

Cyanobacteria from the Big A Butte Member of the Supai Formation (Lower Permian) in the Holbrook Basin of Arizona: Indications of a Fresh to Brackish Water Depositional Environment*

Karl W. Schwab¹, Michael A. Smith², and Carmon D. Bonanno³

Search and Discovery Article #51647 (2020)**

Posted July 6, 2020

*Manuscript received February 6, 2020, accepted February 19, 2020

**Datapages © 2020 Serial rights given by author. For all other rights contact author directly. DOI:10.1306/51647Schwab2020

¹Consultant, 1718 Triway Ln, Houston, Texas 77043 (karlwschwab@sbcglobal.net)

²Consultant, G-2 Group, 1042A NW 12th St., Pendleton, Oregon 97801

³BECI, Holbrook, Arizona

Abstract

An exceptionally well-preserved assemblage of colonial-coccoid and filamentous fossil cyanobacteria can be found throughout the entire Supai Formation in the Blackstone Exploration Company, Rocking Chair Ranch No. 4 Well, located in Navajo County, Arizona. Of special interest is the variety of filamentous cyanobacteria extracted from the Big A Butte Member of the Supai Formation.

Fossil cyanobacteria in the Big A Butte Member are predominantly of the filamentous type, many of which have a striking resemblance to the extant genera *Tolypothrix sp.*, *Rivularia sp.*, *Jaaginema sp.*, *Geitlerinema sp.*, *Pseudanabaena sp.* and *Fischerella sp.* These cyanobacteria, according to the literature, are most often found associated with fresh to brackish shallow water habitats or terrestrial depositional environments. This being true, and assuming our fossil material is *in situ*, it is our opinion that the Big A Butte Member of the Supai Formation, in this geographical location, most likely represents an environmental ecosystem that was associated with streams, rivers, estuaries, lagoons, tidal flats, littoral zones of intermountain lakes and/or even a large continental sabkha.

Additionally, the conspicuous absence of recognizable marine palynomorphs and other microfossils in our borehole cuttings samples from the Big A Butte Member, is further evidence that points towards an environmentally restricted depositional ecosystem that was more likely to be associated with a fresh to brackish water habitat, rather than a marine environment.

Introduction

The widespread geographical and time-stratigraphic distribution of cyanobacteria throughout Earth's history, provides exploration geologists with an additional "tool" that can be used by biologists and paleontologists to help in the determination, past and/or present, of environmental

conditions. Although the cyanobacteria have seldom been used by Micropaleontologists and Palynologists for age dating or as environmental indicators, it is clear, based on the work of Komarek et al., 2003, that this group of organisms is among some of the most important environmental indicators for those studying regional and local environmental conditions.

Globally, cyanobacteria are found in all types of environments from hot springs in volcanic areas (e.g., Yellowstone National Park) to the freezing cold of the Arctic and Antarctic ice fields. Many are extremely sensitive to water conditions which makes them doubly important in helping to understand past paleo-environmental habitats. The presence of cyanobacteria in the Permian of Arizona, especially within the Grand Canyon, is well documented. However, most of the reports and articles that have been published are discussions on the presence of stromatolites and not the filamentous forms that we observe in the Supai Formation of east-central Arizona.

The abundance of filamentous cyanobacteria in the Lower Permian Supai Formation of the Holbrook Salt Basin of east-central Arizona ([Figure 1](#), [Figure 2](#), [Figure 3](#)) have, as far as these writers know, never been mentioned and/or documented in past geological studies. It is the writers' opinion that the cyanobacteria, especially the filamentous forms, may offer paleontologists and paleobiologists an additional criterion upon which past environmental conditions can be evaluated. The fact that these organisms are so abundant and prevalent throughout the entire Supai Formation in the Holbrook Basin is something that needs to be studied in detail and further evaluated.

Rauzi (2000) has published a good summary of the Supai Formation in the Holbrook Basin along with references of other geologists who have studied the Supai Formation in detail [Winters (1963, p. 9), Gerrard (1964), Peirce and Gerrard (1966), Blakey (1979, 1990), Handford (1981), Elston and DiPaolo (1979), Peirce (1989), Conley (1977), and Rauzi (1999)]. While all these authors have done an outstanding job in providing the readers with excellent geological and paleontological criteria, there has been no mention of the micro-fauna and/or flora of the Big A Butte Member of the Supai Formation. This is especially true when discussing the subsurface stratigraphic section of the Big A Butte within the confines of the Holbrook Salt Basin.

Based on the Mud Loggers drilling report of the Blackstone Exploration Rocking Chair Ranch No. 4 Well, published by MBC Well Logging LLC, Meade, Kansas (2016), the top of Big A Butte Member of the Supai Formation was penetrated at a depth of approximately 1,700 feet ([Figure 4](#)). Although this stratigraphic unit is only represented by approximately 152 feet of section, several hundred feet of the Big A Butte is interpreted to be present below the T.D. of 1,852 feet. [NOTE: This interpretation is based on the cross section prepared by Rauzi, 2000, Plate 4, which shows a nearby well less than 1 mile southeast of the RCR No. 4 Well, the Taubert and Steed No.1 Babbitt Brothers Well located in Sec. 35, T. 14 N., R. 19 E., that contains approximately 580 feet of Big A Butte section].

According to mud logger Mr. Austin Garner with MBC Well Logging LLC, the Big A Butte Member of the Supai Formation, as interpreted by these writers, extends from about 1,700 to 1,852 feet on the Dual Induction Log shown in [Figure 4](#) and consists predominantly of carbonaceous shales and anhydrites. Mottled dolomitic carbonates and red silty and sandy shale in the upper portion, become more brick red in color mixed with traces of light orange fine-grained sandy silt and shale in the lower portion of the unit.

Schwab et al. (2017), in a Source Rock Potential study, subdivided the Supai Formation within the Blackstone Rocking Chair Ranch No. 4 Well into three zones based on changes in the level of Thermal Maturity (Visual Kerogen TAI and estimated Vitrinite Reflectance values, changes in floral composition and significant changes and variations in the Total Organic Carbon Content of the sediments themselves.

The Corduroy Sandstone Member of the Supai (Zone “A”) was defined as that section from $\pm 1,415$ feet (our shallowest sample) to $\pm 1,572$ feet. The Fort Apache Limestone Member of the Supai (Zone “B”) was interpreted to be represented by the section from $\pm 1,572$ to $\pm 1,728$ feet and the Big A Butte Member (Zone “C”) was identified as that sequence from $\pm 1,728$ to $\pm 1,852$ feet (the deepest sample attained).

Based on the observations of Schwab et al. (2017) and without the aid of the newly acquired paleontological data, the writers believed that the upper portion of the Supai Formation, the Corduroy Sandstone and Fort Apache Limestone Members, were associated with a restricted or semi-restricted basin having a dominantly fresh to brackish water depositional environment. The Big A Butte Member was interpreted as being distinctly different from the Corduroy and Fort Apache Members and to have been deposited in a deeper water environment. Although the writers still believe that their initial interpretation of the Corduroy and Fort Apache members were correct, they have since revised their interpretation of the Big A Butte Member of the Supai based on the newly discovered cyanobacterial data.

Purpose of Study

This study is part of an ongoing investigation by the writers into the various depositional environments associated with the Supai Formation in the Blackstone Exploration, Rocking Chair Ranch No. 4 Well, in the Holbrook Basin of east-central Arizona. From the senior writers’ previous investigations regarding the Source-Rock Potential of the Lower Permian Supai Formation, it became clear that each Member of the Supai Formation had a unique and significantly different floral assemblage. This being true, the writers feel that each Member of the Supai Formation (the Corduroy Sandstone, Fort Apache Limestone, The Big A Butte and the Amos Wash members) must be studied as separate units, each independent of the other. The writers believe that once this is accomplished, geologists will be able to get a clearer understanding of the parameters under which the Supai Formation (in total) was deposited.

The purpose of this article on the Big A Butte Member is two-fold and is based on the recovery and identification of filamentous cyanophytes obtained from the organic residues that were extracted from the drill cuttings samples collected from the Blackstone RCR No. 4 Well. First and foremost, we will document the occurrence of several common filamentous cyanobacteria that were observed in the Big A Butte Member of the Supai Formation and compare these fossil organisms to currently published and well-known extant genera and species. Secondly, the writers will use the fossil Cyanobacteria suite extracted from the Big A Butte as a means of defining the depositional habitat that most likely prevailed during the deposition of the stratigraphic sequence during lower Permian time. [NOTE: All the generic identifications of the fossil cyanobacteria presented here were made by the Senior author. He alone is responsible for any misidentifications and/or inaccuracies in the geologic interpretations that may have resulted from them.]

Methods

Most Sedimentary Petrographers and some Micropaleontologists interpret microfossil assemblages by studying the rocks in thin-section. The advantage to looking at fossils using this method is that the analyst can observe the entire fossil assemblage as the organisms inter-related to each other during their existence, before death and prior to fossilization. Palynologists, and most Micropaleontologists, study fossil organisms that have been extracted from the rocks by acidification. Their analytical work is based almost entirely on isolated organic constituents that have been extracted from the rock matrix. Consequently, they seldom see how the individual components of the fossil suite relate one to another.

Microfossil assemblages look entirely different in dispersed organic matter mounts than those observed in thin-section analyses. The advantage to looking at organic residues is that most individual organisms are viewed as dispersed, whole, and complete, individuals. The downside is that most palynologists generally sieve their samples and try to high grade the coarser material (pollen, spores and dinoflagellates above 10 μm in size). Cyanobacteria and other extremely small organisms, usually less than 10 μm in size, are generally sieved out of the processed sample material and flushed down the drain.

In our palynological preparations, the organic matter has been extracted from rock cutting samples by using a combination of concentrated Hydrochloric Acid (HCl) and Hydrofluoric Acid (HF). The extracted organic residue, following acidization, is thoroughly washed, mounted on a cover glass and examined with a precision binocular research microscope equipped with high quality 40x and 100x objectives. Depending on the nature of the organic material, the analyst may choose to examine the organic debris in brightfield illumination, phase-contrast illumination, interference contrast, dark field illumination and/or fluorescence. Regardless of what light source is being used, the maximum effective magnification of the light microscope is generally around 4,000 times through the oculars depending on the microscope being used and how it is equipped (e.g., magnification level of the oculars and/or the presence of an Optivar).

If the analyst is lucky enough to have the use of a Scanning Electron Microscope (SEM), magnifications in excess of 20,000 to 40,000 times is possible. The only drawback in using a SEM, is that one cannot see through the fossilized specimen as in transmitted light. Consequently, only the surface morphology is generally seen, not the intricate internal structure of the cellular tissue and/or color renditions.

Using Isolated organic matter preparations also offer the analyst an advantage in being able to use the sample material for several other types of analyses, not just palynological age dating. Organic residues can aid the geologist in understanding levels of thermal maturity, water salinity (the effect of high concentrations of salt on palynomorphs), hydrogen content (determined by fluorescence microscopy) and the type of hydrocarbon that can be expected to be produced. They also provide clues as to provenience, evidence regarding the recycling of older geological strata into younger age sediments and they often can be used to recognize problems related to the drilling conditions encountered in the well bore (mud additives, number of bit-trips that were made, etc.).

In the study made by these writers, the data presented are based entirely on extracted organic residues recovered from the acid treatment of drilled rock cuttings samples. Unlike most palynological studies, the organic debris has not been sieved so that the fine organic debris is equally distributed along with the coarse debris. The drill cuttings samples used in this investigation were graciously provided by Mr. Carmon

D. Bonanno, formerly the CEO of the Blackstone Exploration Company LLC and co-author of this article. All interpretations presented in this manuscript are based on the writers' belief that the fossil material recovered from the drilled cuttings samples is *in situ* and not the result of contamination due to up-hole caved rock material and/or contaminants associated with drilling mud additives

Discussion

The Big A Butte Member of the Supai Formation is one of four Members proposed by Winters (1963). Winters in his article "Supai Formation (Permian) of Eastern Arizona", Geological Society of America, Memoir 89, defined the Big A Butte Member as that sequence of sediments that underlies the Fort Apache Member of the Supai (whose name was coined by Stoyanow, 1936) and overlies the Amos Wash Member (whose name was proposed and established by Winters, 1963) of the Lower Permian Supai Formation along the western, southwestern and southern margins of the Mogollon Rim in north-central and east-central Arizona. Winters (1963) terminology is currently used almost exclusively within the subsurface of the Holbrook Basin of east-central Arizona ([Figure 5](#)).

As mentioned earlier, there is essentially no information available regarding the paleontology of the Big A Butte Member of the Supai Formation in the subsurface of the Holbrook Basin. Most of the emphasis in past scientific articles (e.g., Winters, 1962, 1963; Gerrard, 1964), has been placed on the overlying more fossiliferous Fort Apache Member of the Supai Formation. Even then, the discussions usually center around the outcrop areas that extend from near Sedona into the Fort Apache Reservation in east-central Arizona. The Sedona area is approximately 80 miles to the northwest of the Blackstone Rocking Chair Ranch No. 4 Well while the Fort Apache location is approximately 60 miles to the southeast ([Figure 1](#) and [Figure 2](#)). While that may not sound like a great distance, especially in the State of Arizona, it can be as different as night and day in the field of geology. Without good paleontological and time-stratigraphic information, coupled with the depositional history of the various Members of the Supai Formation, understanding the geological framework and conditions under which the Holbrook Basin formed (including its tectonic history) is at best, guess work.

Schwab et al. (2017, Figures 19 and 20) illustrated some of the fossil spores and pollen extracted from the Big A Butte Member of the Supai but only a few of the palynomorphs seemed to have any relative stratigraphic significance (the gymnosperms and some of the algae). Since that article was an investigation regarding the Source Rock Potential of the Supai Formation, little attention was paid to the overall floral suite, especially the algae, as they pertained to the environment of deposition for each Member of the Supai.

While researching the various articles in the literature pertaining to cyanobacteria, it quickly became apparent that the writers might be able to use these unique and previously unreported fossils to derive important criteria in the determination of past environmental conditions. In the stratigraphic section between 1,697 and 1,852 feet of the Blackstone Rocking Chair Ranch No. 4 Well various algae, including members of the cyanobacteria, are the most abundant fossil types. In this article, the writers deal specifically with the environment of deposition as defined by the algal flora (cyanobacteria) that is present. The overall goal, present and future, of the writers is to examine each member of the Supai Formation in detail and present our findings, regarding the micro-algal flora, on a Member by Member basis.

Using published information from studies of extant cyanobacteria, the writers have attempted to apply this knowledge to better understanding the environmental conditions and ecological habitats of the Big A Butte Member of the Supai Formation. In doing so, the writers relied almost exclusively on the published works of Komarek et al. (2003) in making generic and specific identifications.

[NOTE: For those who have never used an identification key, such as that presented by Komarek et al. (2003, p. 121-125) please be aware that “size” is not always given as one of the identifying characteristics of a genus and/or species. It is the writers’ belief that Komarek, et al. prepared their “Identification Key” knowing that size differences were most likely a “species-vs-environment” variation and not necessarily a genetic characteristic.]

Depositional Environment of the Big A Butte Member - An Interpretation Based on Cyanobacteria

In the stratigraphic section between 1,697 and 1,852 feet of the Blackstone Rocking Chair Ranch No. 4 Well, interpreted herein as the Big A Butte Member of the Supai Formation, the algae, and in particularly the cyanobacteria, are abundant and well preserved. Because of the overwhelming presence of cyanophytes, it is only natural that the writers would be interested in what the abundant concentration might indicate, especially when it comes to understanding the depositional environment.

Based on our observations of the organic matter slides representing the Big A Butte Member the writers are of the opinion that most of the genera and species of filamentous cyanobacteria are associated with cyanobacteria belonging to the Family Rivulariaceae. Because of their extremely small size, and due to them being heavily calcified, crushed, folded over and altered as a result of mineralization and the effects of the fossilization process, the writers are unable to be 100 percent certain of their generic identifications. However, based on our knowledge of the filamentous cyanobacteria, and the well documented data published by Komarek et al. (2003) we have concluded that most genera and species of our fossil filamentous cyanobacteria are most likely related to the extant Cyanobacteria, *Tolypothrix sp.*, *Rivularia sp.*, *Geitlerinema sp.*, *Jaaginema sp.*, *Fischerella sp.*, and *Pseudanabaena sp.*

In the extant genera and species of filamentous cyanobacteria, the morphological criterion used to identify these forms is based largely on whether the filaments of the colony possess heterocytes, akinetes, false akinetes, whether the trichomes are in a sheath or not, the cellular structure of the trichome itself, the overall shape of the trichome, if the trichomes show true branching or false branching, whether aerotopes (gas vesicles) are present or not, etc. In cyanobacteria like *Pseudanabaena sp.*, the morphology of the individual cells, cell walls and cell wall junctions play an important role as to their identification. We presume that one would also use similar criterion when trying to identify fossil cyanobacteria. Although the writers can recognize certain morphological features in the fossil cyanophytes, features such as akinetes and aerotopes, are difficult to recognize, especially if the fossils are heavily calcified. This, plus their minute size, makes recognizing structures less than 0.5 µm in size almost impossible. What is needed in this instance is to be able to examine the trichomes using a SEM (Scanning Electron Microscope) or some by some other high definition photographic process.

Fragments of the cyanobacteria *Jaaginema sp.*, which are generally easy to recognize, are common not only in the Big A Butte Member of the Supai Formation, but throughout the Fort Apache and Corduroy members as well. Other cyanobacteria, having similarities in their gross morphology to the genera *Geitlerinema sp.*, and *Fischerella sp.*, are also present. These two genera differ from many of the others in our

samples because *Geitlerinema sp.*, often has a distinct hook-shaped feature on the terminal ends of their cells while *Fischerella sp.*, appears to have club shaped filaments. As was noted in our observation on the genus *Jaaginema sp.*, both forms appear to have very fine ridges on the surface of their filaments. Whether these ridges are representative of a growth-ring pattern and/or reflect the arrangement of internal cellular components, we do not know ([Figure 13](#), [Figure 14](#), and [Figure 15](#)). No information regarding morphological features having similarities to what we describe as being “ridges” or “growth-rings” is mentioned in the writings of Komarek et al. (2003). Whether the “ridges” or “growth-ring pattern” are a feature associated with the process of fossilization or associated with a thin membrane covering the filament of the cyanobacteria, is open to speculation.

Based on this new information pertaining to the abundance of cyanobacterial organisms in the Big A Butte Member, the writers believe that this stratigraphic unit was most likely associated with an environmental ecosystem that can be linked to streams, rivers, estuaries, lagoons, tidal flats, littoral zones of intermountain lakes and/or even a large continental sabkha. We do not believe that the Big A Butte Member, at this location within Holbrook Basin, was deposited in a marine environment. Based on what we have read in the literature regarding the habitats of these cyanobacterial types we interpret the general condition of the waters in which the organisms lived to have been moderately clear, not heavily polluted, and probably less than 10 meters in depth.

The Paleoecological Significance of Cyanobacteria

Most Micropaleontologists and Palynologists have little working knowledge about the Cyanobacteria (cyanophytes) and what the presence of these organisms means when it comes to defining environments of deposition. The reason for that is, in part, because most Universities do not recommend that their geology students branch out and try to link their research projects with research being conducted by other departments of science. This results in a general lack of inter-departmental cross-over between the various scientific disciplines. As a result, microfossils like the cyanobacteria are generally overlooked or ignored by most Micropaleontologists and Palynologists. This is understandable, especially when there have already been so much data accumulated and published regarding the use of other fossil groups that are well documented as time-stratigraphic indicators, many of which are better understood and easier to work with. However, in depositional settings, such as the Big A Butte Member of the Supai Formation, where the more commonly used fossil forms are absent or scarce, cyanophytes may prove to be of value as good environmental indicators. Unfortunately, there is almost a total lack of information pertaining to the occurrences and environmental significance of the Cyanobacteria in the geological literature. What information is present pertains primarily to the occurrences of the larger colonial forms and not the more delicate coccoid and filamentous types that are extracted as isolated acid insoluble entities used in Palynological and Visual Kerogen analyses.

