Dwarf Hepatic Floral Fragments (Possibly Liverworts) from the Upper Mississippian Barnett Shale in the Fort Worth Basin of North Central Texas*

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Abstract

Bryophytes represent a group of terrestrial multicellular eukaryotic land plants (of which only a few species are aquatic) that are believed to have evolved from, or contemporaneously with, algal ancestors. Although they have been reported from the lower Upper Cretaceous of Texas, they have not, to our knowledge, been reported from Upper Mississippian sediments. While undertaking a detailed analytical thermal maturity study of the lower Barnett Shale (mudstone) in the Mitchell Energy W.C. (Bill) Young No. 2 well in Wise, County, Texas, the authors found bryophyte-like fragments (possibly liverworts, hornworts and mosses) to be a common floral constituent in the organic matter residue.

Based on our observations and limited knowledge of the various bryophyte genera, we believe forms having a striking resemblance to the genera, *Asterella* (or possibly *Reboulia* and/or *Conocephalum*), *Riccardia, Lunularia,* and *Marchantia*, all belonging to the Phylum Marchantiophyta, may be present in the organic matter residues extracted from the core chip samples taken between 6891.0 and 7211.0 feet of the Mitchell Energy W.C. (Bill) Young No. 2 well.

These bryophyte-like components, in conjunction with numerous fresh water algal components, suggest that much of the lower part of the Barnett Shale (mudstone) may not have been deposited in a deep-marine environment (lower slope to deep-basin setting; 400 to 700 feet of water depth) as interpreted by Loucks and Ruppel (2007, p. 597). The authors interpret the deposition of the lower Barnett section, in the Mitchell Energy W.C. (Bill) Young No. 2 well, to have taken place in an anoxic, or partly anoxic, environment (in muds) on a gently dipping flood plain near, or at, the shoreline-water interface. The environmental setting is interpreted to have been in association with a wetlands type of environment that included scattered ponds, lakes, marshes, bogs, swamps, and fens that were predominantly fresh water in

nature. We propose that high discharge of fresh water into the Fort Worth Basin (which may have been semi-restricted at this point in time) produced a brackish-water environment. Although the fossil material could have been easily transported into a basin having predominantly marine conditions, we have not observed any marine fauna and flora in any of the lower Barnett core samples from the Mitchell W.C. Young No. 2 well to support this interpretation. The overwhelming abundance of a terrestrial to fresh-water flora, suggests that the deposition of the lower Barnett Shale (mudstone) in the Young No. 2 well was more likely associated with a shallow-water environment (shoreline to shallow-water shelf) and not a deep-water setting as proposed by Loucks and Ruppel (2007, p. 599).

The continued abundance of the bryophytic-like flora throughout the cored interval, between 6,891.0 and 7,211.0 feet, without any noticeable changes in floral types, suggests that the Mitchell W.C. (Bill) Young No. 2 well probably never penetrated upper Ordovician sediments (Viola, Simpson or Ellenburger) at 7,168.0 feet as initially reported by Steward and Paniszczyn (2007, p. 58).

Introduction

Essentially nothing has been published on the dwarf hepatic reproductive fragments that occur within the Upper Mississippian lower Barnett Shale (mudstone) of the Fort Worth Basin of north-central Texas. The primary reason for this oversight is most likely due to their extremely small size combined with their delicate nature, the latter making the preservation of these forms as fossils difficult.

These particular fossil constituents, observed in the core chip samples from the Mitchell Energy W.C. (Bill) Young No. 2, range in size from 5 to 20 micrometers in size and are several hundreds of times smaller than extant liverworts. Because of their extremely small size and preservation, some bryologists (e.g., Drs. Ray Stotler, Department of Plant Biology, University of Southern Illinois, Carbondale, Illinois, and A. Jonathan Shaw, Department of Biology, Duke University, Durham, North Carolina; personal communication, July 2010) have expressed difficulty in accepting their validity as being bryophytic in origin. Dr. Stotler also questioned whether the picture of the fossil, in this instance the photograph showing a fragment of what we believe to be related to *Riccardia sp.* (Plate 2, Figure B; Plate 3) actually shows cellular structures as we believe it does. The senior author of this article mentioned to Dr. Stotler that the cell-like structures were approximately 2 to 3 micrometers in diameter. Dr. Stotler wrote back saying that the cellular size was much too small for organisms belonging to the Eukaryotes. The writers will address this particular issue later.

