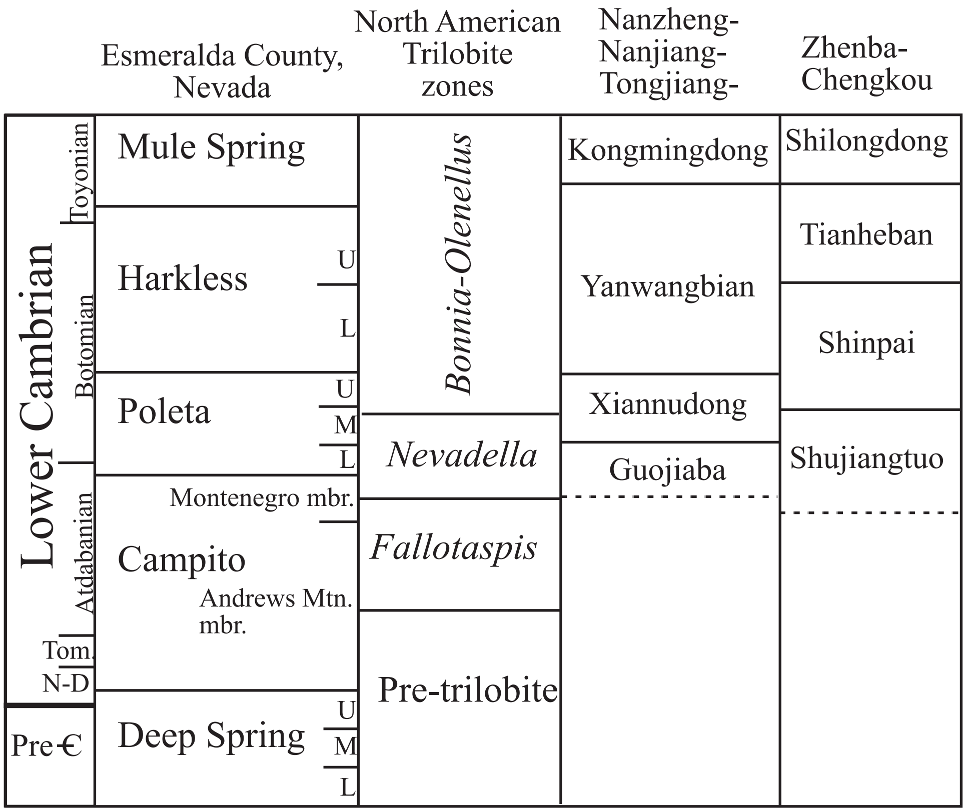

Figure 2. Early Cambrian stratigraphy of Esmeralda County, Nevada. Nanzheng-Nanjiang-Tongjiang are apart of western South China and Zhenba-Chengkou is in eastern South China.

stromatolites, where archaeocyaths are growing on and among stromatolite columns. Archaeocyaths do not appear to form bioherms in all six units; instead, archaeocyath grainstone is observed in-between microbialite boundstone, indicating transportation to their present position. In the Xinchao section (south Shaanxi province, near village of Tongjiang), the Xiannudong Formation is stratigraphically thicker and contains two archaeocyathan-bearing units in the upper portion. In both units, the archaeocyaths are transported either as debris or as nuclei in oncoids. An erosive contact between the Xiannudong and the overlying Yanwanbian is noted.

The final section, Wangjiaping, is located in the Hubei province near the city of Yichang. The Tianheban Formation that is exposed at this locality is younger than the Xiannudong Formation and is hypothesized to be approximately the same age as the Upper Harkless Formation in Nevada (Figure 2). One compound archaeocyathan reef is found in this section. It is approximately 2.1 meters thick with an undeterminable width due to interfingering by mottled limestone and plant coverage. The reef consists of a distinct lower mound that is 1.3 meters thick and an upper mound that is 0.8 meters thick.