As stated earlier, the Senior author based the generic interpretations in this study exclusively on the Generic Identification Key of Extant Cyanobacteria published and illustrated by Komarek et al. (2003, p. 121-125). In the years since Komarek et al. published their Identification Key, much work on the cyanobacteria has been done. Today most identifications of extant genera and species require additional, more sophisticated biochemical-marker information as well as DNA Sequencing. Unfortunately, the use of these techniques is beyond the scope of this article. Being independent researchers, the writers do not have access to all the published information that Institutions of higher learning are privy, so we are limited and hampered in our acquisition of data.

As geologists and paleontologists, the writers are somewhat restricted in our approach to the identification of fossil organisms. We hesitate to clutter the literature by erecting new genera and species just because we cannot find forms that are exactly like the ones we observe. Because many algae, including the Cyanobacteria, are polymorphic in nature, the same genus may exist in several different forms depending on environmental conditions. Even though we attempted to try and key-out the morphological features of our fossil material and compare it to extant organisms, we may or may not have our genera correctly identified.

In this manuscript, the writers have gone to great lengths to properly document and illustrate the fossil cyanobacteria that we have observed within the Big A Butte Member of the Supai. The photographic figures presented are a little different than normal photomicrographs taken through the microscope. Most of the photomicrographs in this manuscript, are composed from a series of stacked images that have been made into three dimensional-like photographic images using the Helicon Focus 6 Software Package. The fact that many of the cyanobacteria filaments cannot be viewed in a single focal plane, due to being intertwined and highly flexible, makes it necessary to utilize this type of software in order to be able to properly display the fossil filaments in their entirety. All the generic identifications made during this study have been based solely on the external and internal morphological details that were observed in the fossil material.

What Are Cyanobacteria?

The Cyanobacteria, also called the blue-green algae and/or cyanophytes, are among the oldest living group of organisms on Earth. They are classified within the Eubacteria because of their simple prokaryotic cellular structure and rigid cell wall. They stain gram-negative when using the Gram and Zeil Neelsen staining method (common stains used in Bacteriology for separating gram negative from gram positive bacteria).

Their origin in time goes back Eons, at least to the Archean-Proterozoic of the Precambrian, 2.5 to 3.5 billion years ago or more. The cyanobacteria make up a large and diverse group of organisms here on Earth. They occur in all types of environments, from terrestrial soil profiles, to fresh, brackish and marine waters, and in more extreme habitats such as hot springs, hypersaline lakes, desert environments and even the arctic cold. Cyanobacteria are found on decaying vegetation and even deep below the Earth's surface in the total darkness of rock crevices and fractures, caves and caverns, hundreds of feet below the Earth's surface. The current classification of the cyanobacteria, originally based on their morphological characteristics and biochemical properties, has now become more complicated and precise thanks to DNA Sequencing Methods and new Biochemical Techniques. Rather than get into a lengthy discussion regarding the taxonomy, identification and ecology of the cyanobacteria, the writers suggest that those wanting to know more about this group of organisms, see Komarek et al. (2003) (p. 117-196) or their new and revised manuscript in the 2015 second edition of *Freshwater Algae of North America, Ecology and Classification* by Wehr, Sheath and Kociolek, ISBN-978-0-12-385876-4.

Komarek et al. (2003) divided the cyanobacteria into two broad groups, the Coccoid and Colonial Cyanobacteria and the Filamentous Cyanobacteria. In this study, the writers are primarily concerned with the Filamentous Cyanobacteria. Although members of the Coccoid and Colonial Cyanobacteria are present throughout the Supai Formation, we believe that it is the filamentous forms that will provide the most useful information regarding depositional environments.

Filamentous Cyanobacteria

To quote Komarek et al. (2003) (p. 117) “filamentous cyanobacteria (blue-green algae, cyanoprokaryotes) include some of the most widely recognized and important freshwater algae in the world, many of which produce surface blooms, fix atmospheric nitrogen, and are important components of global carbon.” The fact that many of the filamentous cyanobacteria are indicators of a specific environmental ecosystem, makes them well-suited for their application in the study of the Big A Butte Member of the Supai Formation. As noted by Komarek et al. (2003) the classification system that is used for distinguishing genera of filamentous cyanobacteria is based on phenotypic characters that have been supported by ultrastructure and molecular data. Of interest is the fact that Komarek et al. (2003) rarely use size as one of the characteristics for identification. In some instances, a size range is mentioned in his “Key and Descriptions of Genera (Figures 1-40, p. 121-125), in others it is not. The extant species of filamentous cyanobacteria genera that we discuss here, *Tolpothrix sp.*, *Rivularia sp.*, *Jaaginema sp.*, and *Fischerella sp.*, may vary considerably in size. We base this premise on the fact that Komarek, et al. (2003) did not assign a given size-range for members within these genera. The writers feel that this omission is of great importance when it comes to identifying fossil cyanobacteria. It suggests that size is more associated with environmental conditions than a characteristic of the genus and/or species itself. This is of primary importance since the size range of our fossilized material is several magnitudes smaller in size than the extant (living) forms published in the literature. Other extant genera mentioned in the manuscript, e.g., *Geitlerinema sp.* and *Pseudanabaena sp.*, have specific size values that have definitive limits. The question is: Do these size limits hold true for fossil forms that lived during the Lower Permian? We do not know.

Although the Generic Classification Key presented by Komarek et al. (2003) is one of the most widely used method for the identifying and classifying extant genera and species of cyanobacteria, recent advances in the study of cyanobacteria using ultramolecular biochemical typing and DNA Sequencing Methods may force a change in how the extant cyanobacteria will be classified in the future. More and more researchers, using sophisticated biochemical and DNA information, are expanding the “Clads” to which the cyanobacteria belong. [NOTE: A Clad is a taxonomic grouping of organisms that is recognized to have forms descending from a common ancestor. Detailed biochemistry has shown some species to have definite traits that can be related to more than half a dozen different genera. Could this be related to polymorphism? These writers do not have an answer for that question. While all these new techniques are useful and good, it also makes one wonder if taxonomic identification is becoming overly specific to a point that it becomes impractical for the average Microscopist to try and define a given cyanobacteria down to the species or sub-species level.] How this will affect the identification and generic speciation of both extant and fossil material in the future is open to question

In this study, and probably all future studies where fossil material is being used, the classification of fossil cyanobacteria will most likely be confined to using the morphological and ultrastructure portion of the Identification Key published by Komarek et al. (2003). The reason for this is that in studying fossil cyanobacteria, palynologists must rely primarily on the morphological and internal structures of the organism because the fossilized organic material generally represents only a “replica” of what was once the true individual. That is not to say that some organisms having cellulosic or chitinous bodies are not preserved pretty much intact, they sure can be. Normally, in fossilized organic soft bodied organisms, we are generally not looking at the actual chemical composition of the individual. The delicate soft tissues, linings and ornamentation of the living organisms are, more often than one realizes, replaced by various mineral components (e.g., calcite, hydroxyapatite, amorphous silica, pyrite, etc.). Replacement and replication of the finite structures can be so complete that the analyst believes that the

organism is exactly as it was during life. In some recent findings, paleontologists have discovered mammals are preserved so well, even the hair strands, blood and internal fluids are still present.

Interpretation of Data

As mentioned earlier, the basis for our interpretation is predicated on the belief that the cyanobacteria observed in our organic matter residues from the Big A Butte Member of the Supai Formation in the Blackstone Rocking Chair Ranch No. 4 Well are *in situ* and not the result of contamination (e.g., due to up-hole cave, recycling, stratigraphic leakage and/or from drilling mud additives).

The writers, whenever and where possible, have attempted to compare the fossilized materials of the Big A Butte to more pristine extant organisms. [Figure 6](#) shows the comparison of filaments from the extant cyanobacteria *Gloeotrichia sp.*, cf. *G. echinulata* to those cyanobacteria filaments extracted from the Big A Butte Member. The fossil filaments, based on their morphology, are interpreted to belong to, or be related to, the cyanobacteria *Rivularia sp.* The comparison between the extant genus *Gloeotrichia sp.* and the fossil specimen, interpreted as belonging to the genus *Rivularia sp.*, is intended to show the reader some of the differences between the two genera. In *Gloeotrichia sp.*, one can clearly see that the filament possesses a somewhat small circular or globular basal heterocyte next to a thickened darker-colored collar-like mass called an akinete. Compare that to the filaments from *Rivularia sp.* The basal heterocytes are more elliptical and larger than the diameter of the filament and look more like a donut than those of *Gloeotrichia sp.* Also, there is the total absence of anything that even might resemble an akinete. A question one might ask is: Has this always been a distinguishing factor throughout geologic time? That we cannot answer and most likely the experts in the field do not know the answer either.

Terminology

As in any study where morphological terms are used for taxonomic identification, the reader is expected to know what is being discussed. Not everyone, even paleontologists, can fully understand all the terminology that is currently being used in the various scientific disciplines. To avoid some of these problems, the writers have included the definitions for a few of the morphological terms used by analysts in their identification of Cyanobacteria. We include these “morphological terms” in the hope that it will lead the reader of this article to a better understanding of what is being discussed in this study.

The terms listed below and in [Table 1](#) are but a few of the more important physical criteria used by microbiologists to define to what genus and/or species a known filamentous cyanobacteria might be assigned. The terms are included here to help educate the reader to a better understanding of what the writers will be discussing in this portion of the text. Most of the definitions for the morphological terms given below are from Wehr and Sheath (2003, p. 835-848). Others are from other online sources (dictionaries, etc.). Understanding the morphological terminology used to describe the Cyanobacteria, and the meaning of those terms, is essential to their identification.

Aerotope:

The term Aerotope refers to clusters of gas vesicles that form within the filaments of some cyanobacteria. These are also referred to as gas vacuoles in older reports.

Akinetes:

What are Akinetes? Simply put, an akinete as stated by Wehr and Sheath (2003, p. 835) is “A thick-walled cell produced by members of several algal classes, may be released by vegetative cells or attached to filaments.” The cell functions as an asexual resting-spore and is resistant to low temperatures and other harsh climate conditions. When conditions become more favorable for plant life, the resting spore germinates into a new colony.

Epilithic:

A term used to describe Cyanobacteria (or plants) growing on the surface of stones and rocks.

Epiphyte:

A term used to describe a plant that grows on another plant but is not parasitic.

False Branching:

According to Wehr and Sheath (2003, p. 839), False branching is “a condition where branches arise from a break in the main filament (due to the death of a cell within the filament) and the continued growth of one or both ends.” In cyanobacteria, only the sheath splits while the vegetative trichomes separate.

Filament:

The term filament, as defined by Wehr and Sheath (2003, p. 840), is a common type of thallus (undifferentiated vegetative tissue of some organisms such as algae, fungi, liverworts, etc.) in which the cells are arranged in a series and where the cells share a common cross-wall with the adjacent cells. Sometimes the writers refer to filaments as trichomes. [NOTE: Depending on how the term trichome is used, it may or may not be grammatically correct. A trichome refers to the row of cells in a filament of a Cyanobacteria, while the trichome with the enclosing mucilaginous sheath, is collectively termed the filament.]

Filamentous Sheath:

The filamentous sheath is a mucilaginous covering surrounding the cells of the filament. The sheath can completely enclose the filament or be partially open.

Heterocyst (Heterocyte):

A heterocyst, also called heterocytes in older literature, as defined by Wehr and Sheath (2003, p. 841), is a thick-walled, multilayered cell that is present in some cyanobacteria. It is gas-tight and aerobic. Heterocysts contain the nitrogenase enzyme that allows the organism to fix atmospheric nitrogen used for the fixation of gaseous nitrogen (N_2). In the filamentous cyanophytes they often appear at the base of the filament (trichome) and are therefore often referred to as basal heterocytes.

Heteropolar:

Heteropolar filaments are those with distinct basal and apical components or cells that are asymmetrical along the transverse axis.

Isopolar:

In the Cyanobacteria, this term means symmetric to the transverse (longitudinal) axis of a filament.

Thallus:

Refers to the plant body of algae. The thallus, or thalli, of algae is not differentiated into a stem or leaves and lacks the true roots system that is common in a vascular plant system.

Trichome:

The term Trichome, as used in the cyanobacteria morphology is, according to Wehr and Sheath (2003, p. 847), is the filament portion of the cyanobacteria without its sheath.

Filamentous Cyanobacteria from the Big A Butte Member of the Supai Formation

In this study of the Big A Butte Member of the Supai Formation, the writers discuss and illustrate six well known genera of filamentous cyanobacteria, *Tolypothrix sp.*, *Rivularia sp.*, *Geitlerinema sp.*, *Jaaginema sp.*, *Pseudanabaena sp.*, and *Fischerella sp.*, that were observed in their organic matter slides. We believe that the extraordinarily large concentrations of these cyanophytes provide geologists and paleontologists with important new clues and previously unknown data pertaining to the water conditions that existed within the deposition environment of the Big A Butte sequence in the Blackstone Exploration Rocking Chair Ranch No. 4 Well of the Holbrook Basin during Early Permian time.

The cyanobacteria, listed above, are unique because, (1) they have never been reported from the Lower Permian of Arizona before, and (2) their fossil representatives have never been used by geologists to try and determine the environmental conditions that prevailed during the Lower Permian depositional cycles within the Holbrook Salt Basin.

In this portion of the report, the writers illustrate and include a short description of the cyanobacterial genera being discussed. As in all studies of this nature, the Senior writer focused heavily on the internal and external anatomical structures of the cyanobacterial remains, including subtle changes in shape, size and thickness as observed in brightfield and phase contrast illumination. Oftentimes the Senior author used other lighting techniques that are available with the editing tools that come with Adobe Photoshop and/or Ulead Systems Photo Impact Pro as well as the examination of some of the organic constituents in Polarized light.

Genera of Filamentous Cyanobacteria Observed in the Rocking Chair Ranch No. 4 Well

Tolypothrix sp., [Figure 7](#), [Figure 8](#), [Figure 9](#)

According to Komarek et al. (2003, p. 161) the extant Genus *Tolypothrix sp.* belongs in the Order of cyanobacteria identified as the Nostocales. This is one of the largest groups of extant filamentous cyanobacteria. The filamentous cyanobacteria may be simple filaments or branched, some have heterocysts, and some are encapsulated within a sheath.

The genus *Tolypothrix sp.*, as described by Komarek, is as follows, “Thalli (a plant-like body) that form wooly mats, tufts, or caespitose (tuff-like clumps) colonies.” Filaments of *Tolypothrix sp.* are heteropolar, often very long with basal heterocytes and free apical ends. The heterocytes are generally spherical, cylindrical or hoop-shaped with one or two pores. The heterocytes are often situated intercalary, singly or in pairs, and often at the base of the branches (false branching).

Tolypothrix sp. often exhibits signs of false branching. False branching in this genus begins next to the heterocytes, diverging slightly from the main filament and forming two morphologically identical branches. A good example of false branching is shown by Komarek et al. (2003, p. 160, Figure 22).

The genus *Tolypothrix sp.* is generally found associated with unpolluted freshwaters, often attached to stones and other vegetation or forming mats. They are known to grow in temperate environments with poor light conditions and high phytoplankton biomass, such as those found in shallow lakes. Some are found in mineral springs, streams and alkaline swamps or subaerial habitats. Many species are known from tropical and subtropical environments. The writers are unaware of the genus having been reported from deep-marine environments.

The specimens of *Tolypothrix sp.* in our samples from the Big A Butte Member have basal heterocytes that are approximately 1.5 to 2.0 μm in size. These heterocytes have a circular to oval shape, often containing tiny pore-like structures (one, sometimes two) that are stained dark red. Whether the red stain is due to the accumulation of certain chemicals and mineral components in the “pore area” or reflects changes in chemical composition within the tissue of the heterocyte, we do not know. All we can say is that when “pores” are present, the area is marked by a reddish-colored stain. Filaments in the samples range in length from approximately 10.0 to 20.0 μm (from the base of the heterocyst to the tip of the filament). The filaments of *Tolypothrix sp.* in our samples are “whip-like”, and their length is approximately 10 to 12 times the diameter of the heterocyte. Akinetes and aerotopes are absent.

Rivularia sp., [Figure 10](#), [Figure 11](#), [Figure 12](#)

The extant genus *Rivularia sp.*, according to Komarek et al. (2003, p. 166, 168-169, Figure 27), is a filamentous cyanobacteria whose thallus is composed of filaments arranged in parallel. Like *Tolypothrix sp.*, the genus is thought to belong to the Order Nostocales but there is some uncertainty in its position by various taxonomists.

Rivularia sp. is commonly attached basally to the substrate, rocks or other pieces of vegetation, forming hemispherical colonies. The colonies are highly variable in size. As the colonies grow and become macroscopic, they become layered (hemispherical, flat and/or irregular in shape and up to several millimeters thick. The filaments are heteropolar and covered by a firm, mucilaginous or gelatinous sheath which easily become encrusted with calcium carbonate. Trichomes are hair-like and cylindrical to subcylindrical with basal heterocytes. Cells making up the filaments are barrel-shaped or cylindrical, elongate, narrow at the apex without aerotopes and do not contain aerotopes. Heterocytes are spherical to hemispherical and positioned basally or occasionally intercalary. No species in this genus has been reported to have akinetes.

Over 20 extant species of the Genus *Rivularia sp.* have been described and recognized by taxonomists. Most are epilithic, especially on calcareous (limestone) substrates (strata), or epiphytic. They are known to form travertine deposits [Note: Travertine is a sedimentary rock. It is

generally found associated with hot springs. Travertine is a variety of limestone that is chiefly composed of calcium carbonate. Varieties of Travertine are individually characterized by the types of accessory pigments and other minerals that occur within natural cavities in the rock.] Most fresh water species colonize in clear, unpolluted standing and running waters. Several species are known to occur in marine littoral waters. The extant calcified species, *Rivularia dura*, is mainly distributed in tropical and subtropical limestone regions, but it has also been reported from regions in the eastern Arctic of Canada. Whether the fossil representatives of this genus occupied similar habitats during the Lower Permian, we do not know. We can only assume that they lived and proliferated in a similar environment then as they do today.