In an exchange of emails and photographs, Drs. Li Zhang and Christine Cargill, two bryologists and former students of Dr. Stotler, did not completely reject the idea that these fossil fragments may be bryophytic in origin, but neither did they readily accept the writers' interpretations. All the bryophyte experts that we have talked with reject the bryophytic origin of our fossil material primarily because of their minute size.

[NOTE: For those who are interested, Dr. Li Zhang currently lives in China and can be contacted by email at Zhangli@scib.ac.an. Dr. Christine Cargill lives in Australia and can be contacted by email at Chris.Cargill@environment.gov.au].

The first question one will probably ask is "How do we know the fossils that we are seeing belong with the bryophytes and not the algae"? This is not an easy question to answer, especially when algae and plants share some of the same general characteristics.

The difference between extant algae, bryophytes, and vascular plants lies predominantly in their chemical and cellular structure. All plants are interpreted as being multicellular Eukaryotes that have their cell walls made of cellulose. Green algae, share many characteristics with plants, including their photosynthetic pigments and cell wall composition (cellulose). A few green algae (i.e., Spirogyra, Volvox and Ulva) are also multicellular. Algae, once interpreted to be plants, are now classified separately. They differ from true plants because they lack a true root system, stems, leaves and embryos. Bryophytes, (along with other land plants) also referred to as Embryophytes, differ from algae in that they have true embryos. Some bryophytes, such as the mosses and leafy liverworts, have leaves or leaf-like structures, while others (i.e., thalloid liverworts and hornworts) have flat sheet-like bodies. All bryophytes have a rudimentary root-like structure referred to as rhizoids which are used, in part, to attach the organism to the substrate (wood, rocks, other plant tissues, sediment, etc.).

Because the individual cellular structure and material of most organisms (i.e., the cytoplasm, mitochondria, etc.) are normally not preserved in fossil material, paleontologists are often forced to make an educated guess as to what group an organism belongs to, or may be related to, based primarily on the fossil's external and internal morphology. This is why morphological comparisons of fossil tissues with recent plant life is so important. It becomes absolutely critical when studying fragments of a fossil that are often no more than just a small part of a much larger entity.

Based on our knowledge and years of experience examining both fossil and recent algal material, along with the spores and pollen of vascular and non-vascular plants, the writers have concluded that the fossil material extracted from the Mitchell Energy W.C. (Bill) Young No. 2 well, and discussed herein, is more likely to be of bryophytic origin rather than algal in nature. The external morphology looks more bryophytic in nature and can be readily compared to extant bryophytic genera. We do not know of any algae groups, or genera, that have a similar external morphology to what can be seen in this fossil material.

This article describes and illustrates several of the various fossil types extracted from core chips samples taken in the lower Barnett Shale (mudstone) of north-central Texas. The writers observed these minute fossil fragments while doing an in-depth study of the thermal maturity and geochemistry of the Mitchell Energy W.C. (Bill) Young No. 2 well, located in Wise County, Texas (Figures 1a, b and 2). Tissue fragments of what we believe to have been derived from mosses and hornworts were also observed in the core chip samples. Evidence of their occurrence, will be presented in a separate paper.

[NOTE: It should be mentioned here that the writers observed an almost identical bryophyte-like floral assemblage in the upper and lower Eagle Ford Shale of Webb and La Salle counties in south Texas. In the core and cuttings samples of the Eagle Ford Shale sections that the writers examined, the bryophyte-like fossil material is most common in the upper part of the Eagle Ford. They are associated with planktonic forams and calcareous nanofossils. This is a clear indication that the depositional environment was marine and/or brackish water in nature. The bryophyte-like fossil material was most likely transported into the shallow marine or brackish water environment by fresh water rivers, streams and water runoff (overflow) from coastal lakes, salt marshes, and estuaries. Yoder (personal communication, Oct. 2010) states that the planktonic forams are greatly reduced in size and suggests it is the result of the zooplankton living in a highly stressed hyposaline environment created by the influx and mixing of fresh and marine waters. Yoder suggests that this density-flow method of transport may also account for mechanical sorting and may help explain the very small size of the bryophytic assemblages occurring in the Eagle Ford Shale.]