Detailed Stratigraphy of the Fucheng Section

The Xiannudong Formation at Fucheng is 67.3 meters thick, and is divided into fourteen beds of which 6 are archaeocyath bearing (Fig. 3). Overall the Xiannudong Formation at Fucheng cycles from massive microbialite limestone with silt drapes to flaky calcareous mudstone and siltstone. Approximately 39 meters are limestone while 28 meters are siliciclastic material. All contacts between limestone and siltstone are sharp and undulatory.

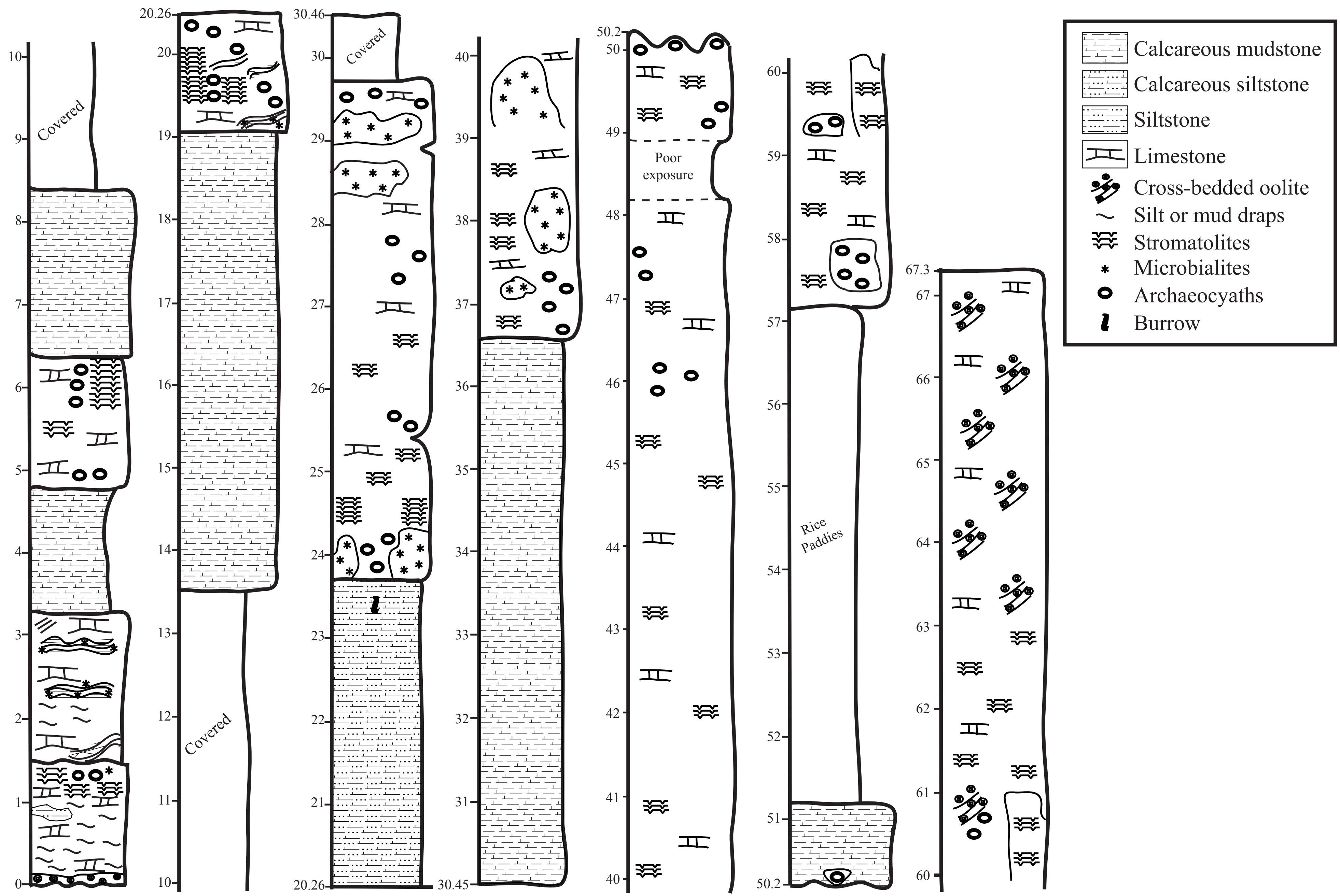

Figure 3. Measured Xiannudong Formation at the Fuchenge section.