In the Big A Butte Member, fossils that the writers interpret as belonging to the genus *Rivularia sp.*, appear to be well represented. Figure 10, shows a colony of cyanobacteria that the writers believe to be *Rivularia sp.* Note the “thumb print-shaped” colony and especially the concentration of the filaments in a hemispherical (heteropolar) arrangement. The specimens of *Rivularia sp.*, in the Big A Butte Member are associated with orange to red, shale with some very fine grained siltstone and sandstone. This suggests that the colony may have been associated with wet river channels or mud flats bordering a large body of water. Specimens of *Rivularia sp.* in our sample material from 1,852 feet in the Blackstone Exploration Rocking Chair Ranch No. 4 Well, have circular to sub-circular heterocytes. The heterocytes are approximately 0.8 to 1.0 μm in size and do not show the presence of any pores. Akinetes and aerotopes appear to be absent. The filaments are about the same length as those observed in the genus *Tolypothrix sp.* They appear slightly thicker (or flatter) and do not appear to be as sinuous and/or whip-like as those of *Tolypothrix sp.*

[NOTE: A question that is sure to arise is: Could the fossil specimens we are calling *Rivularia sp.*, belong to the genus *Gloeotrichia sp.*? The writers do not believe that any of the fossil specimens they observed in the assemblage from the Big A Butte Member of the Supai Formation belong to the genus *Gloeotrichia sp.* While the genus *Rivularia sp.* has a similar appearance in size and shape to *Gloeotrichia sp.* it does not possess akinetes like the genus *Gloeotrichia sp.* However, when the akinetes of *Gloeotrichia sp.* cannot be seen clearly, it becomes nearly impossible to tell the difference between the two genera. This is especially true for those specimens which have been fossilized. Until such time as we can accurately identify cyanobacterial filaments having akinetes present near the basal heterocyst, we will regard our fossilized sample material as belonging to the genus *Rivularia sp.*

Jaaginema sp. [Figure 13](#), [Figure 14](#), [Figure 15](#)

Fossil cyanobacteria that appear very much like the genus *Jaaginema sp.*, are very common in drill cuttings samples from the Big A Butte Member. *Jaaginema sp.*, according to Komarek et al. (2003, p. 128) are placed in the Order Oscillatoriales. The genus is part of a group of cyanobacteria all of which have cylindrical cells that are joined end-to-end forming simple, unbranched, thread-like filaments. The extant genus is readily identified by its distinct morphology (shape and size), although other forms having a similar morphology to *Jaaginema sp.* (e.g., *Pseudanabaena sp.*) are also present.

In our organic matter slides, *Jaaginema sp.* has the appearance of minute, thin, straw-like or cane-like rods interspersed throughout the organic matter suite. They often occur as long, solitary fragments of individuals and/or in a maze of shorter fragments stacked haphazardly in clumps. Although Komarek et al. (2003) state that the trichomes (filaments) can be up to 3.0 μm in width, most of our fossil specimens' range in size

from approximately 0.5 to 1.0 μm in diameter. The cells making up the filamentous rods of the extant genera of *Jaaginema sp.* are cylindrical and uniform in appearance. They do not contain aerotopes (gas bubbles or cavities) and are not constricted at the cross-walls.

As defined by Komarek et al. (2003, p. 126) members of the genus *Jaaginema sp.* form as thin, membranous thalli without sheaths, often in entangled clusters. They are always nonmotile. Reproduction is via fragmentation. According to Komarek et al., the genus *Jaaginema sp.* consists of over 20 species, most of which are benthic, living in shallow water in or on sediments and aquatic plants. The cyanophyte *Jaaginema sp.* is found in all types of waters, freshwater to marine, often loosely associated with aquatic plants. Several species are known from thermal or mineral springs in North America (e.g., Yellowstone National Park in Wyoming) and some marine forms have been reported.

The specimens of *Jaaginema sp.* in the samples from the Big A Butte are as Komarek et al. (2003) described. However, our fossilized specimens appear to have a thin gelatinous or mucilaginous sheath that has “growth rings” along the entirety of the specimen. We are not sure if the pattern of finite ridges on the exterior of the cyanobacteria represents growth stages or reflects the location and position of internal cellular structures (i.e., cell walls). The ridges vary from approximately 0.1 to 0.8 μm in width along the entire length of the filament and are difficult to see in transmitted illumination. We have taken the liberty, using our computer software tools to enhance and illustrate their presence in our photomicrographs ([Figure 13C](#), [Figure 14C](#), [Figure 15C](#)).

Geitlerinema sp., [Figure 16](#)

Cyanobacteria placed in the genus *Geitlerinema sp.*, Order Oscillatoriales, according to Komarek et al. (2003) are characterized by having a thin thallus with trichomes ranging from approximately 0.6 to 6.5 μm wide. They usually occur in parallel arrangements, cylindrical, straight or slightly flexuous and/or rarely coiled (screw-like). The filaments are without sheaths and the cell cross-walls are generally not constricted (some may show a slight constriction). The filaments are sometimes tapered. The individual cells of the filament are several times longer than they are wide.

Apical cells (pertaining to the end portion of the cell) are often conical, hooked or bent, having a distinct flexuous appearance due to their shriveled appearance. Most are tapered or rounded while occasionally spherical to capitate (ending in a distinct compact head). The trichomes are motile, with strong gliding movements in the direction of the longitudinal axis.

Environmentally, *Geitlerinema sp.* has been observed to occur in thin mats on soils or in various aquatic habitats (often on macrophytes and other substrates). The genus is often associated with unpolluted waters. It is the most common species in the periphyton (the community of tiny organisms that lives on the surfaces of rooted aquatic plants) of oligotrophic to mesotrophic waters in the north-temperate region (the zone of the Earth lying between the Tropic of Cancer and the Arctic Circle). It is common in soft-water granite bottom lakes in the western and eastern portions of Canada where mountain bedrock is exposed in lake bottoms. Some species have been reported from thermal and mineral springs in Yellowstone National Park, Wyoming and from various localities of Puerto Rico.

Although Komarek et al. (2003, p. 126) do not mention the genus being associated with marine environments, a recent article by Tinpranee et al. (2018) indicates the genus also occurs in the marine waters of Thailand. With the high influx of coastal freshwater entering these offshore

marine areas, the writers suspect the coastal marine waters mentioned by Tinpranee et al. (2018) are probably more brackish in nature than highly marine.

Pseudanabaena sp., [Figure 17](#), [Figure 18](#)

The genus *Pseudanabaena* sp., also classified as a filamentous form of cyanobacteria in the Order Oscillatoriales has a completely difference appearance than the filamentous forms, *Tolypothrix* sp. and *Rivularia* sp., previously mentioned. This organism typically has a cylindrical and rod-shaped morphology with slight constrictions at the cell cross-walls. The colonies of *Pseudanabaena* sp. are generally not very long and commonly occur as short rod-shaped constituents. Heterocytes, akinetes, branching in any form are notably absent. The trichomes generally occur as solitary filaments or in fine mats. According to Komarek et al. (2003, p. 129) the colony is constructed of cells that are separated from one another by distinct cross-walls. The organism is generally 1.0 to 3.5 µm in diameter and the trichomes lack firm sheaths (although some have a wide, fine, diffused mucilage). A good example of the morphological variations (which reminds one of a long line of sausage-shaped individuals laid out in a row) can be seen on page 127, Figure 1B, illustrated in Komarek et al. (2003). Cells of *Pseudanabaena* sp. may or may not have polar aerotopes. If aerotopes do occur, they are typically localized in the ends of cells (in polar positions). The ends of the cells are typically rounded, but can be conical, blunted or sharply pointed.

Ecologically, *Pseudanabaena* sp. is most often found associated with planktonic, metaphytic, periphytic or benthic habitats in waters of different trophic (feeding positions in various water environments) levels. Several species are known to be associated with mineral and hot springs and saline or hypersaline localities. Some occur in the soil and mucilage of other algal types. Some species have been recorded from oligotrophic and eutrophic waters of North America, while several have been found within alkaline conditions. To our knowledge, they are not commonly found in marine conditions.

Fischerella sp., [Figure 19](#), [Figure 20](#)

[NOTE: Prior to discussing the extant genus *Fischerella* sp., Order Nostocales, the writers want to stress that some fossil cyanobacteria are difficult to identify even to the Order or Family level, not to mention the Genus and/or species. Such is the case with the fossil forms that we have identified as belonging to the genus *Fischerella* sp. Although this fossilized specimen of cyanobacteria appears to be well preserved, the writers cannot see enough morphological detail to accurately determine whether the cyanophyte exhibits true branching or false branching. The organism illustrated herein as *Fischerella* sp. could possibly fit into two of the following four extant genera, *Fischerella* sp., *Schmidleinema* sp., *Geitleria* sp., or *Colteronema* sp. It is the Senior writer's opinion that the fossil organism appears to exhibit true or pseudo-dichotomous branching and because of its overall leaf-like external morphology (based on the Komarek et al., 2003, drawing in Figure 37A on p.185), it belongs in the Order Nostocales, Family Hapalosiphonaceae. The Senior writer interprets the fossil cyanobacterium, illustrated in [Figure 19](#) and [Figure 20](#) to represent a fragment of thalli from either *Fischerella* sp. or *Colteronema* sp. (Order Nostocales-Stigonematales). It is the Senior writer's opinion that the fragment illustrate herein belongs to the genus *Fischerella* sp. The reason for this interpretation will become clear when the genus *Colteronema* sp. is discussed later in the text.]

According to Komarek et al. (2003, p. 184) the extant cyanobacteria *Fischerella* sp. consists of a thallus that is morphologically diverse. The thallus of *Fischerella* sp. can be uniseriate or multiseriate (bifurcate and trifurcate). It is composed of elongated creeping, wavy or finger-like filaments that develop from erect uniseriate branches. The thalli often break off the main portion of the thallus forming cluster of two or more appendages (thalli). (See Komarek et al., 2003, p. 185, figure 37A.)

Sometimes the filaments branching off the uniseriate branches are solitary, or they can be grouped in pairs or in multiple numbers. They are often thick due to the presence of a laminate gelatinous sheath surrounding the cells of the filament. The thickened gelatinous sheath often makes them appear as flattened, undulated and elongated, leaf-like extensions. Akinetes are known in only a few species. Some branches contain aerotopes, in a polar (?) position. The overall colony produces creeping mats, a velvet-like or felt-like covering, on the surface of wet rocks and other moist substrates.

Regarding the habitat of *Fischerella* sp., Komarek et al. (2003, p. 184) state that most species of this genus are subaerial and epilithic, often found growing on wet acidic rocks (extrusive or volcanic igneous rocks that have cooled on the surface), in soils and on other substrates. Several species have been reported from tropical areas, growing on, and/or associated with, mosses while other species have been reported from thermal water sources in Hawaii and British Columbia, Canada. Some species have been found growing on submerged plant vegetation in freshwater settings of North Carolina.

The single specimen of what the Senior writer believes to be a fragment of *Fischerella* sp., illustrated in [Figure 19](#) and [Figure 20](#), appears to have similarities in construction to that observed in the cyanobacteria *Jaaginema* sp. Morphological features on the external surface of the mucilaginous or gelatinous sheath of *Fischerella* sp. like that of *Jaaginema* sp. consist of very fine ridges that can be observed along the entire length of the filament (thalli). The ridges are approximately 0.1 µm in width. Again, the Senior writer is not sure if the ridges are growth lines or reflect the position of cells beneath the gelatinous sheath on the internal portion of the thalli. The filaments (thalli) are branched and club shaped, one end of the filament being thicker than the other end. Portions of the filaments (thalli) appear to be “hollow” which may reflect the presence of aerotopes along their long axis.

[NOTE: A question may arise concerning the identification of the fossil that the Senior author identified as *Fischerella* sp. One might wonder if the fossil could be a fragment of *Colteronema* sp. The thallus in the genus *Colteronema* sp. is more leathery, fibrous and membranous than that of *Fischerella* sp. The main difference between the two genera that the Senior writer is aware of, is that *Fischerella* sp. has more erect true branching, with the latter being uniseriate or multiseriate (with only T-type branching). Branches in *Fischerella* sp. are typically bifurcate or trifurcate. Heterocytes are intercalary, subspherical in basal trichomes and cylindrical in branches whereas heterocytes, akinetes and aerotopes have not been reported in the *Colteronema* sp. True trichome branching in *Colteronema* sp. can be of two types, “T” and/or “V” with pseudo-dichotomous branching arising after longitudinal division of the apical cells. Lateral branching can also occur from intercalary cells. No mention of the branches being multiseriate (other than bifurcated) has been reported. According to Komarek, et al. (2003, p.125) the genus *Colteronema* sp., consists of one species, *C. funebre*, and is known only from terrestrial, atmophytic habitats near hot springs in Yellowstone National Park, Wyoming.]

Conclusions

- 1) The presence of the filamentous cyanobacteria, *Tolypothrix sp.*, *Rivularia sp.*, *Geitlerinema sp.*, *Jaaginema sp.*, *Pseudanabaena sp.*, and *Fischerella sp.* in the organic matter residues extracted from borehole drill cutting samples collected between 1,697 and 1,825 feet in the Blackstone Rocking Chair Ranch No. 4 Well, Navajo County, Arizona, and representing the Big A Butte Member of the Supai Formation, suggests that the environment of deposition for this sequence was, more likely than not, associated with a predominantly fresh to brackish water and/or terrestrial depositional ecosystem.
[NOTE: Although the cyanobacteria *Geitlerinema sp.* and *Pseudanabaena sp.*, can be found in mineral and/or hot springs and in salinic or hypersalinic localities, most are found in fresh-water habitats. *Fischerella sp.*, is more commonly associated with a subaerial environment and is commonly epilithic on wet rocks and soils.]
- 2) The absence of well-defined “open marine” fossil indicators (i.e., foraminiferal linings, scolecodonts, graptolites, and identifiable marine dinoflagellates) in the Big A Butte Member of the Supai Formation is additional evidence that can be used to support the writers’ interpretation of a more terrestrial or fresh to slightly brackish water depositional environment for this particular stratigraphic unit.
- 3) The noticeable absence in the diversity and overall low abundance of other fossilized organisms in our samples, other than algal fragments, may be an indication that the flora of the Big A Butte Member was associated with a semi-restricted or restricted depositional environment.
- 4) To the writers’ knowledge, cyanobacteria belonging to the genera *Tolypothrix sp.*, *Rivularia sp.*, *Jaaginema sp.*, *Geitlerinema sp.*, *Pseudanabaena sp.*, and *Fischerella sp.* have never been reported from the Big A Butte Member of the Supai Formation. The presence of these previously unreported fossil genera of Cyanobacteria in the Supai Formation of east-central Arizona may provide geologists and palynologists with a new tool to help establish and better understand the various depositional environments and cycles that prevailed within the Holbrook Basin during Early Permian time.

Acknowledgements

The writers thank Lisa Glogg and the Otago Regional Council, 1954 Dunedin, New Zealand, for allowing us to use the photomicrograph of *Gloeotrichia sp.*, cf. *G. echinulata* ([Figure 6A, 6B](#)) in our manuscript.

References Cited

Blakey, R.C., 1979, Lower Permian stratigraphy of the southern Colorado Plateau, in D.L. Baars, ed., Permianland: Four Corners Geological Society 9th Field Conference Guidebook, p. 115-129.

Blakey, R.C., 1990, Stratigraphy and geologic history of Pennsylvanian and Permian rocks, Mogollon Rim region, central Arizona and vicinity: Geological Society of America Bulletin, v.102, p. 1189-1217.

Conley, J.N., 1977, Subsurface structure maps, eastern Mogollon slope region, east-central Arizona: Arizona Oil and Gas Conservation Commission, 1:500,000: Arizona Geological Survey Publication OG-21.

Elston, D.P., and W.D. DiPaolo, 1979, Pennsylvanian-Permian stratigraphy of the Sedona area and environs, central and northern Arizona, *in* D.L. Baars, ed., Permianland: Four Corners Geological Society 9th Field Conference Guidebook, p. 131-141.

Gerrard, T.A., 1964, Environmental Studies of the Fort Apache Member, Supai Formation (Permian), East-central Arizona: Unpublished Ph.D. dissertation, The University of Arizona, Tucson, Arizona, 181 p. Website accessed March 5, 2020.
<http://arizona.openrepository.com/arizona/handle/10150/565623>

Handford, C.R., 1981, Coastal sabkha and salt pan deposition of the lower Clear Fork Formation (Permian), Texas: Journal of Sedimentary Petrology, v. 51/3, p. 761-778.

Komárek, Jiří, Hedy Kling, and Jaroslava Komarkova, 2003, Filamentous Cyanobacteria, p. 117-196, *in* Wehr and Sheath, eds., Freshwater Algae of North America: Ecology and Classification: Academic Press, 918 p. ISBN: 0-12-741550-5; Library of Congress Control Number: 2002107708

MBC Well Logging LLC, 2016, Mud Log for the Rocking Chair Ranch No. 4 Well, Blackstone Exploration LLC, Navajo County, Arizona. Website accessed March 5, 2020.
<http://azoilgas.com/wp-content/uploads/2016/05/MUD.LOG-4-ROCKING-CHAIR-RANCH-1980FNL-1980FWL-S-27-T14n-R19e-RTD-GAMMA.pdf>.

Peirce, H.W., and T.A. Gerrard, 1966, Evaporite deposits of the Permian Holbrook basin, Arizona, *in*, J.L. Rau, ed., Second Symposium on Salt: Cleveland, Northern Ohio Geological Society, v.1, p. 1-10.

Peirce, H.W., 1989, Correlation problems of Pennsylvanian-Permian strata of the Colorado Plateau of Arizona, *in* J.P. Jenney and S.J. Reynolds, eds., Geologic evolution of Arizona: Tucson, Arizona Geological Society Digest, v. 17, p. 349-368.

Rauzi, S.L., 1999, Carbon dioxide in the St. Johns-Springerville area, Apache County, Arizona: Arizona Geological Survey Open-File Report OFR 99-2, 22 p.

Rauzi, S.L., 2000, Permian Salt in the Holbrook Basin, Arizona: Arizona Geological Survey Open-File Report OFR-00-03, 6 map plates, 20 p.

Schwab, Karl W., Halsey W. Miller, and Michael A. Smith, 2017, Source-Rock Potential of the Lower Permian Supai Formation in the Blackstone Exploration Company Rocking Chair Ranch No. 4 Well, Navajo County, Arizona: [AAPG/Datapages Search and Discovery Article #80601 \(2017\)](#).

Stoyanow, A.A., 1936, Correlation of Arizona Paleozoic formations: Geological Society of America Bulletin, v. 47, p. 459-540.