The dwarf floral elements are best studied in transmitted illumination with a high resolution light microscope equipped with a 100x objective. A Scanning Electron Microscope (SEM) or Transmission Electron Microscope (TEM) could also be used. The drawback in using these two techniques is primarily in the expense of conducting such an examination and in not being able to adequately see subtle changes in the colors of the bryophyte tissue. The latter is important in helping to distinguish features (i.e., gemmae cups and cells) which might be suppressed and or hidden when viewed with the SEM or TEM. Most analysts, whether they work for a petroleum company or an independent service company, examine the organic matter debris that is extracted from cores cuttings and/or outcrop samples on a glass slide (called a visual kerogen slide) using a 25x to 40x objective. As a result, they often overlook these abnormally small constituents.

[NOTE: The main reason why the fossil material in this study was not examined using SEM or TEM was due to a shortage of core chip material. All the core material the writers had was used in our geochemical evaluation of the Young No. 2 well. As a result we are only able to present photomicrographs taken through the light microscope].

Where possible, the authors have tried to make a direct comparison of the fossil material, based on their morphological similarities, to extant forms. Because none of the authors are taxonomists, we have purposely omitted proposing new taxonomic names for the fossils that we observed. All the bryophyte-like constituents observed thus far can, for all practical purposes, be compared fairly well to extant genera. It is important to recognize the significance of this particular group of fossils in the Upper Mississippian of the Fort Worth Basin of Texas. The implications of their presence impact reconstructions of the depositional environment, and/or climatic conditions, that were prevalent throughout this portion of the geologic section during Late Mississippian time.

There is no doubt that many bryologists will strongly disagree with some of our findings and suppositions. To those individuals who have never worked with well cuttings samples and/or cored material, we ask that they please understand that we are limited in our investigations to a very small amount of organic material with which to work. Most of the organic detritus is highly fragmented, extremely small, and not always preserved in the manner (i.e., large fragments) we would like. Although the writers interpret the majority of the organic detritus to be *in situ* (not recycled from older sediments) they also recognize the fact that it may have been transported over a considerable distance before being redeposited in its current location.

Bryophytes

What are Bryophytes?

Bryophytes are a group of plants that include the mosses, liverworts and hornworts. They were once believed to be nonvascular plants. Vanderpoorten and Goffinet (2009, p. 17-25) state that bryophytes do, in fact, have a vascular system, although it is considerably different than that found in the more advanced plants. Most extant bryophytes are terrestrial although a few are known to be aquatic. The extant aquatic forms are only associated with a nonmarine, fresh-water environment (which may or may not have been true during Late Mississippian time). All bryophytes produce spores rather than seeds, the latter being typical of the tracheophyta, or vascular land plants. Bryophytes also lack flowers.

Present day bryophytes are found in a wide variety of environments, from the Arctic and Antarctic to the Equator. They can be found in high altitudes as well as along the shorelines of oceans. They are commonly found living in a humid environment but are also known to thrive in arid desert locations. Bryophytes are commonly found growing on rocks, soil, trees and other forms of terrestrial vegetation (living and decaying). They are among the first plants to grow on a barren terrain (especially after periods of volcanism) and help initiate soil formation. Some forms have the ability to take in calcium from the substrate and deposit mineral components such as calcite and/or gypsum within, and/or upon, their cell walls. Because of these attributes, bryophytes are often referred to as "rock or soil builders".

Although the bryophytes have a long geological history, extending back some 500 million years or more, it is difficult to find a lot of detailed information about fossil forms in the literature (geological and/or botanical publications). The reasons for this are three fold. First, many paleontologists (micropaleontologists and palynologists) do not study extant bryophytes and therefore really do not know what they look like in thin sections and/or in their organic matter residues. Second, most micropaleontologists and palynologists have been trained to work with specific groups of fossils (i.e., forams, ostracods, calcareous nannofossils, fungal spores, trilete spores, pollen, dinoflagellates, etc.) but not bryophytes. Third, bryophytes, many of which are very small to begin with, are often not preserved as fossils in the sedimentary record. Their sporophytes and other reproductive structures, often used in making identifications, are delicate and fragile in nature. The soft vegetative portions of the bryophyte generally do not survive intact during the process of sedimentation (i.e., transport and accumulation). More often than not, the only indication that bryophytes may have been present in a given locality is based entirely on the recognition of their spores, which in many instances, are unique.