Stromatolites and thrombolites commonly construct reefs at this particular section of the Xiannudong. Archaeocyaths are present as debris located in-between domal stromatolites and thrombolites, as separate entities within stromatolites, or as small (1-meter-thick) discrete bafflestone. Typical thick-bedded limestone cycles consist of massive, microbially mediated, light gray limestone with brown silt and mud drapes. Prominent stromatolite and thrombolite columns alternate with microbially induced, domed laminae that are often preferentially stylolitized (Fig 4). The genera of microbes are not yet known. Archaeocyath debris is common as pods in-between or overlying stromatolites and thrombolites, and in the basal beds several instances of archaeocyaths within a domal stromatolite is noted (Fig 5). Some layers contain ooids and archaeocyath debris flanking microbialite bioherms. Archaeocyath bafflestone (approximately 1 meter thick) is rare, but is noted in at least one bed near the top of the formation. Archaeocyathan genera have not been identified, but will be identified to species level in future laboratory work. Several instances of measurable westward dipping cross-beds occur in the thick limestone units and in oolite-bearing units.

All limestone units are theorized to represent "Bahamas type" deposition. A shallow, (intertidal to subtidal) carbonate platform with numerous microbial reefs and migrating ooid shoals. Except for one bed containing the archaeocyathan bafflestone found near the top of this section, additional archaeocyathan bioherms must be located elsewhere on the carbonate platform, for almost all material found flanking the microbial bioherms shows signs of transport.

Cycles of calcareous to non-calcareous, laminated silts and muds occur throughout the Fucheng Section. These siliciclastic cycles are marked by the rarity of

Figure 4. Photograph of typical Xiannudong Formation limestone at the Fucheng section. Styolitic laminae shown above are theorized to be preferentially following microbially induced laminations.

Figure 5. Photograph of archaeocyaths present within a stromalolite. The stromatolite is approximately 27cm in length.

body and trace fossils. Most units are described as recessive, “flaky”, nodular, laminated siltstone and mudstone that is highly porous. Bedding varies in thickness from millimeter to centimeter scale (Fig. 6). Centimeter to several centimeter long horizontal cavities occur throughout these units, which give the nodular appearance.

Discussion

All siliciclastic intervals represent deeper water deposits (deep subtidal). The fine laminations, deposition of muds and fine silts, and few body or trace fossils suggest sea level rise placing the microbial and archaeocyathan reefs into a deeper water regime. The deep water environment cycle was terminated by sea level lowering, which allowed for the recovery of the reefs in that area.

The cyclicity of the Xiannudong Formation at the Fucheng Section represents cyclicity of sea level fluctuations. The presence of microbial bioherms with ooid and archaeocyath debris indicates a shallow subtidal to intertidal zone. The calcareous silts and muds that contain rare body or trace fossils indicate a deeper water setting. These short-term fluctuations in sea level are theorized to be due to a regional tectonic event that is presently unknown.

Future Work

Carbon isotope chemostratigraphy will be used to correlate the sections of China to sections in North America. As a supplement to the carbonate chemostratigraphy, biostratigraphy also will be used as a correlation tool.

Figure 6. Photograph of typical siliciclastic interval of the Xiannudong Formation at the Fucheng section. Note the centimeter scale flaky to nodular bedding.

Isotopic samples collected at 1-meter intervals from the Fucheng, Xinchao, and Wangjiaping Sections will be thin sectioned, examined petrographically for degree of diagenesis, and prepared for carbon isotopic analyses. Currently, thin sections are being prepared for carbon isotope sample extraction.

The Fucheng and Xinchao sections containing the Xiannudong Formation will be correlated with the Middle Poleta Formation in Nevada, while the Wangjiaping Section containing the Tianheban Formation will be correlated to the Upper Harkless in Nevada.

The overall paleoecology of the Poleta reefs will be compared and contrasted to the Xiannudong reefs, while the Upper Harkless reefs will be compared and contrasted to the Tianheban reefs. Determining the paleoecology involves describing the overall morphology and size of the reefs, diversity of organisms throughout the reefs, community structure and possible zonation within the reefs, and the overall paleoenvironment in which the reefs formed.