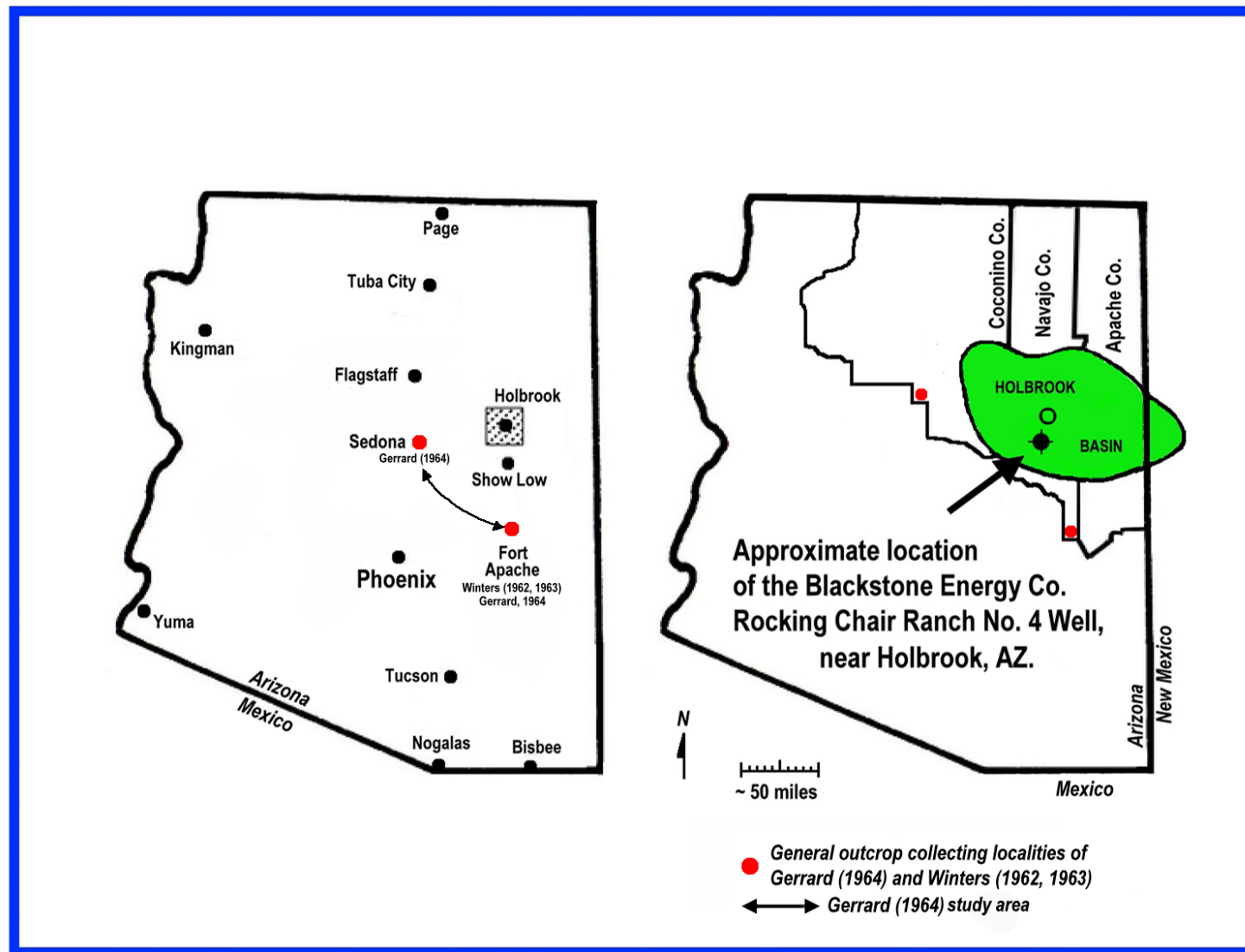
Tinpranee, N., A. Inchargensakdi, and S. Phunpruch, 2018, Screening cyanobacteria from marine coastal waters of Thailand for biohydrogen production: Journal of Applied Phycology, v. 30, p. 3471-3481. SpringerLink, Online publication, accessed March 5, 2020. <https://doi.org/10.1007/s10811-1490-6>

Wehr, John D., and Robert G. Sheath, 2003, Freshwater Algae of North America: Ecology and Classification, Academic Press, p. 1-918, ISBN: 0-12-741550-5; Library of Congress Control Number: 2002107708.

Wehr, John D., Robert G. Sheath, and Patrick J. Kociolek, 2015, Freshwater Algae of North America: Ecology and Classification, 2nd Edition, 1066 p., Elsevier-Academic Press, ISBN: 978-0-12-385876-4; eBook ISBN: 9780123858771

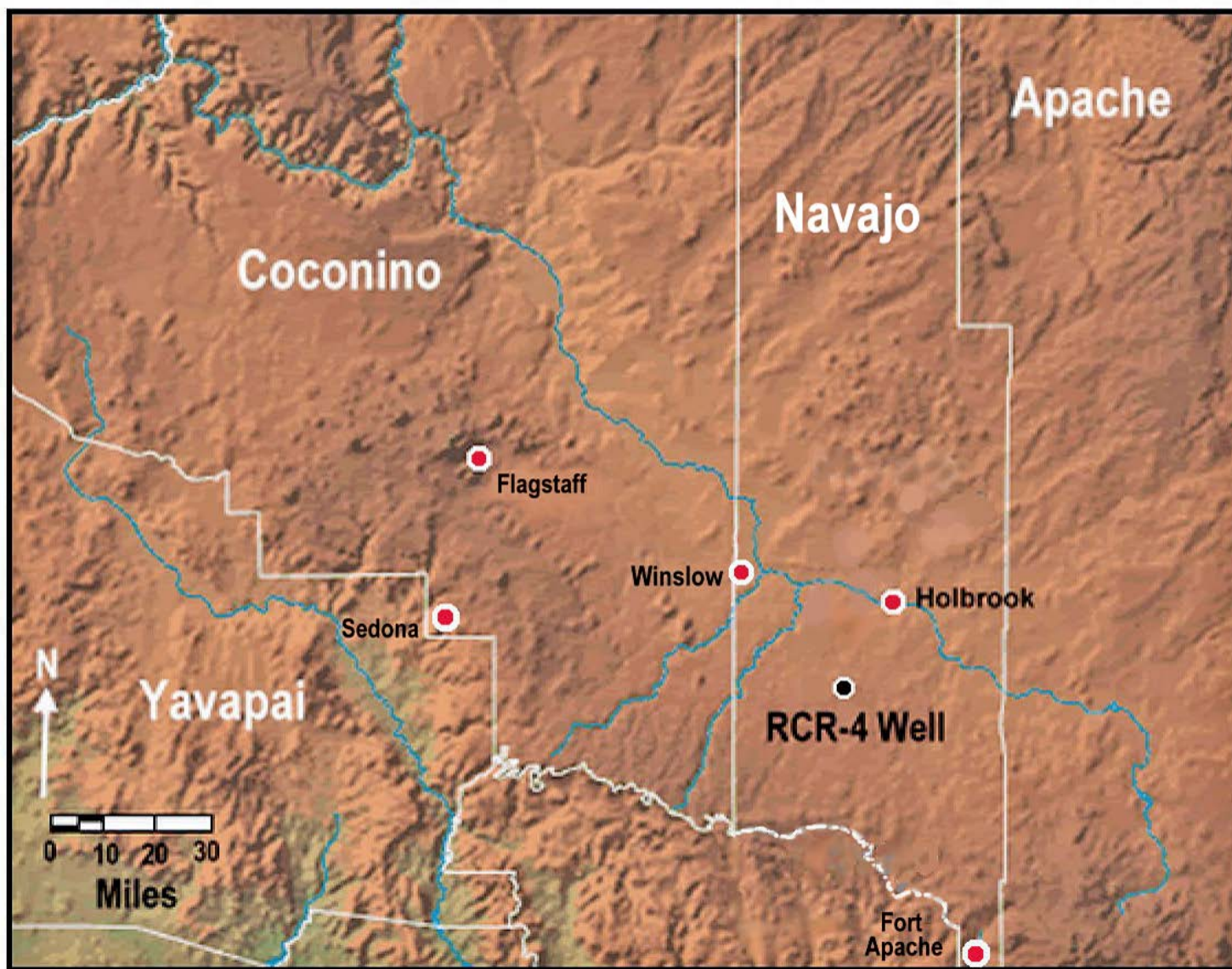
Winters, S.S., 1962, Lithology and stratigraphy of the Supai Formation, Fort Apache Indian Reservation, Arizona: Guidebook of the Mogollon Rim Region, East-Central Arizona, New Mexico Geological Society Thirteenth Field Conference, p. 87-88.

Winters, S.S., 1963, Supai Formation (Permian) of Eastern Arizona: Geological Society of America, Memoir 89, 97 p.



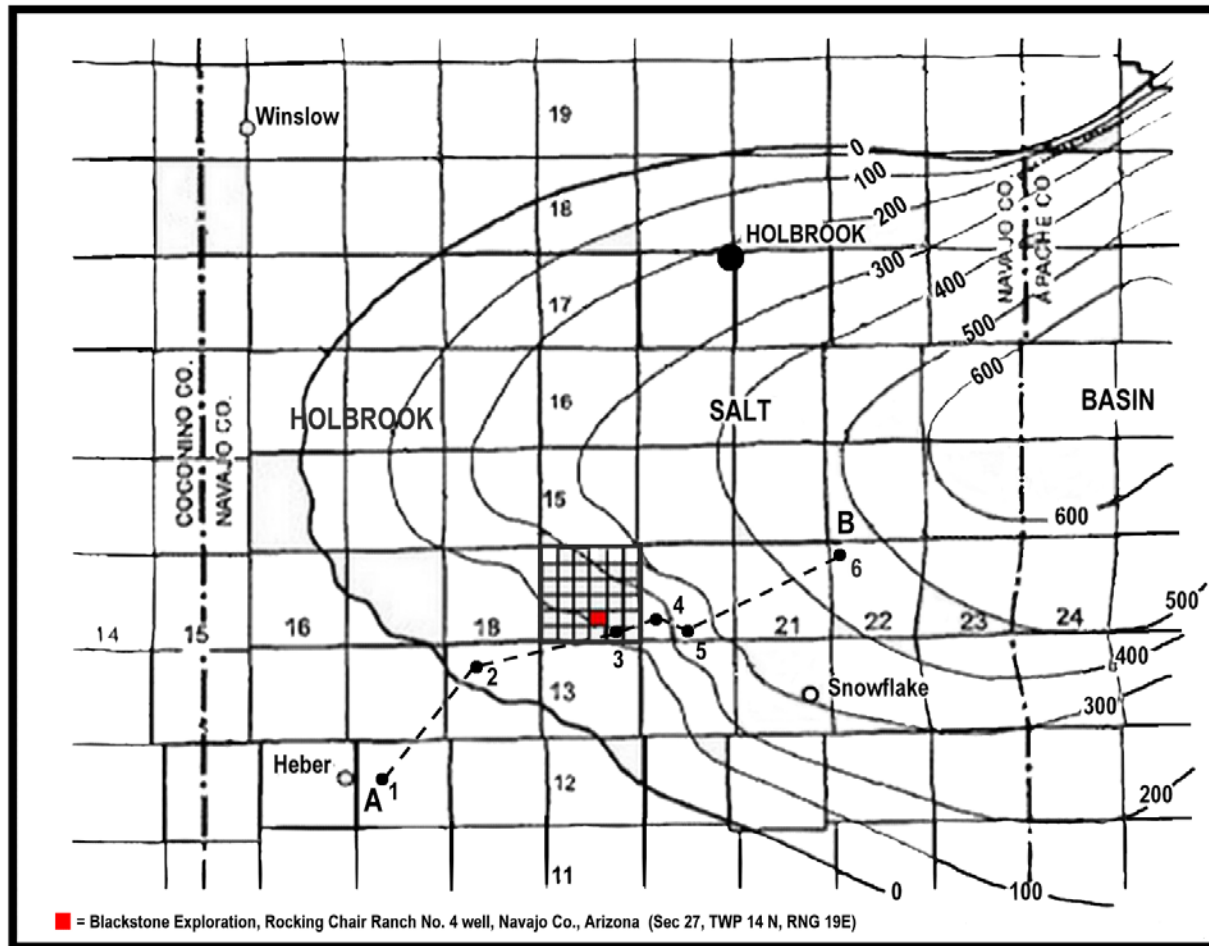
Generalized map of Arizona showing the approximate location of the Holbrook Basin and the Blackstone Rocking Chair Ranch No. 4 Well.

Figure 1. Location Map of the Holbrook Basin in east-central Arizona.



Map of northern and central Arizona showing the general location of the Rocking Chair Ranch No. 4 well. Sec. 27, Twp. 14 N., Rge 19 E.

Figure 2. Location Map of the RCR No. 4 Well in the Holbrook Basin of east-central Arizona.

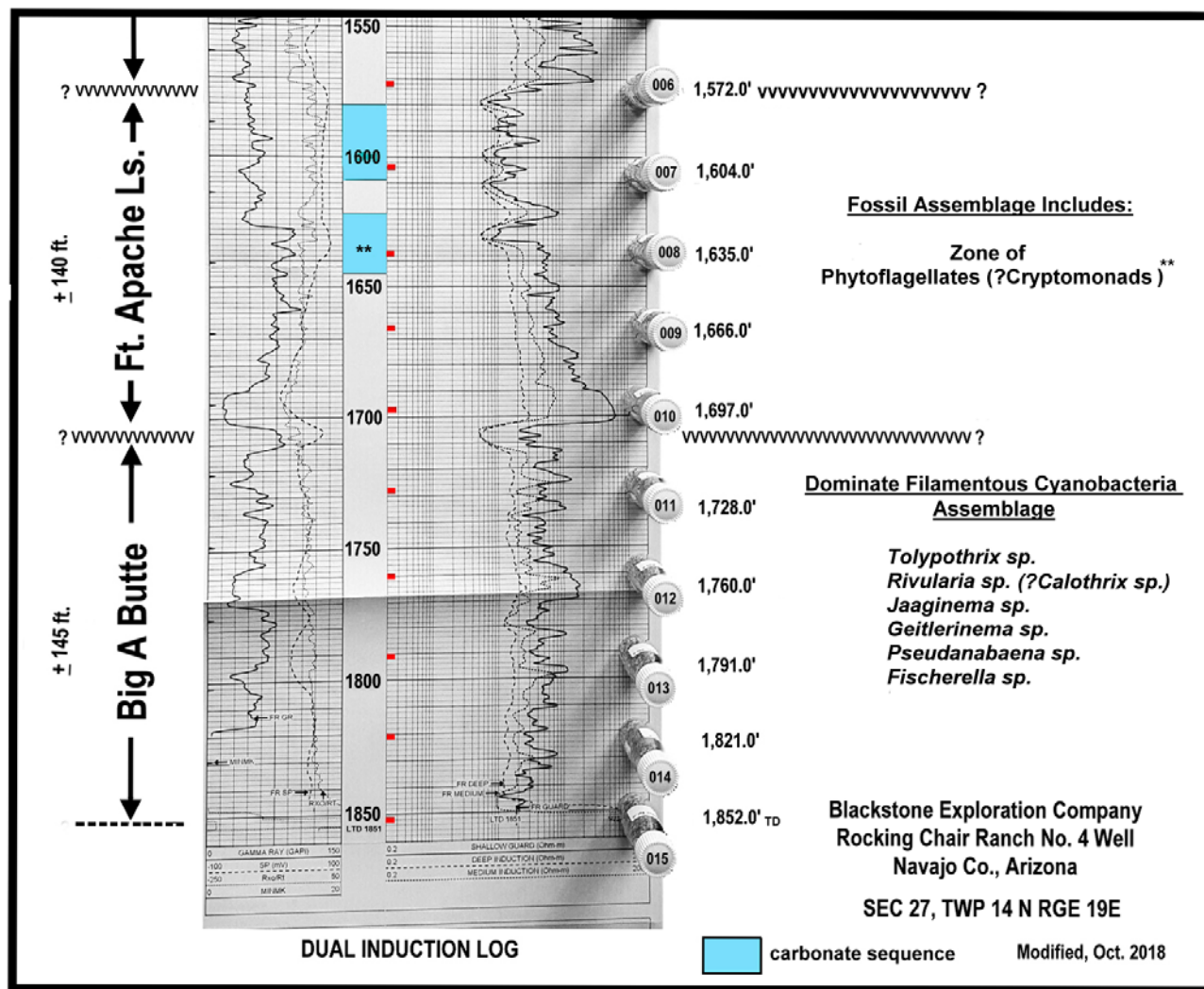


Map of the western portion of the Holbrook Salt Basin, showing the aggregated thickness of the lower Permian (?Corduroy) Salt and the location of the Blackstone RCR No. 4 Well. Modified from Rauzi, Geological Survey Report OFR 00-03, June 2000.

Wells on cross-sectional line A-B, according to Rauzi, are: 1) *Tenneco No. 1 Federal A, 18-12N-17E*; 2) *Morton Bros. No. 8-1 Federal, 8-13N-18E*; 3) *Taubert and Steed No. 1 Babbitt Bros., 35-14N-19E*; 4) *Webb Resources No. 29-1 Federal, 29-14N-20E*; 5) *Lockhart No. 1 Aztec Land and Cattle, 33-14N-20E*; and 6) *Webb Resources No. 6-1 NMAL, 6-14N-22E*.

Figure 3. Map of the Holbrook Salt Basin showing a more detailed location of the RCR No. 4 Well.

DUAL INDUCTION LOG OF THE ROCKING CHAIR RANCH NO. 4 WELL, NAVAJO COUNTY, ARIZONA



**Fort Apache and Big A Butte Members of the Supai Formation
showing depth intervals and dominate fossil assemblage.**

Figure 4. Dual-Induction Log of the Fort Apache Limestone and Big A Butte Members of the Supai Formation in the RCR No. 4 Well.

CORRELATION OF PENNSYLVANIAN AND PERMIAN STRATIGRAPHIC UNITS ACROSS NORTHERN, EASTERN, SOUTHEASTERN ARIZONA AND CENTRAL NEW MEXICO

PERIOD	SERIES	Oak Creek Canyon Arizona		Fossil Creek Canyon Arizona	Holbrook Basin Ft. Apache Res. Arizona +		Northeastern Arizona	Southeastern Arizona	Central New Mexico	
U. PERM.	GUADALUPIAN									
L. PERMIAN	LEONARDIAN	Kaibab		?	?	?		Concha	San Andres	
		Toroweap		Coconino	Coconino	De Chelly		Sherrer	Glorieta	
		Coconino								
		SUPAI	Corduroy Ss.	Corduroy Ss.	Corduroy Ss.	Organ Rock	Epitaph	Colina	Yeso	
			Fort Apache	Fort Apache	Fort Apache					
			SUPAI	Big A Ss.	Big A Ss.					Big A Butte
	SUPAI	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
	SUPAI	Big A Ss.				Big A Ss.	Big A Butte	CUTLER		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER
SUPAI	Big A Ss.	Big A Ss.				Big A Butte	CUTLER	Cedar Mesa		
			SUPAI	Big A Ss.	Big A Ss.				Big A But	

+ Supai based on RCR-4 Well

*Peirce (1958)

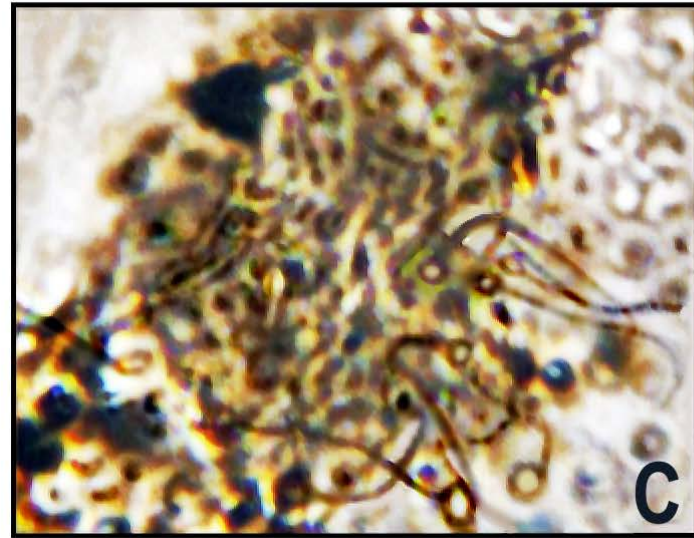
modified from Passmore (1969)

Figure 5. Correlation Chart for the Upper Pennsylvanian and Lower Permian Formations of east-central Arizona.

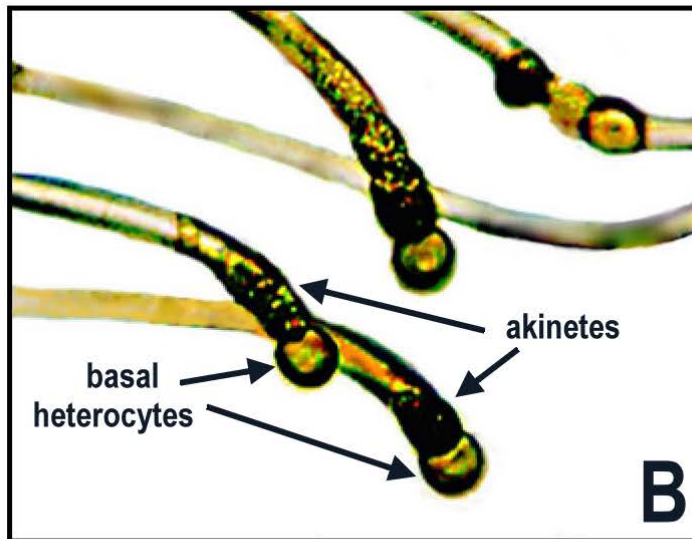
VARIATIONS IN PRESERVATION: EXTANT vs. FOSSIL FILAMENTOUS CYANOBACTERIA



Extant filaments of *Gloeotrichia echinulata*



Fossilized filaments of cf. *Rivularia* sp.