The fact that most extant bryophytes are terrestrial in origin, growing close to the ground and anchored to the substrate by filamentous rhizoids, generally prevents the plants themselves from being transported by wind currents (like the spores and pollen from the higher land plants). They can however, and often are, carried to other locations by water currents (generally attached to woody debris, other plant tissues, pebbles, etc.). They have the unique capability of being able to regenerate their kind, even from the smallest of fragment of the parent plant. . In order for the bryophytic tissues, which decay rapidly on the death of the individual, to remain intact and recognizable as fossils, they must be buried rapidly. Burial is generally associated with anoxic or partly anoxic conditions (i.e., in coastal swamps and bogs that occur on flood plains and/or in semi-enclosed bodies of water (estuaries) that often form along the margins of lakes and oceans).

What is a Hepatic Flora?

A hepatic flora is one that consists of bryophytes belonging only to the Phylum Marchantiophyta, the liverworts. The liverworts are a group of plants that are relatively small in size (as denoted by the suffix, "wort", which means small plant). Today many scientists are studying their medicinal properties and applying this knowledge in the treatment of cancer (Vanderpoorten and Goffinet, 2009, p. 32). Because bryophytes are highly sensitive to environment changes, climatologists and bryologists are studying them in order to gain a better understanding of the effects of global warming on their habitat and survival.

They differ from the higher land plants in that they produce spores, rather than seeds, some of which are borne in small capsules. As mentioned earlier, liverworts do not produce flowers, as is typical of the more advanced vascular plants. In the liverworts, as in all bryophytes, there is a gametophyte stage and a sporophyte stage (a haploid, and diploid reproductive stage). Bryologists have subdivided the liverworts into two groups, the leafy liverworts, which consist of leafy and simple thalloid liverworts, and the complex thallose liverworts. The latter are subdivided further into the Simple Thallose Liverworts and the Complex Thallose Liverworts. According to Christine Cargill (personal communication, December 2010), molecular studies have shown that the simple thalloid liverworts are more closely related to the leafy liverworts than to the complex thalloid forms.

Leafy Liverworts

In the leafy liverworts, the gametophyte portion of the plant consists of leaves and stems. The sporophyte portion consists primarily of dark brown to black capsules that, when mature, rise above the gametophyte on a thin, elongated, semi-transparent, stalk or seta. The sporophyte, once raised above the gametophyte (which bears the egg-producing organs, the Archegonium), splits open along four, pre-defined, zones of weakness. The spores are liberated, some with the aid of elaters, and dispersed by the wind to suitable habitats where they germinate and grow to reproduce a new gametophyte generation. Shortly after the sporophyte splits open and the spores have been liberated, the stalk, or seta, collapses. Often, the only evidence of the existence of the sporophyte is the thickened dehisced (ruptured) capsules. This particular group of liverworts comprises the majority of extant types.

Complex Thallose Liverworts

The complex thallose liverworts represent a group of bryophytes that have thalli which are generally thick, lobed (like a mitten or glove) and generally appear somewhat fleshy. Some forms have a rough, rugose-looking appearance, or texture (looking similar to the skin of a lizard), due to the many pores and/or cellular network that covers their upper surface (dorsal side). Others may appear smooth. The lower surface of the thallus (ventral side) is normally covered by fine hair-like filaments, or rhizoids. Their function was once interpreted only as a mechanism for attaching the plant to the substrate. Current thought is that the rhizoids serve as means of distributing nutrients to the entire surface of the bryophyte itself. [NOTE: The rhizoids do not, "however", actively absorb nutrients like vascular plants.]. It is also the surface from which some of the reproductive structures originate from specially formed cells.

The term "thallose" is used to describe the appearance of the liverwort. It is the name given to the individual flat, sheet-like, portion of the plant (the thallus is the general form of the body of the plant and it is undifferentiated as to stem, root, or leaf).

Thallose liverworts whose thalli contain cells, in which there is no major differentiation, in function, are called simple thallose liverworts and are more closely related to the leafy liverworts. Liverworts whose thalli are generally thick and are differentiated into different cell layers with a number of functions are called “complex thallose liverworts“.