Large (approximately 30cm x 20cm) samples were collected whenever possible for serial cuts. This technique allows for a detailed analysis of the interaction and growth of archaeocyaths and other organisms. Lithologic samples were collected immediately surrounding the reefs and will be slabbed, thin sectioned and analyzed for lithology, peripheral reef dwellers, and presence or absence of reef debris.

Polished slabs, serial slabs, and thin sections will reveal microfossils, intimate fossil relationships, and the autecology of the archaeocyaths, calcimicrobes, and other reef-dwellers. Autecology involves the analysis of a population or group describing their habitat, diversity, and trophic level. This allows for a more comprehensive description of the community structure and vertical community successions.

Reefs that span from the mid-Early Cambrian will be compared to reefs of the late-Early Cambrian. The reef comparison from peak to decline will include not only the Nevadan and Chinese reefs but will also include a literature analysis of mid-Early to late-Early Cambrian reefs from Australia (Youngs, 1978; Kruse, 1991; Brock and Cooper, 1993), Northwestern Mexico (Debrenne et al., 1989), Mongolia (Wood et al., 1993; Kruse et al., 1996), Antarctica (Rees et al., 1989), Spain (Alvaro et al., 2000), western Canada (Debrenne and Mansy, 1981), Morocco (Debrenne and Debrenne, 1995), and Labrador and Newfoundland, Canada (Debrenne and James, 1981; James and Klappa, 1983).

Information gathered from the literature and laboratory work will includes overall percent of archaeocyaths in the reefs, percentage of ‘Irregulares’ and ‘Regulares’, species richness, percent of branching forms, overall size of the reefs, diversity within the reefs, and presence and abundance of other sponges or corals. This data will be complied into a database, which should expose trends such as decreasing species richness over time and/or increasing prominence of other metazoans like corals or other sponges within the reefs.

The database complied will be the first comprehensive analysis on archaeocyathan decline as documented in the rock record. Changes in community structure, diversity, branching forms, and species richness, as notable in these extinct reefs, may justify speculations on mechanisms, such as changing climate, for their demise.

References

Alvaro, J. J., Vennin, E., Moreno-Eiris, E., Perejon, A., and Bechstaedt, T., 2000, Sedimentary patterns across the Lower-Middle Cambrian transition in the Esla Nappe (Cantabrian Mountains, northern Spain): Sedimentary Geology, vol.137, p.43-61.

Brock, G.A., and Cooper, B.J., 1993, Shelly fossils from the Early Cambrian (Toyonian) Wirrealpa, Aroona Creek and Ramsay Limestones of South Australia: Journal of Paleontology, v. 67, p. 758-787.

Debrenne, F. and James, N.P., 1981, Reef-associated archaeocyathans from the Lower Cambrian of Labrador and Newfoundland: Palaeontology, v. 24, p. 343-378.

Debrenne, F. and Mansy, J.L, 1981, Archaeocyath occurrences and tectonic movements in the Canadian Cordillera: Open-File Report - U. S. Geological Survey, Report: OF 81-0743, p.65-66.

Debrenne, F., Gandin, A., and Rowland, S.M., 1989, Lower Cambrian bioconstructions in northwestern Mexico (Sonora). Depostional setting, paleoeclogy and systematics of archaeocyaths: Geobios, v. 22, p.137-195.

Debrenne, F. and Zhuravlev, A., 1992, Irregular Archaeocyaths: CNRS Editions, Paris, 212p.

Debrenne, F. and Debrenne, M., 1995, Archaeocyaths of the Lower Cambrian of Morocco: Beringeria, Special issue,v.2, p.121-145.

Debrenne, F., Zhuravlev, A.Y., and Kruse, P.D., 2002, Class Archaeocyatha Bornemann, 1884, *in* Systema Porifera: A Guide to the Classification of Sponges, Hooper, J.N.A. and Van Soest, R.W.M., eds., New York, Kluwer Academic/Plenum Publishers, p. 1539-1699.