Used with permission; Lisa Gloag, Otago Regional Council, 1954 Dunedin, NZ 9054 1-24-2019

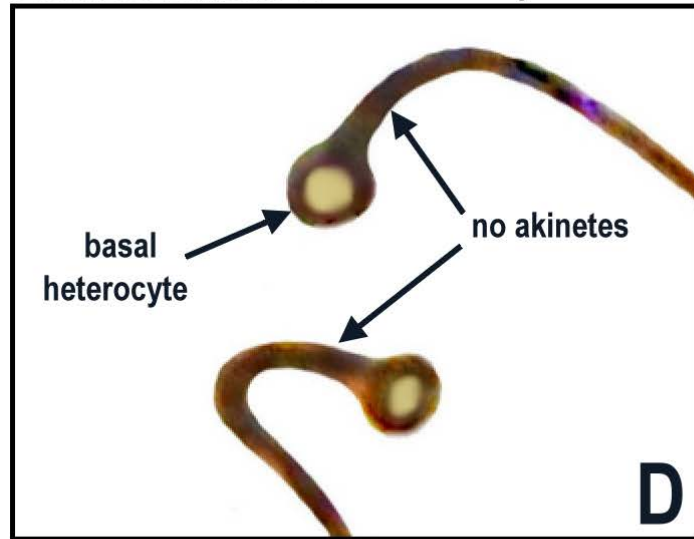


Figure 6. Variations in the preservation of extant and fossil cyanobacteria.

(Big A Butte Member, Supai Fm. --- RCR No. 4 Well, Navajo Co., AZ --- 1,852.0 Ft.)

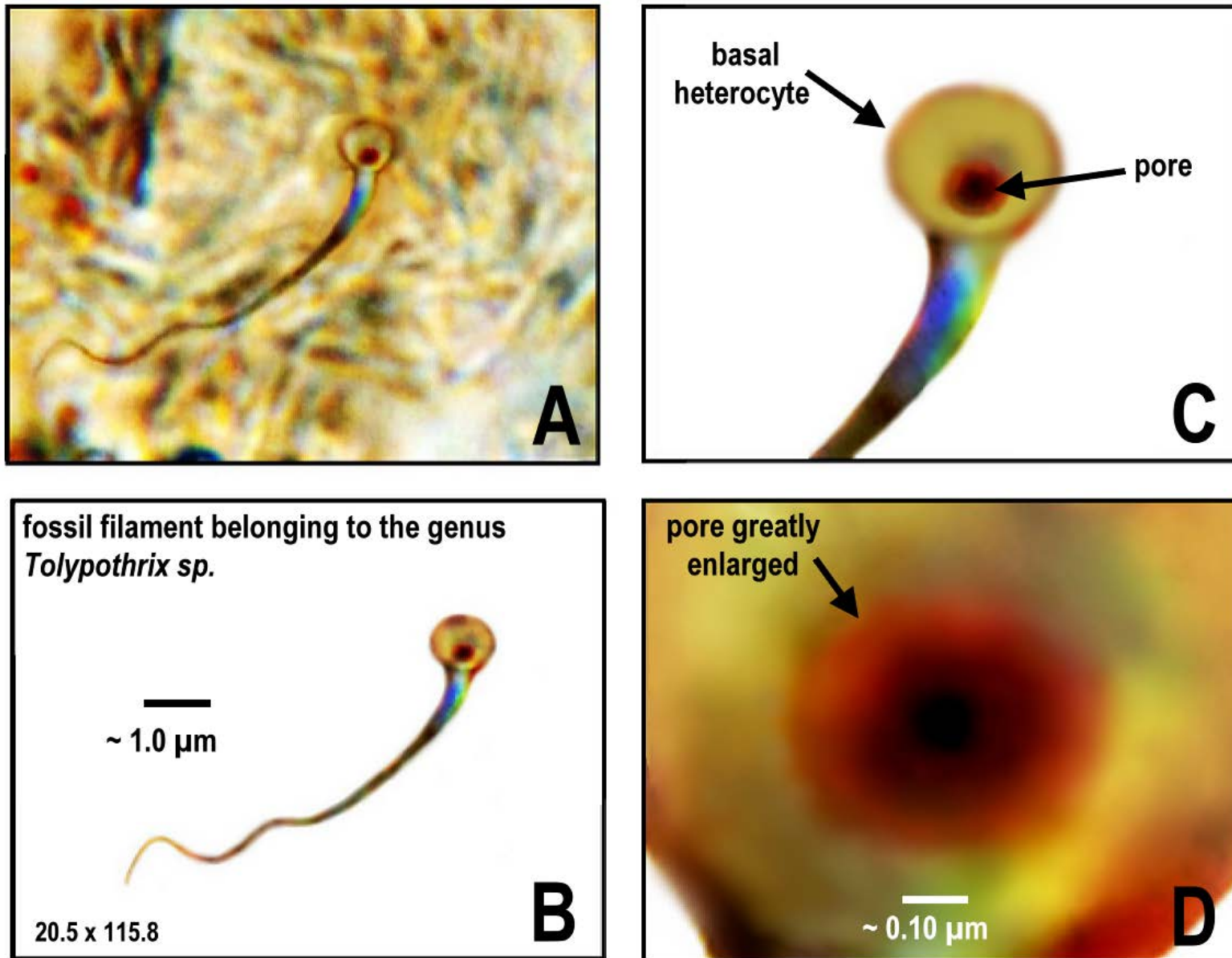


Figure 7. A filament of the cyanobacteria *Tolypothrix* sp. showing a single pore in the heterocyte.

(Big A Butte Member, Supai Fm. --- RCR No. 4 Well, Navajo Co., AZ --- 1,852.0 Ft.)

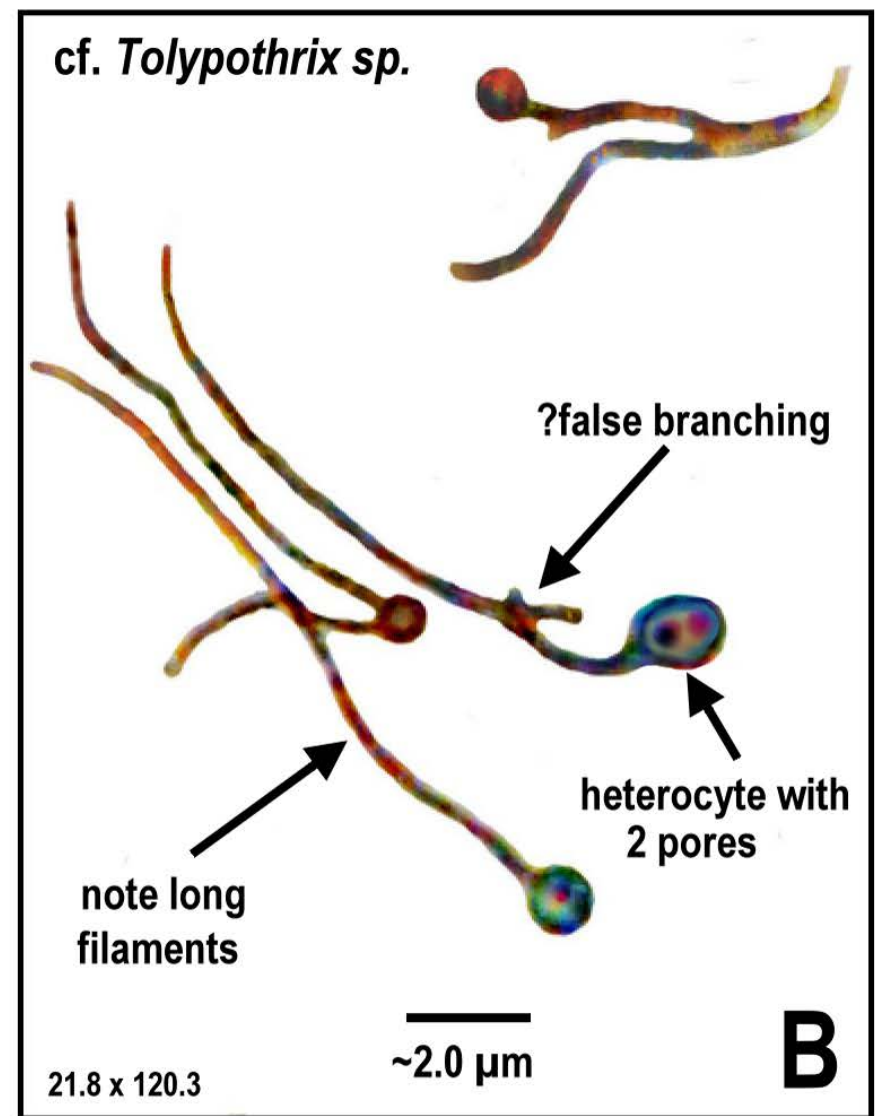
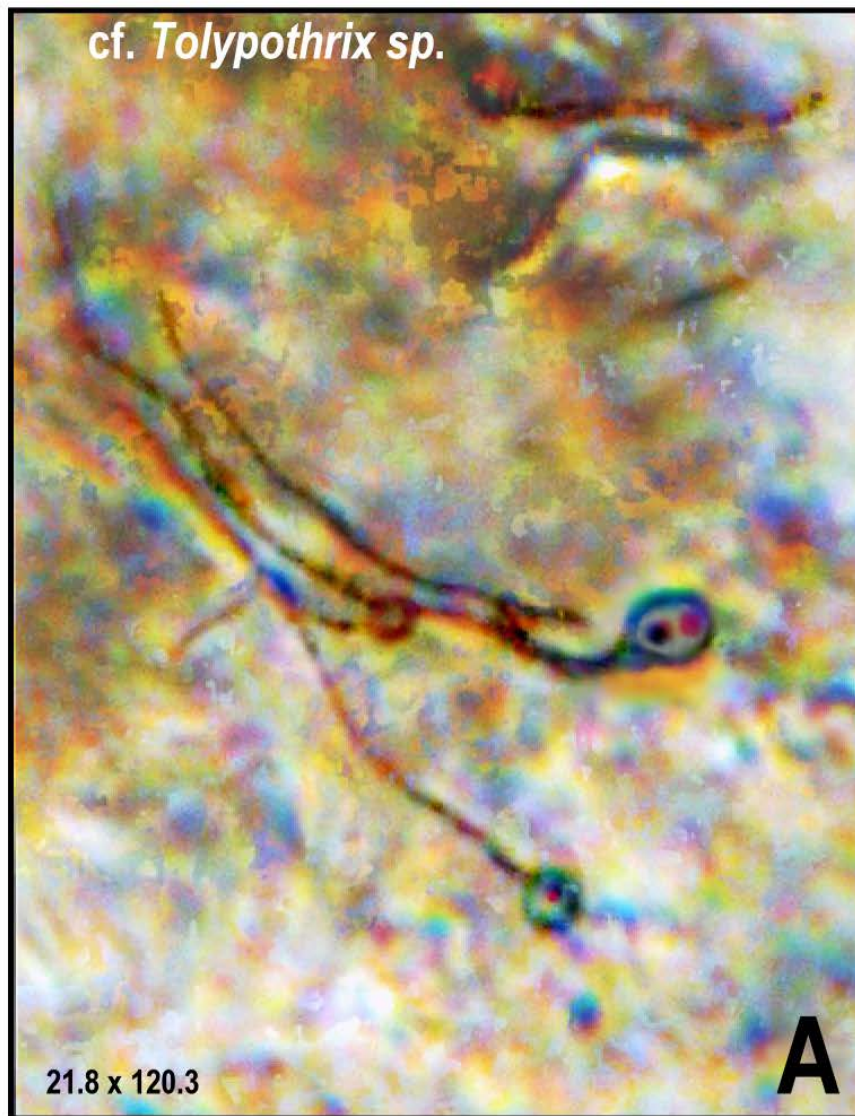


Figure 8. A group of *Tolypothrix* sp. cyanobacteria, one of which shows a double pore in its heterocyte.

(Big A Butte Member, Supai Fm. --- RCR No. 4 Well, Navajo Co., AZ --- 1,852.0 Ft.)

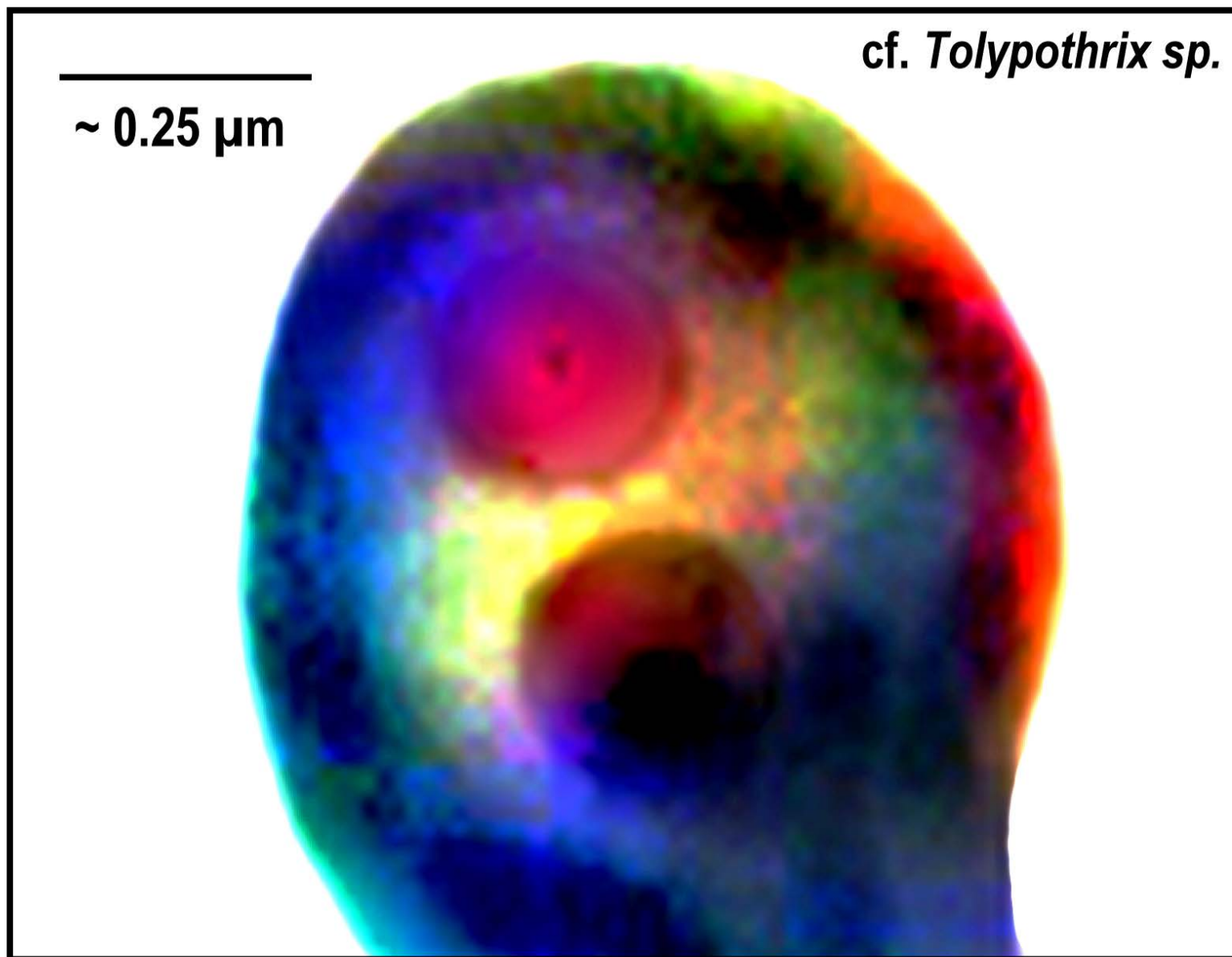


Figure 9. The pores in the heterocyte of *Tolypothrix* sp., as shown in [Figure 8](#), greatly enlarged.

(Big A Butte Member, Supai Fm. --- RCR No. 4 Well, Navajo Co., AZ --- 1,852.0 Ft.)

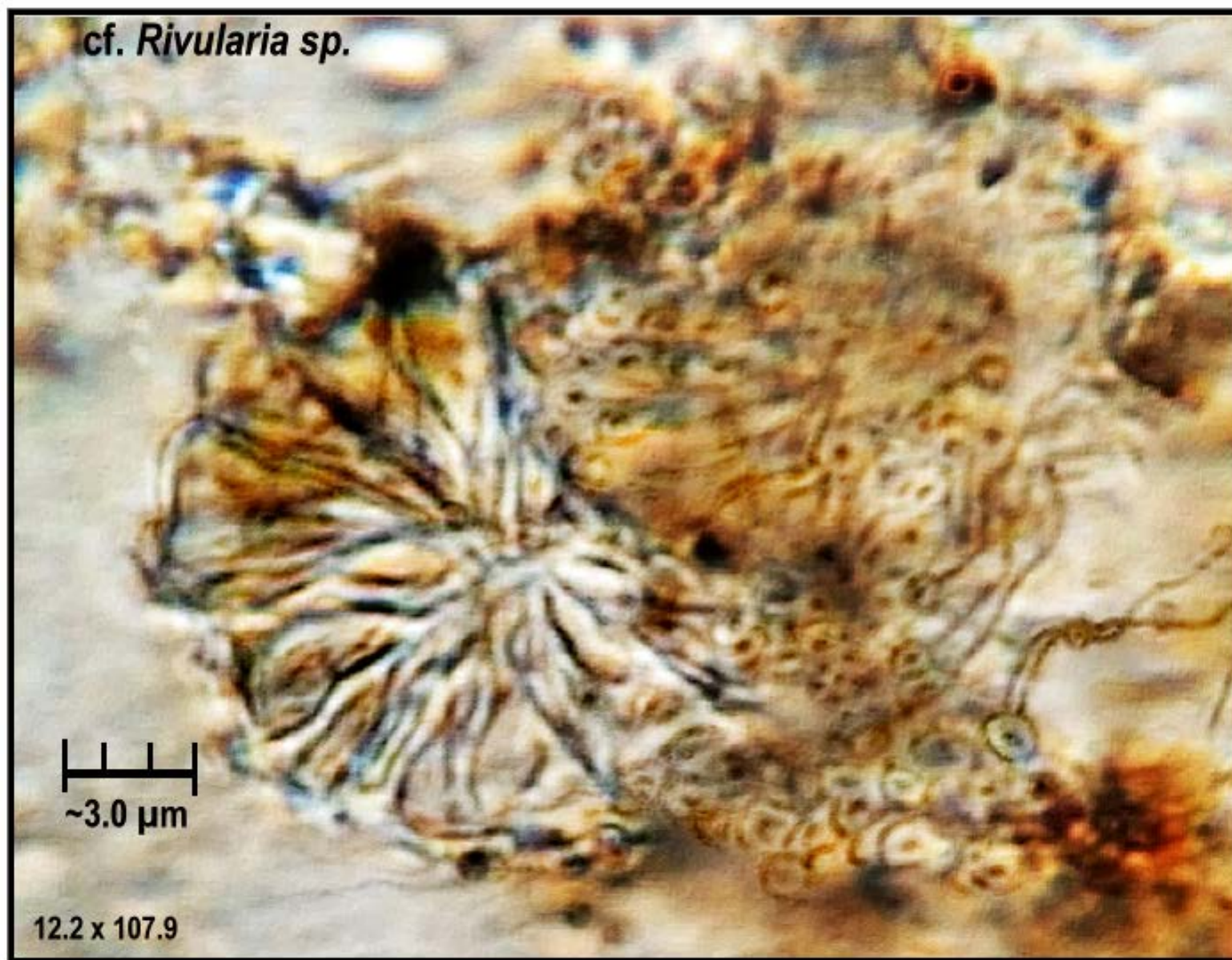


Figure 10. A Thumb-shaped colony of cyanobacteria belonging to the genus *Rivularia* sp.