Regarding their chemical composition, all bryophytes are composed predominantly of cellulose. There is no lignin, per se, present as in the higher vascular land plants. Like other fossils, they are, and can be, preserved under the right conditions (quick burial in an anoxic environment). Most extant liverworts (and presumably their fossil representatives) produce oil bodies, containing terpenoids, within their cells. These entities are not normally preserved within the cell after their death and burial. According to the literature on bryophytes, oil bodies are only found in the liverworts. The function of the oil bodies is somewhat of a mystery. Some bryophyte specialists think they may be used to protect the plant from extreme cold or some other unsuitable environmental condition. Other specialists think they might also be used as a defense mechanism to keep predators away. These writers suggest that they might also have played a role in buoyancy. The oil bodies, plus the occurrence of air chambers throughout the thallus, would help keep the thallus on top of the water column, should adverse conditions occur which might otherwise drown the plant life (i.e., major flooding, etc.). Figure 3 is an excellent illustration of what oil bodies look like in an extant leafy bryophyte. The number and size of the oil bodies vary from one genus and species to another. This photomicrograph was taken by Dr. Steven L. Jessup and depicts cells in the tissue of a lophozioid liverwort. Note the five oil bodies arranged around the inside margins of the cell walls. The photomicrograph, authorized for use by Dr. Jessup, can be found on the Internet at http://www.cavehill.uwi.edu/FPAS/bcs/bl14apl/bryo1.htm.

Figure 4 is a diagrammatic illustration of a typical liverwort, in this instance, *Marchantia*, showing its life cycle and external morphological features. The drawing, as shown here, was produced by the LadyofHats. Its image was placed into the public domain on August 15, 2005. For those who are interested, the LadyofHats statement of release can be viewed on the Internet (http://commons.wikimedia.org/wiki/File:Liverwort_life_cycle.jpg).

Of particular interest here is the fact that in the liverworts, only the genus *Marchantia* produces "circular" or "elliptical" gemmae cups (Munch, 2006, p. 69). This is one of the ways to identify the plant morphologically. It is the criterion we used for our identification of the bryophyte, thought to belong to the *Marchantia,* that we observed in the kerogen residues from the core chip samples of the Mitchell W.C.

(Bill) Young No. 2 well.

As shown in Figure 4, bryophytes may reproduce sexually and asexually. In sexual reproduction there is a mixing of the gametes (egg and sperm) from two different and separate parents. In asexual reproduction, the formation of new individuals from a single individual takes place without the involvement of gametes. The new individual is a clone of its parent. Each reproductive system obviously has its own advantages for the propagation of the species. The reproductive structures such as gemmae cups, antheridia, archegonia, and spores, including their position and morphology, are just some of the criteria used in the identification of extant liverworts.

Bryophyte Cell Size

As mentioned in the preceding paragraphs, there seems to be a great deal of concern regarding the size of what we believe to be cells in the fossil material. The cell size within the fossil specimens seems to be consistent when found. They are normally oval in appearance and range from approximately 2.0 to 3.0 micrometers in size (Plate 3). The writers have been told that this cell size is much too small for the fossils to be interpreted as being bryophytic in nature. According to some bryophyte experts, we need to be looking at cells greater than 10 micrometers in size. The writers reject this idea simply because the extant bryophyte cell-size scenario may not necessarily be applicable to bryophytes that lived during Late Mississippian time. We also reject this hypothesis because of the fact that nobody has (to our knowledge) reported bryophyte-like fragments in the size range observed in this study. Since most bryologists look at extant material, they, more often than not, seldom see or examine fossilized plant materials. We think that it is possible that some forms of bryophytes, living 325 million years ago, may have been dwarf in size. It is very likely that extensive shrinkage of the original plant tissue has taken place and that what we are seeing today is just a facsimile of the actual specimen. The writers understand why current bryologists would have a problem in dealing with entities as small as what have observed, especially since the bryophytes of today are considerably larger. Although the writers cannot find a unanimously accepted explanation that accounts for the size of the fossilized material they are looking at, they propose that the fossil debris is bryophytic in origin.

The fact that the cell size in our fossil material is so small should not disqualify the fossil plant tissue fragments from being grouped with the bryophytes. In the study of "Cell Biology", it is a well known fact that small cell size can be, and oftentimes is, much more efficient in transporting fluids in and out of the cell (through the cell wall or cell membrane) at a faster rate. This is because smaller cells have a more favorable surface area to volume ratio than larger cells. This benefits the organism by helping it to get rid of waste material and the taking in nutrients.

Schopf (1999, p. 88), in a discussion on the size limits of very small microorganisms, states "the actual and theoretical size limits of minute-living microorganisms are incompletely defined and, so the biogenicity of exceedingly small ‘biologic-like’ objects is subject to debate." This is essentially what is happening in this study. In this instance the writers are confident that they can show that the fossil plant life they are looking at is biological in origin. They are not artifacts, as some bryophyte experts have suggested. An important point that Schopf failed to mention in his paper is that if fossil fragments from sediments of one geologic age are identical to, or very similar to (regarding their size and morphology) those found in rocks of another geological age (and at different locations), then they are very likely "real" and not "imagined".