Gandin, A. and Luchinina, V., 1993, Occurrence and environmental meaning of the Early Cambrian calcareous algae of the Tianheban Formtion of China (Yangtze Area): *in* Baratolo F., De Castro, P., & Parente, M. eds., Studies on Fossil Benthic Algae: Boll. Soc. Paleontol. Ital. Spec. v. 1, p. 211-217.

Hicks, M., 2001, Paleoecology of Upper Harkless archaeocyathan reefs in Esmeralda County, Nevada [master's thesis]: University of Nevada, Las Vegas, 159p.

James, N.P. and Klappa, C.F., 1983, Petrogenesis of Early Cambrian Reef Limestones, Labrador, Canada: Journal of Sedimentary Petrology, v.53, p. 1051-1096.

Kruse, P.D., 1991, Cyanobacterial-archaeocyathan-radiocyathan bioherms in the Wirrealpa Limestone of South Australia: Canadian Journal of Earth Science, v. 28, p. 601-615.

Kruse, P.D., Gandin, A., Debrenne, F., and Wood, R., 1996, Early Cambrian bioconstructions in the Zavkhan Basin of western Mongolia: Geological Magazine, v. 133, p. 429-444.

Qin, H. and Yuan, X., 1984, Lower Cambrian archaeocyatha from southern Shaanxi province, China: *in* Proceedings of the Fourth International Symposium on Fossil Cnidaria (and Archaeocyathids and Stromatoporoids): Washington, DC, Palaeontographica America, p.441-443.

Rees, M.N., Pratt, B.R., and Rowell, A.J., 1989, Early Cambrian reefs, reef complexes, and associated lithofacies of the Shackleton Limestone, Transantarctic Mountains: Sedimentology, v. 36, p. 341-361.

Rowland, S. M., 1978, Environmental stratigraphy of the Lower Member of the Poleta Formation (Lower Cambrian), Esmeralda County, Nevada [Ph.D. thesis]: Santa Cruz, University of California, 107p.

Rowland, S.M. and Gangloff, R.A., 1988, Structure and Paleoecology of Lower Cambrian Reefs: PALAIOS, v. 3, p. 111-135.

Rowland, S.M. and Shapiro, R.S., 2002, Reef Patterns in the Cambrian and Earliest Ordovician: *in* Kiessling, W. and Flugel, E., eds., Phanerozoic reef patterns: SEPM Special Publication, no. 72, p. 95-129.

Smith, A.G., 2001, Paleomagnetically and tectonically based global maps for Vendian to mid-Ordovician time, *in* Zhuravlev, A. Yu and Riding R., eds., The ecology of the Cambrian radiation: New York, Columbia Press, p. 47-68.

Wood, R., Zhuravlev, A.Y., and Chimed Tseren, A., 1993, The ecology of Lower Cambrian buildups from Zuune Arts, Mongolia: implications for early metazoan reef evolution: Sedimentology, v. 40, p. 829-858.

Wood, R., 1999, Reef Evolution: Oxford, Oxford University Press, 414p.

Ye, J., Xu, A., Yang, Y., Liu, F., and Yuan K., 1997, Early Cambrian reefs on the northern margin of the Sichuan Basin: Proceedings of the 30th International Geological Conference, v. 8, p. 356-363.

Youngs, B.C., 1978, The petrology and depositonal environments of the Middle Cambrian Wirrealpa and Aroona Creek Limestones (South Australia): Journal of Sedimentary Petrology, v. 48, p. 63-74.

Yuan, K., Zhu, M., Zhang, J., and Van Iten, H., 2001, Biostratigraphy of archaeocyathan horizons in the Lower Cambrian Fucheng section, South Shaanxi province: implications for regional correlations and archaeocyathan evolution: Acta Palaeontologica Sinica, v. 40, p. 115-129.

Zhang, J. and Yuan K., 1994, Archaeocyath reefs from the Lower Cambrian Tianheban Formation at Wangjiaping, Yichan, Hubei and their diagenesis: Scientia Geologica Sinica, v. 29, n. 3, p. 236-245.