(Big A Butte Member, Supai Fm. --- RCR No. 4 Well, Navajo Co., AZ --- 1,852.0 Ft.)

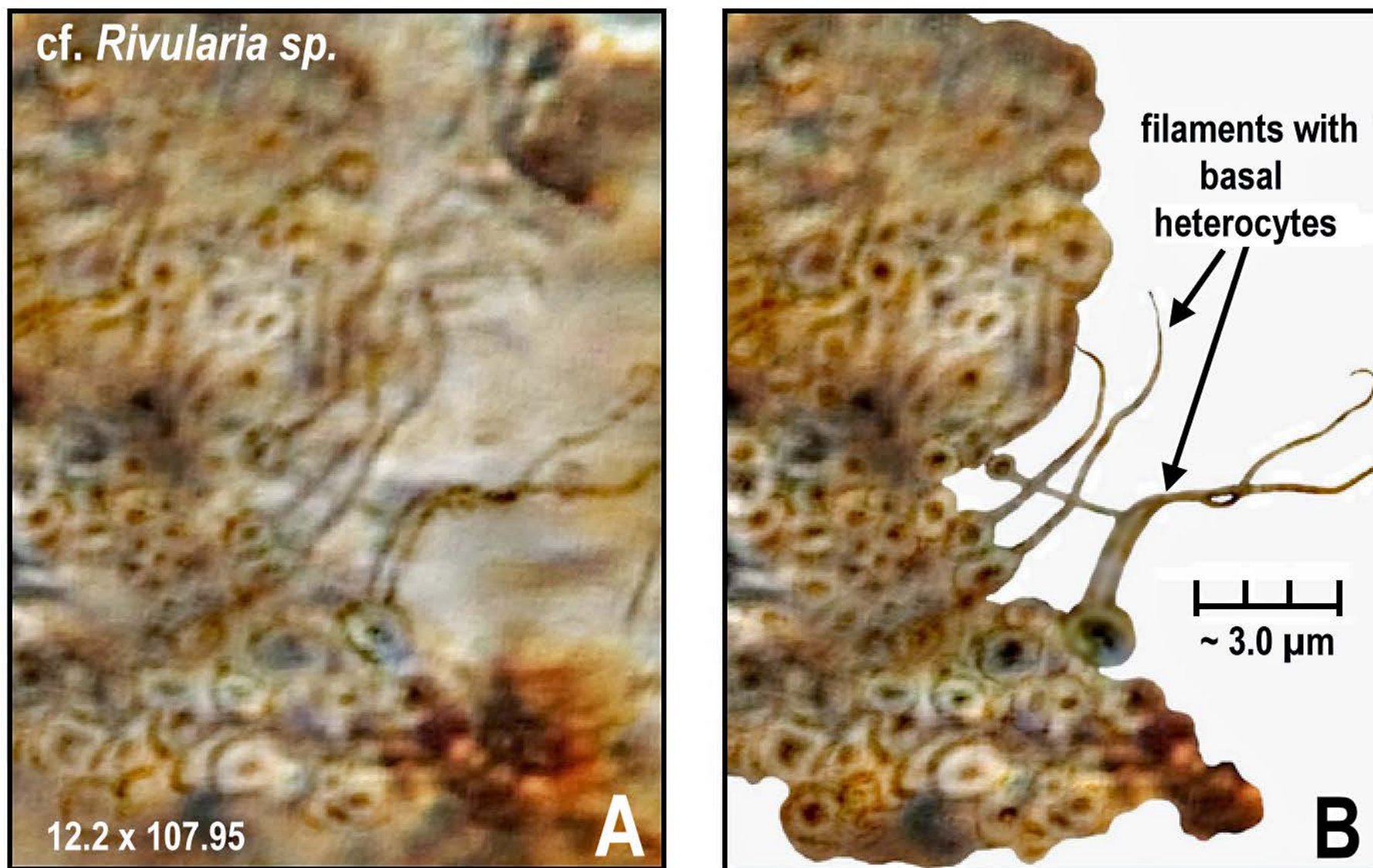


Figure 11. An enlarged portion of [Figure 10](#) showing the arrangement of the filaments in the cyanobacteria *Rivularia* sp.

(Big A Butte Member, Supai Fm. --- RCR No. 4 Well, Navajo Co., AZ --- 1,852.0 Ft.)

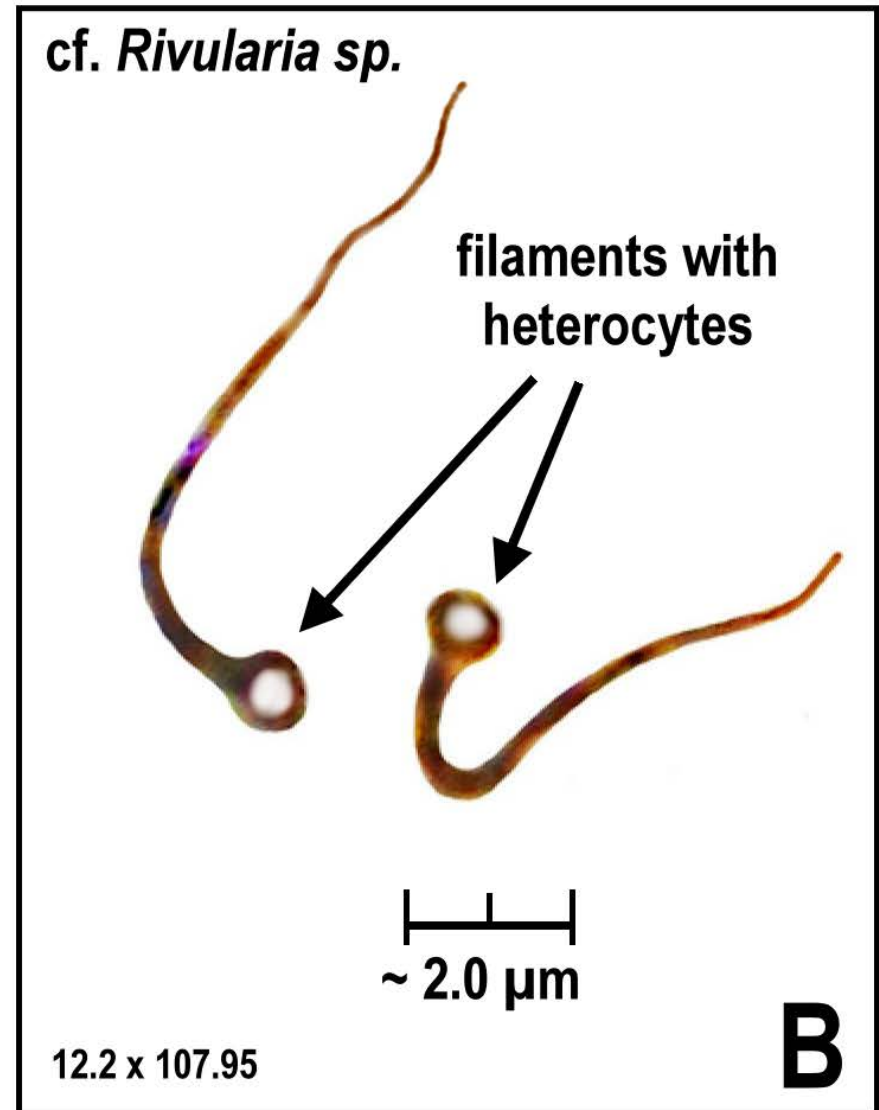
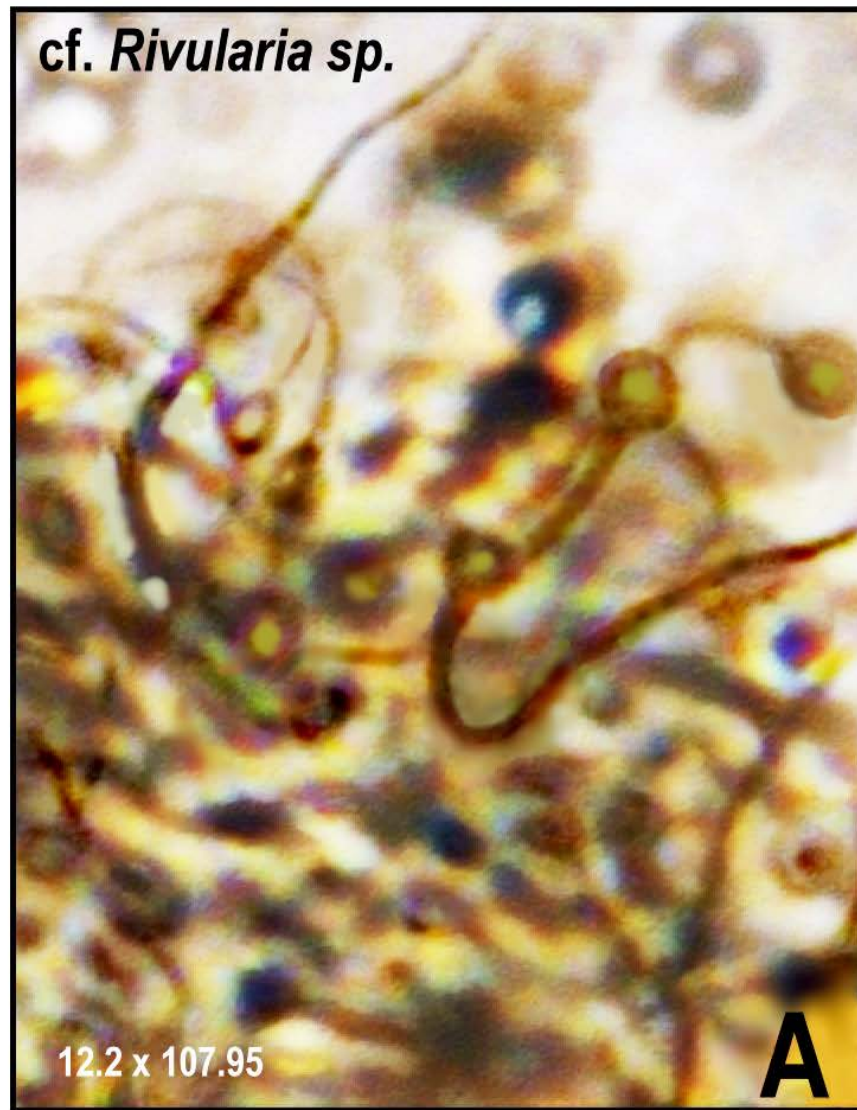


Figure 12. The enlarged view of a cluster of filaments of the cyanobacteria *Rivularia* sp. Figure B represents two filaments that have been digitally isolated to show a more detailed view. Note the distinct absence of akinetes.

(Big A Butte Member, Supai Fm. --- RCR No. 4 Well, Navajo Co., AZ --- 1,852.0 Ft.)

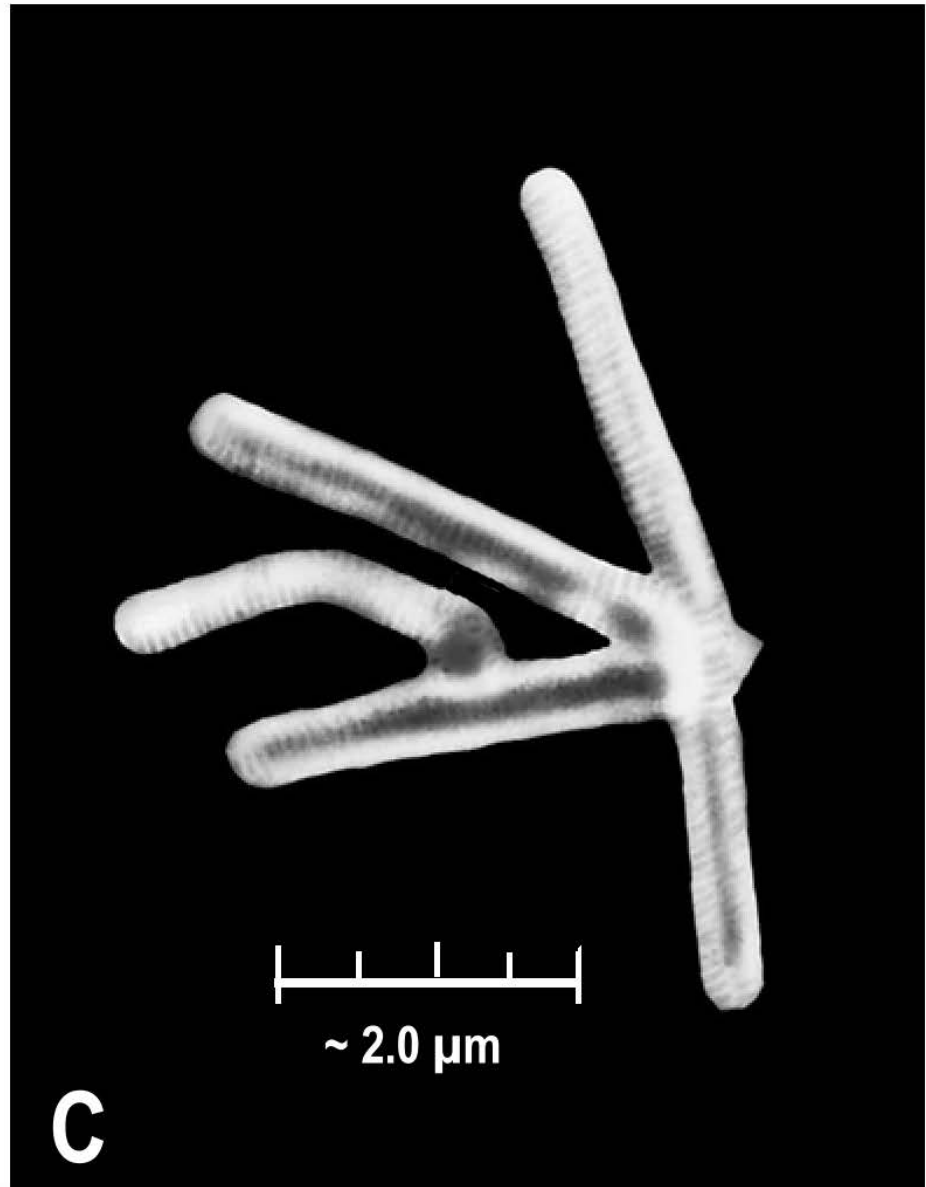
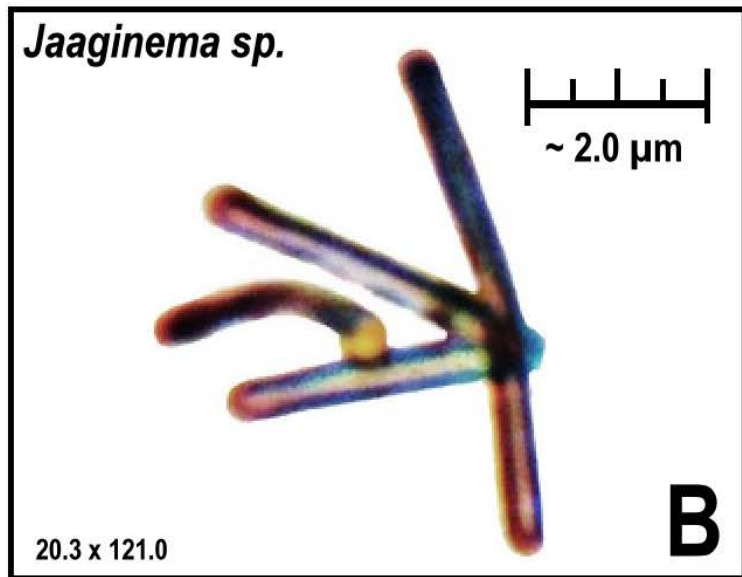
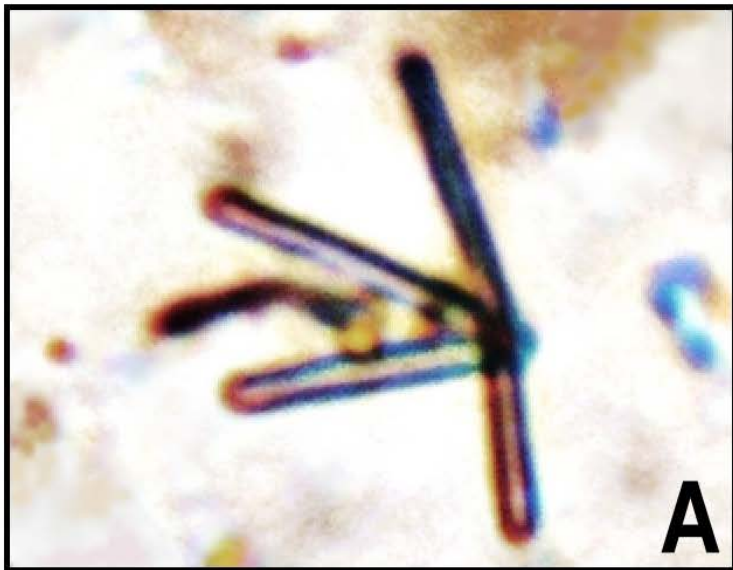


Figure 13. The cyanobacteria *Jaaginema sp.* showing its external morphology.

(Big A Butte Member, Supai Fm. --- RCR No. 4 Well, Navajo Co., AZ --- 1,852.0 Ft.)

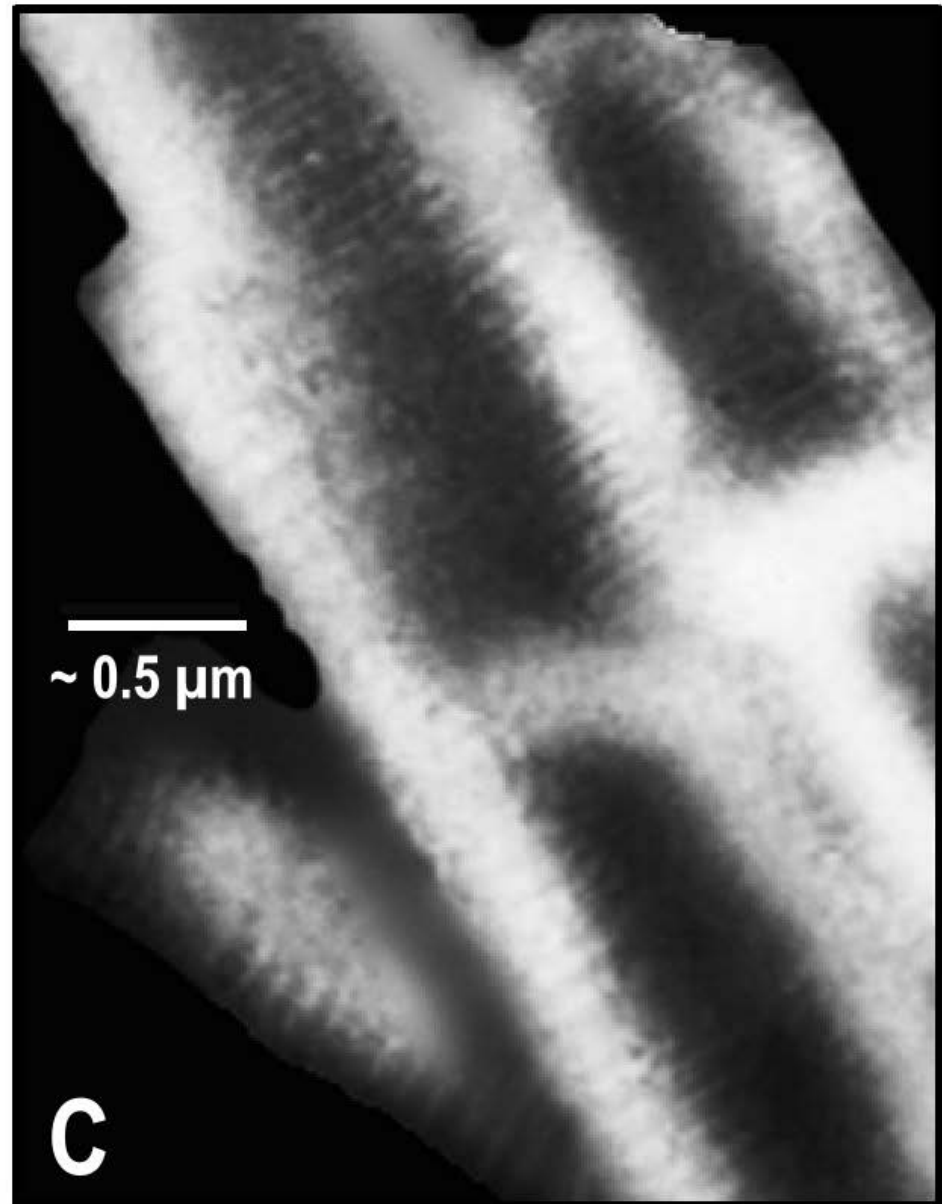
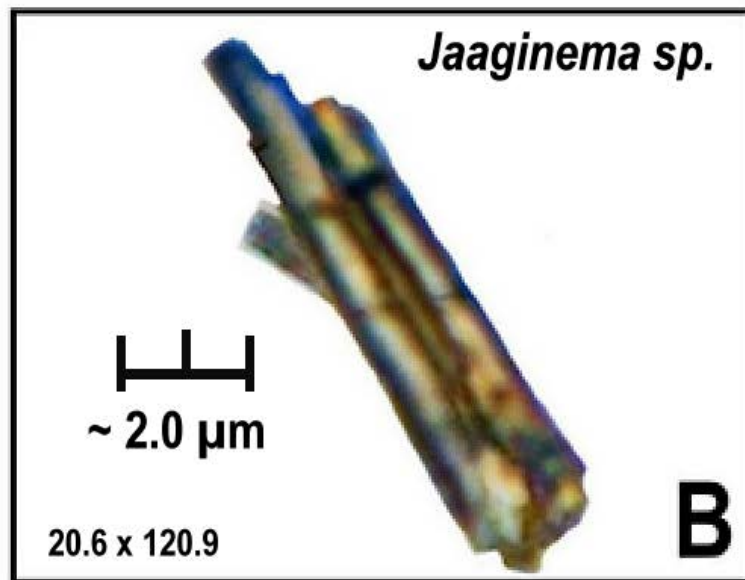


Figure 14. A cluster of tightly packed cyanobacteria filaments belonging to the genus *Jaaginema sp.* showing its external morphology.

(Big A Butte Member, Supai Fm. --- RCR No. 4 Well, Navajo Co., AZ --- 1,852.0 Ft.)

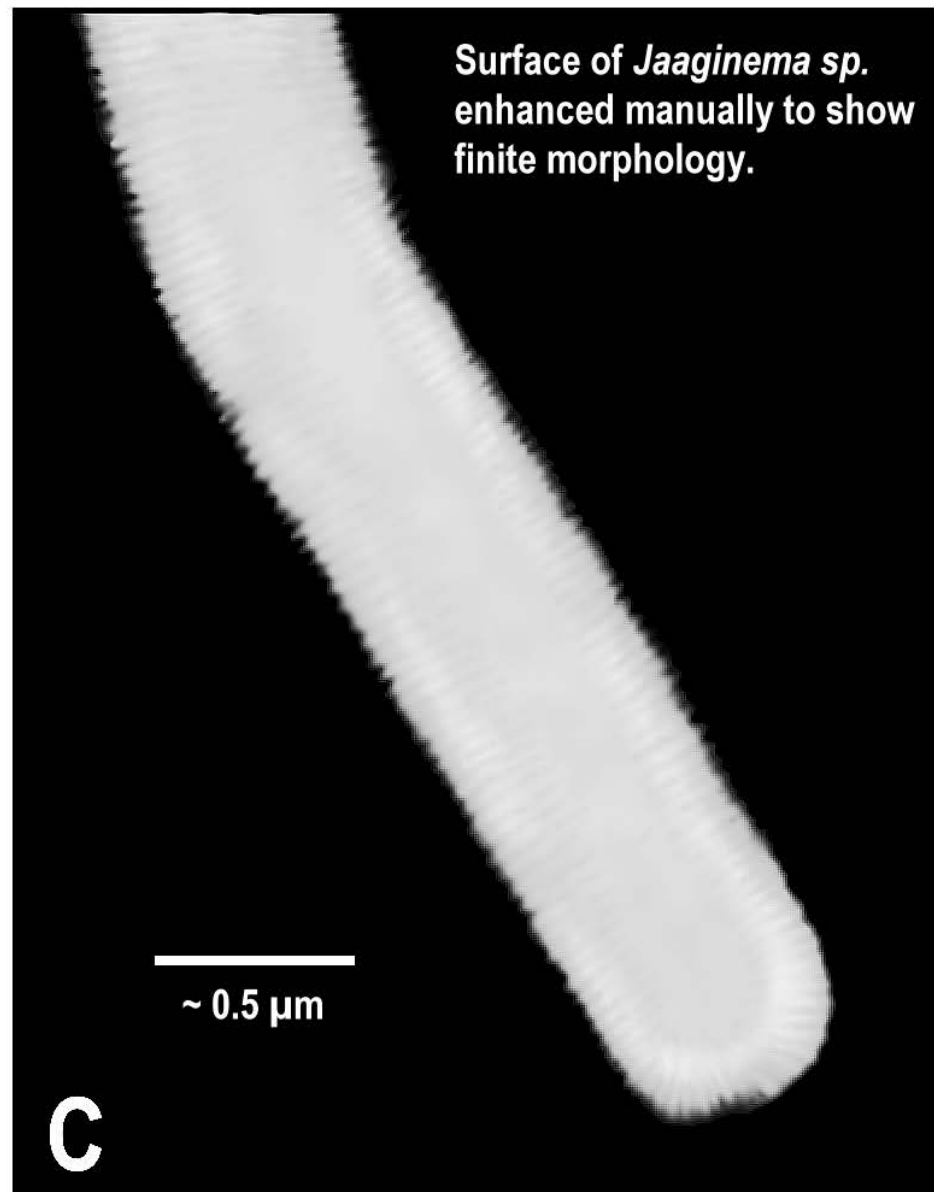
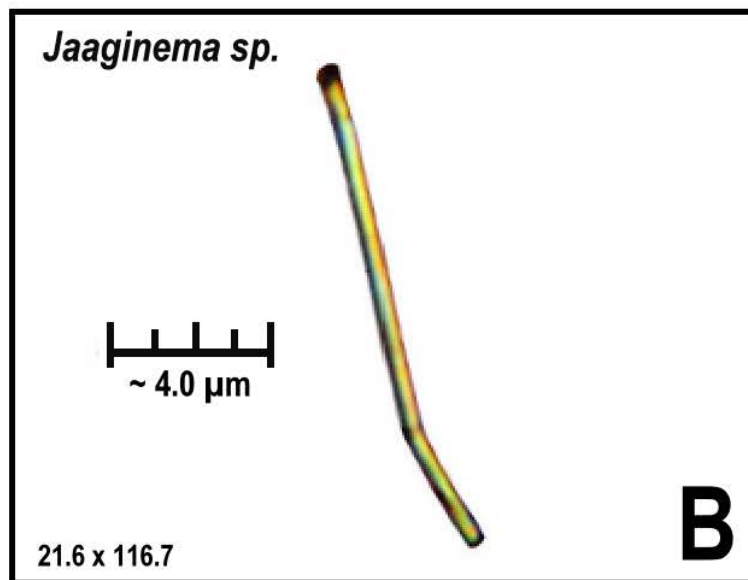


Figure 15. A single filament of *Jaaginema sp.* Note the fine detail shown in photomicrograph C.

(Big A Butte Member of the Supai Formation --- RCR No. 4 Well, Navajo Co., AZ --- 1,852.0 Ft.)

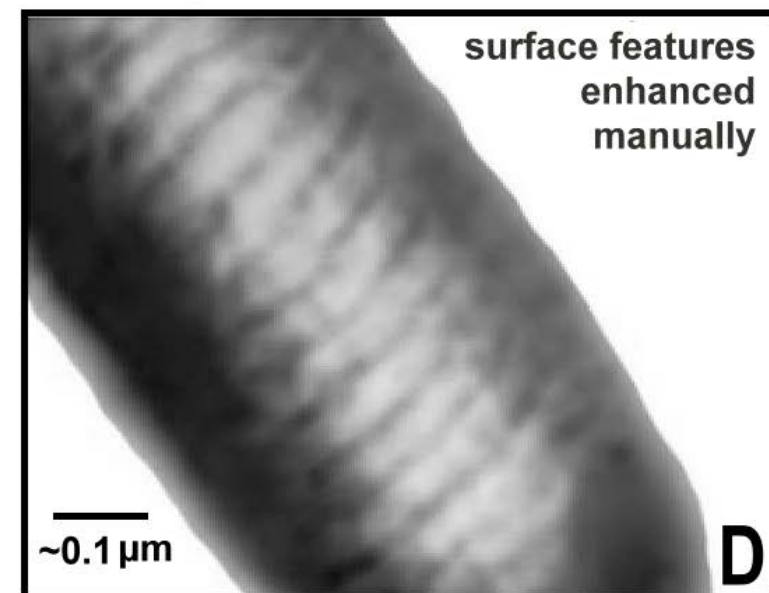
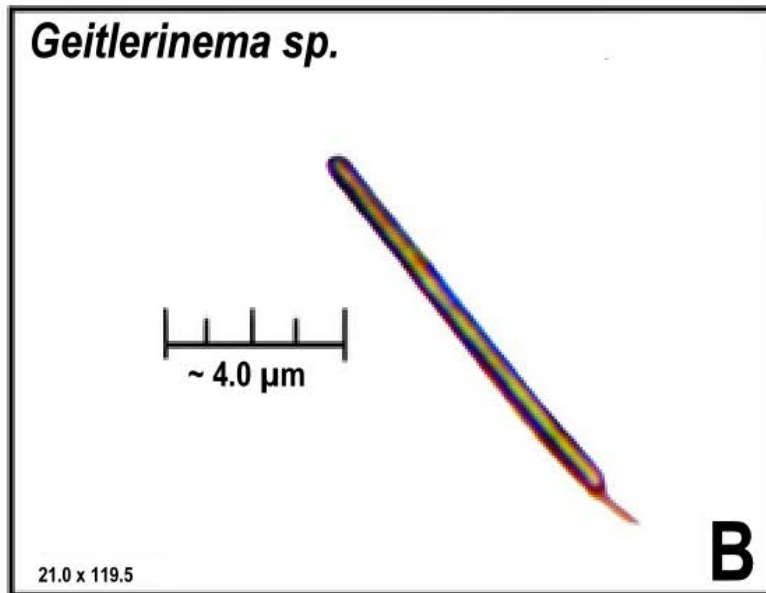
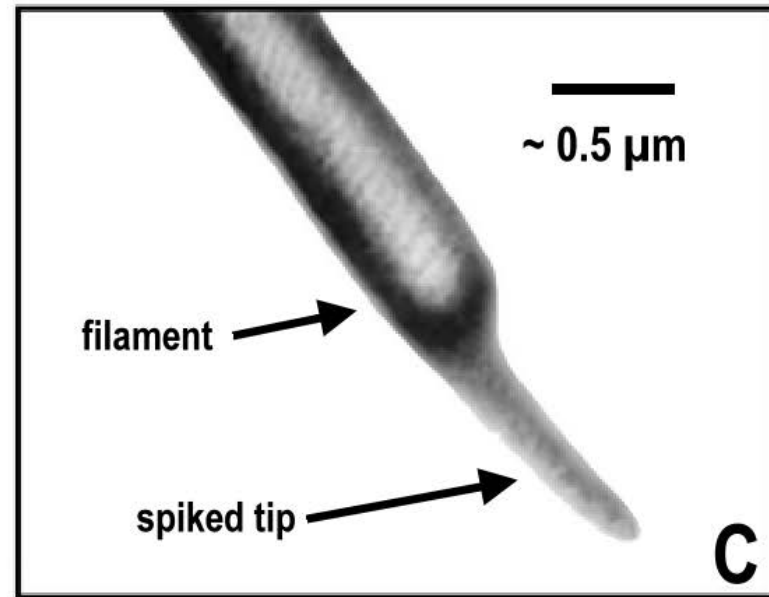
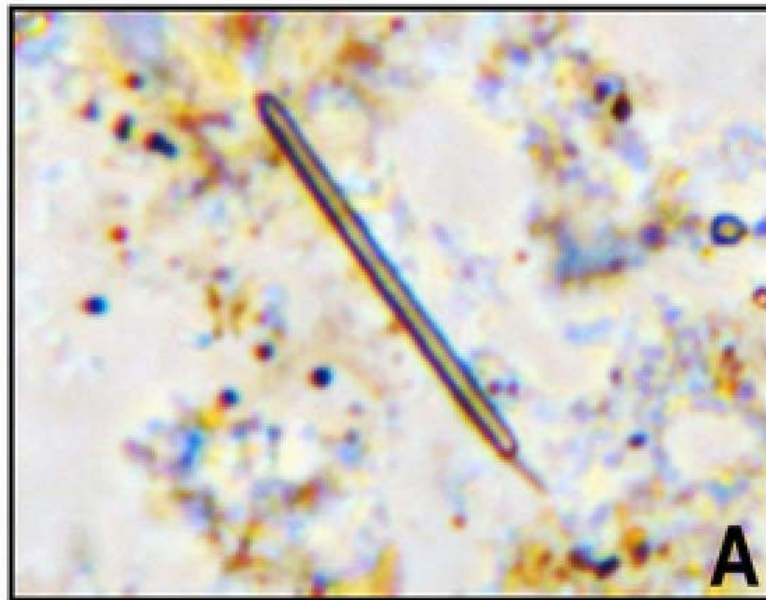


Figure 16. A single filament of the cyanobacteria *Geitlerinema sp.* Note the spiked tip and external morphology.

(Big A Butte Member, Supai Fm. --- RCR No. 4 Well, Navajo Co., AZ --- 1,852.0 Ft.)

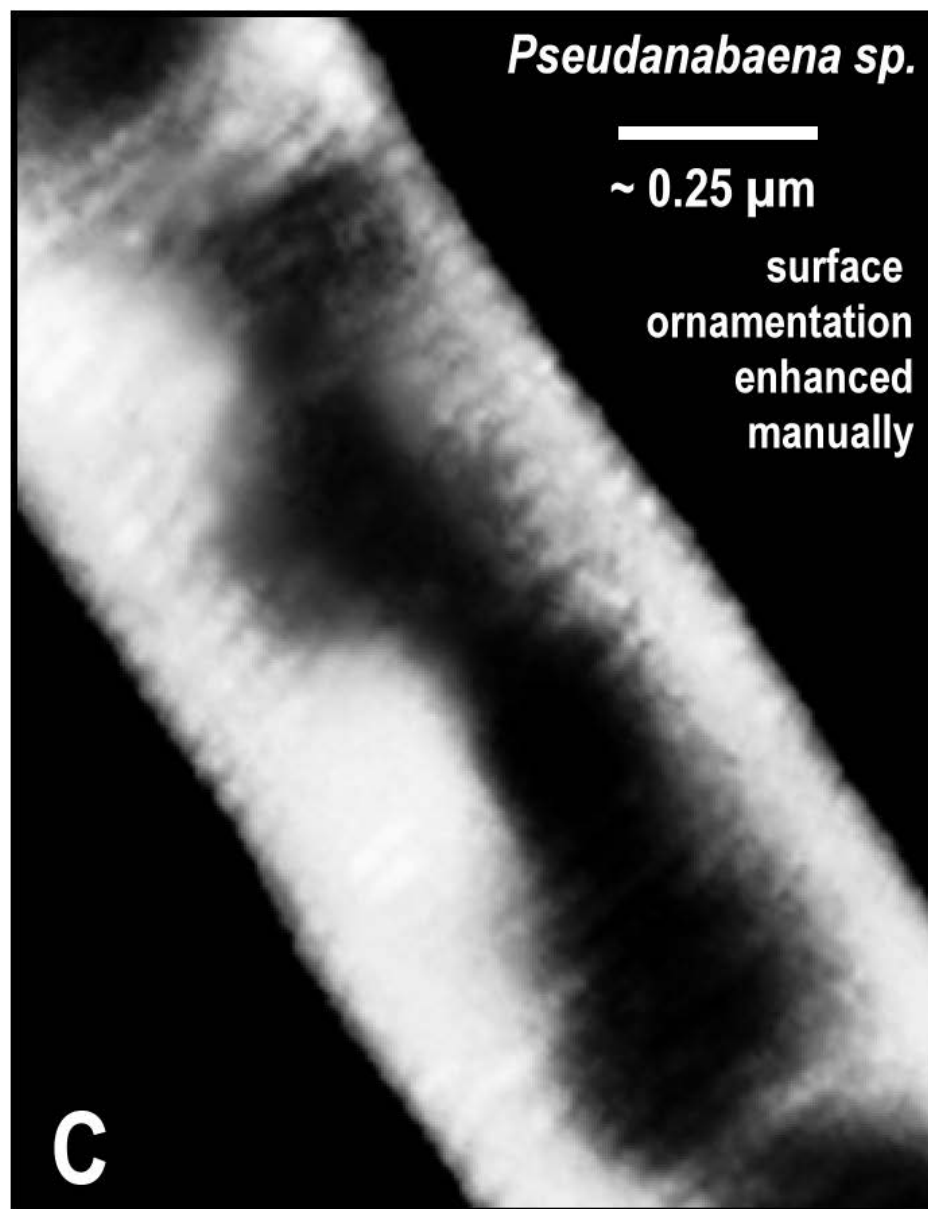
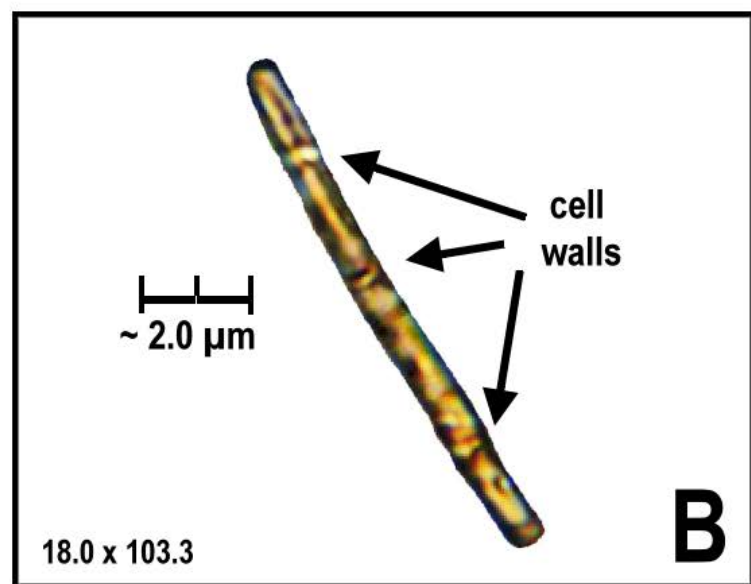


Figure 17. A single filament of the cyanobacteria *Pseudanabaena sp.* Note the detailed external morphology in photomicrograph C.

(Big A Butte Member, Supai Fm. --- RCR No. 4 Well, Navajo Co., AZ --- 1,852.0 Ft.)

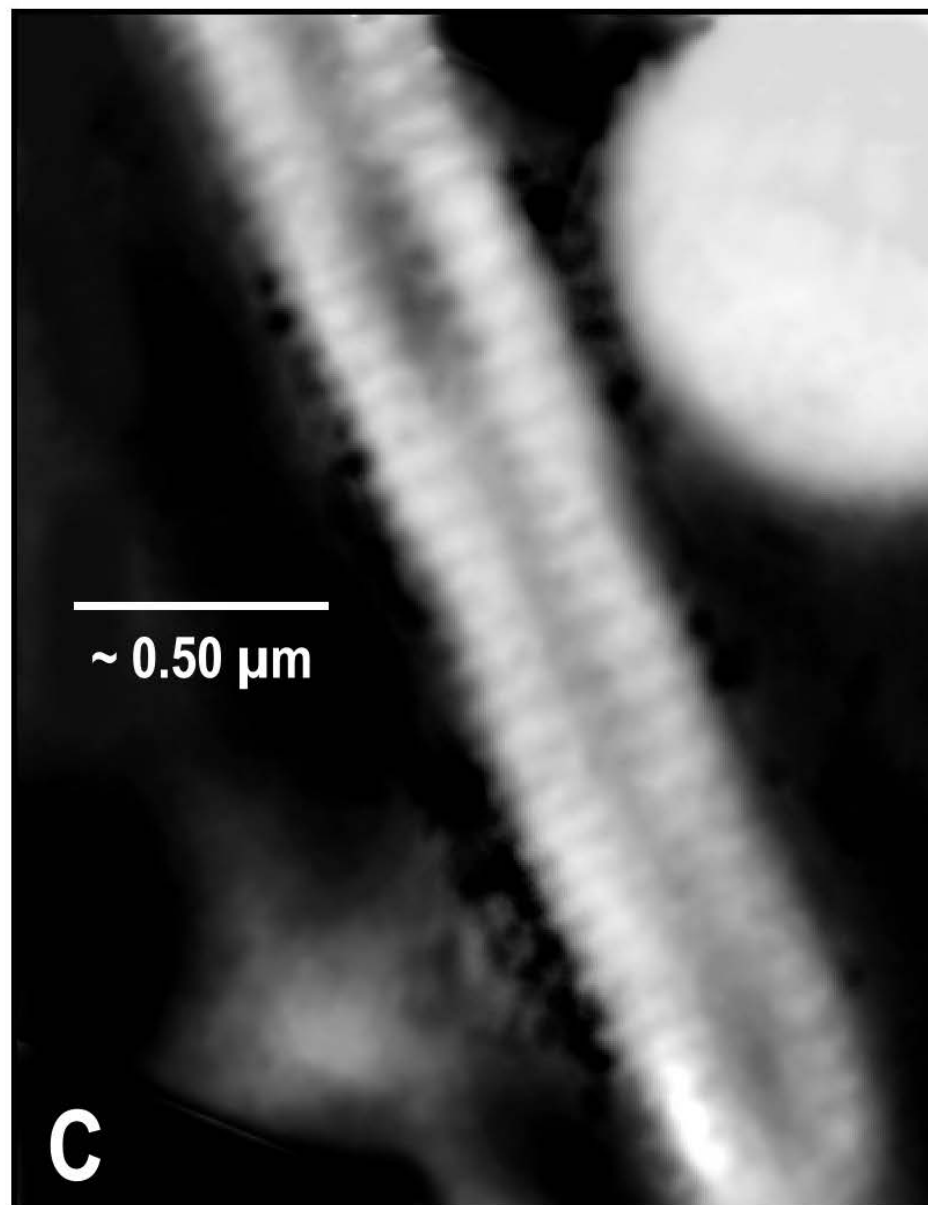
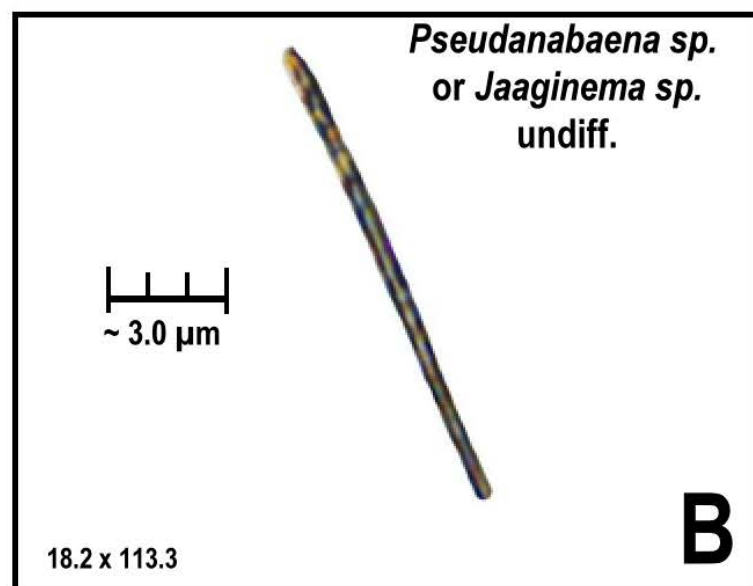
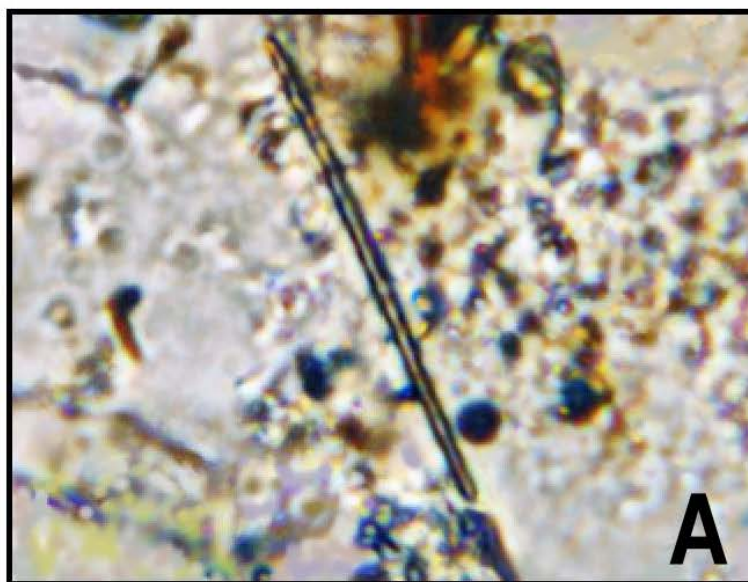
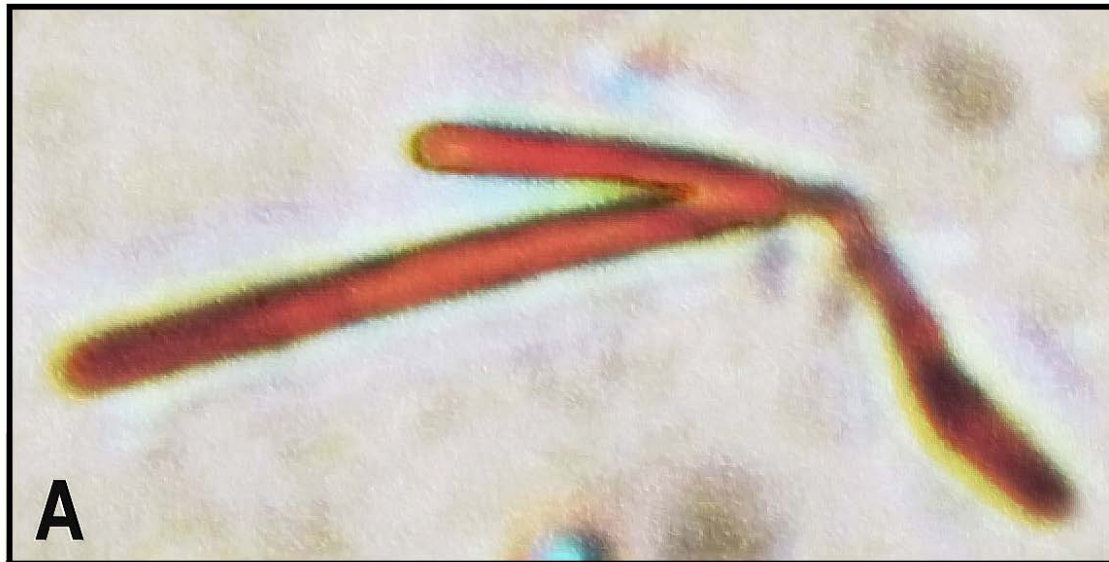


Figure 18. A single filament of a cyanobacteria belonging to either *Pseudanabaena sp.* or *Jaaginema sp.* Note the fine surface ridges shown in Figure C.

(Big A Butte Member, Supai Fm. --- RCR No. 4 Well, Navajo Co., AZ --- 1,852.0 Ft.)



cf. *Fischerella* sp. (broken cluster)

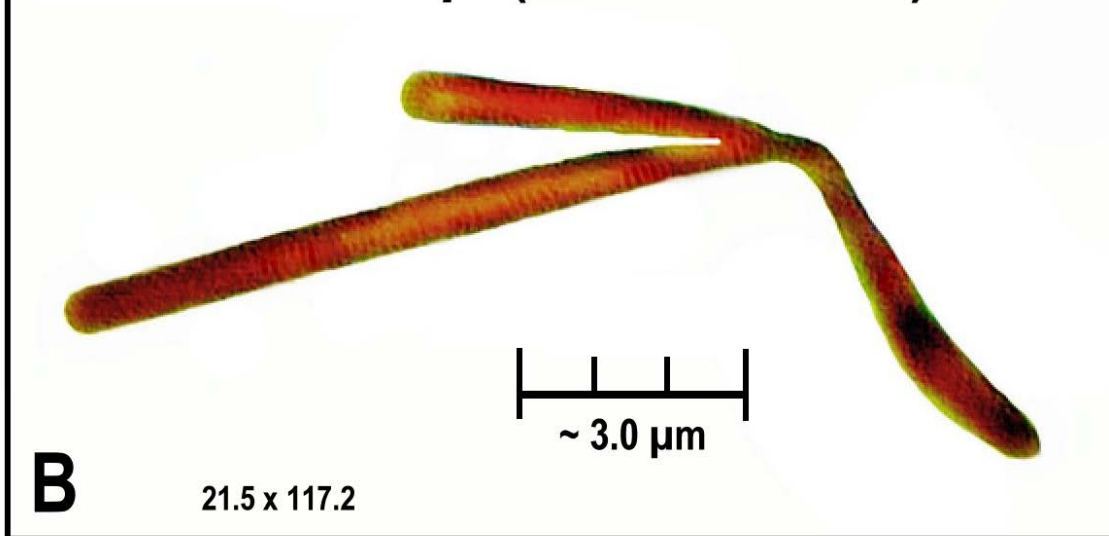


Figure 19. A fragment of the cyanobacteria *Fischerella* sp.

(Big A Butte Member, Supai Fm. --- RCR No. 4 Well, Navajo Co. AZ --- 1,852.0 Ft.)

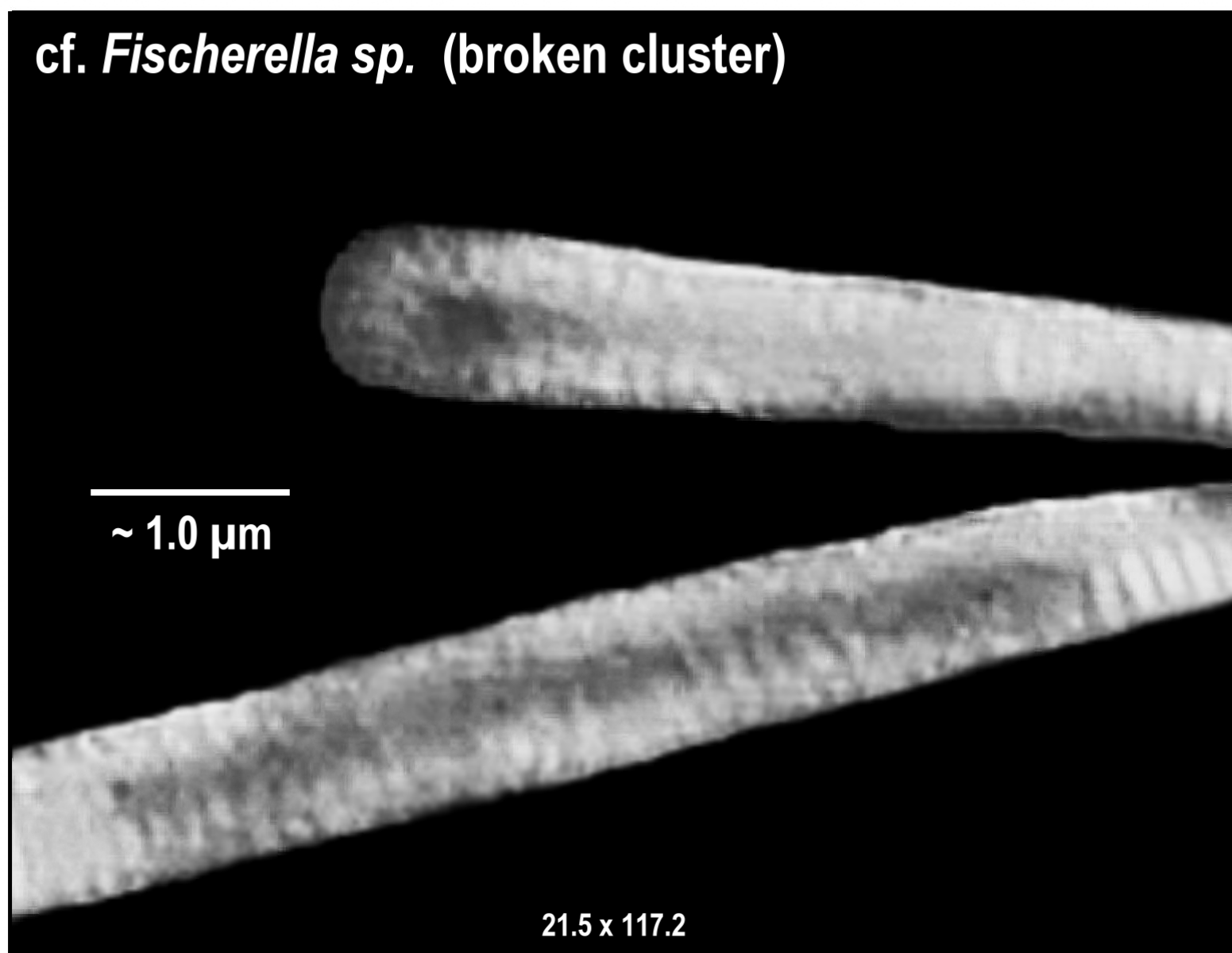


Figure 20. A photomicrograph showing an enlarged portion of *Fischerella* sp. illustrated in [Figure 19](#). Note the fine surface ridges.

Table 1

MORPHOLOGICAL FEATURES OF SELECTED FILAMENTOUS CYANOBACTERIA *

Genus Attribute	p. 161, Fig. 22 <i>Tolypothrix</i> sp.	p. 164, Fig. 25 <i>Calothrix</i> sp.	p. 166, Fig. 27 <i>Rivularia</i> sp.	p. 166, Fig. 26 <i>Gloeotrichia</i> sp.	p. 144, Fig. 12 <i>Symploca</i> sp.	p. 126, Fig. 3 <i>Geitlerinema</i> sp.	p. 126, Fig. 2B <i>Jaaginema</i> sp.	p. 129, Fig. 1B <i>Pseud- anabaena</i> sp.	p. 184, Fig. 37A <i>Fischerella</i> sp.
Heterocytes	One or more at base, with 1 or 2 pores. Heterocytes, circular	Heteropolar, heterocytes not always present	Heterocytes circular to sub-circular in shape	Basal heterocytes, spherical to ellipsoidal in shape	None reported	None reported	None reported	None reported	Intercalary, in basal trichomes, and branches
Akinetes	Very rare or absent	Heteropolar, occasional akinetes	Unknown, none reported	Adjacent to heterocyte, cylindrical or elongated	None reported	None reported	None reported	None reported	Known only in a few species
Filament	Very long with circular basal heterocytes; heteropolar	Attached to substrate forming bristle-like mats	Attached to Ls. substrate often forming hemispherical to flat colonies	In ball-like or hemispherical colonies, often planktonic	Prostrate, erect, irregularly curved, thin, 8-14 µm wide	Common in mats rarely solitary; cells straight, tapered or with a terminal hook	Long, flexible solitary, tangled or in clusters, up to 3µm wide	Trichomes are solitary, wavy, in mats, cylindrical, straight, 1-3.5 µm wide	Uniseriate or multiseriate, erect, creeping in feltlike mats
Filamentous Sheath	None reported	Present, firm, often enlarged forming funnel-shaped collars	Firm, open at tip of trichome; Mucilaginous and Calcareous	Present, distinct Trichomes enclosed by sheath	Thin or thick, distinct	None reported by Komarek, 2003.	Very thin membrane around Trichome	Trichomes lack firm sheaths; some have fine, wide, diffused mucilage	enveloped by a thick, wavy or slightly laminated sheath
Branching	False branching begins next to the heterocyte	False branching occasionally occurs	Yes	False branching very rare	Pseudo-branching	None reported	None reported	None reported	True; "T"-type branching, usually unilateral
Aerotopes	None reported	Absent	Absent	Yes, in cells	None reported	None reported	None reported	Yes, localized in polar positions	Yes, in cells in branches.
Habitat	Unpolluted fresh water, on stones-plants. Mineral springs, alk. swamps, streams and terrestrial.	Fresh water, epiphytic, some marine. In tidal pools, littoral zones. Often terrestrial on decayed veg.	Epiphytic, esp. on calcareous substrate. Few marine, mainly fresh water. often forms Travertine	Fresh water. 1 species reported from brackish water. Planktonic or attached to substrate in lakes, streams.	Most terrestrial on wet surfaces of rocks-cliffs. Subaerophytic Few marine species have been reported.	Terrestrial and in aquatic habitats on macrophytes, planktonic, forms mats, in unpolluted waters, also in thermal and mineral springs	Benthonic in shallow water on sediments or aquatic plants. Some known from mineral springs.	Fresh-brackish water habitats, a few from mineral waters & hot springs Planktonic & Benthonic; also in soil	Subaerial, on wet (often acidic) soils, rocks and vegetation. Some on submerged substrata

*Data from Komarek, et al., 2003

Table 1. Morphological characteristics of selected Filamentous Cyanobacteria.