Raven (1999) states that because bryophytes have an embryo, it is a requirement that the organisms be at least 100 micrometers in size in order to carry out both life cycle generations. The writers are not sure whether Raven's conclusion can be proven or whether they are even fact. Regardless, the reader is reminded that the fossil fragments examined in this study are only a fraction of the size of the entire individual. All one has to do is look at the size of the thalli tips of the extant specimen of *Riccardia* on Plate 1 (Figures B and C) and compare it to the size of the entire plant (Figure A). When it comes to the illustrated examples of the fossil plant thalli versus the entire plant, the writers suspect that it would be easy to find fragments in the size range that we have observed associated with an individual that was 100 micrometers or more in size. Unfortunately, no completely intact bryophytes (or bryophyte-like plants) have been found thus far.

The writers propose that the real question that needs to be answered is why are these fossils so small? If we could find the answer to this question, it would certainly tell us a lot more about what the environment was like during deposition of lower Barnett (Late Mississippian) time and why the flora is composed as it is.

One cannot help but wonder if the plant size is related to the climate, soil, water, nutrients, or a combination of things? Perhaps the answer is simply "shrinkage". According to Mishler and Kelch (2009, p. 177), "limited water availability is probably the most important environmental factor that early land plants had to contend with". Oliver (2009, p. 269) states that bryophytes have the unique ability of being desiccation-tolerant (the ability to resurrected themselves after long periods of severe drought). Perhaps what we are looking in this study are bryophyte-like components that were buried by sediments, due to rapidly changing environmental conditions, and fossilized in a desiccated state. It certainly would help to explain why the fossil material is so small.

Gemmae cups

In the bryophytes, gemmae cups are features normally associated with the complex thalloid liverworts and some mosses. Some people often refer to these structures as "splash cups". They occur in a variety of shapes, sizes, and morphologies. The primary purpose of the gemmae cup is to disperse sperm or disperse gemma. Gemma are small, usually green disk-shaped structures, an aggregate of cells formed by the parent gametophyte, that are formed within the gemma cup. When mature, the gemma sit within the gemmae cup (much like eggs in a birds nest) waiting to be dispersed by water (rain and/or dew). The water carries the gemmae away from the parent so that it can generate a new gametophyte in a suitable habitat in a different location. This is the asexual means by which the species propagates itself. For more detailed information on gemmae cups (splash cups), the reader should see Vanderpoorten and Goffinet (2009, pp. 59-61) and Lepp (http://www.anbg.gov.au/bryophyte/splash-cups.html) (posted November, 2008; accessed January 10, 2011).

Discussion

Plate 1, Figures A-C, and Plate 2, Figures A and C are photographs of the liverwort *Riccardia* sp. (from Sichuan, China) taken by Dr. Li Zhang, formerly a doctoral student at Southern Illinois University at Carbondale, Illinois and now associated with The Fairylake Botanical Garden in Guangdong, China. Dr. Zhang's photographs of the liverwort *Riccarida* sp. show the "Y"-shaped branching (bifurcate and/or trifurcated) of the terminal ends of the thalli. This is one of the distinguishing features of the genus *Riccardia*. This particular genus of bryophyte is commonly found growing on soil, decaying trees, and other plant life. This photograph can be found online (http://bryophytes.plant.siu.edu/imRiccardiaSp.html) (accessed January 10, 2011).

Plate 2, Figures B, D-I and Plate 3 are illustrations of fossil fragments interpreted to be the tips of thalli torn from a 325 million-year-old plant that was similar to the extant genus *Riccardia*. Notice the "Y"-shaped terminal ends of the thallus. As mentioned above, this is one of the major characteristics for the genus *Riccardia*. In Plate 3, the reader is asked to closely examine the surface morphology of the fossil fragment, noting the cell-like structures at the apical end of the thallus and along the margin of the floral structure.

Plate 4, Figures A-C are of the bryophyte *Marchantia berteroana.* This photograph showing the various thalli covered with gemmae cups, was taken by Dr. Ricardo Rozzi, a bryologist currently affiliated with the Department of Philosophy and Religion Studies at the University of North Texas, Denton, Texas. The photograph was sent to the writers by Dr. Rozzi, along with his permission for publication in this article. Dr. Rozzi's photograph shows in detail the external morphology of that particular genus and species. It is of particular importance because it provides the reader with a excellent means of comparing the "cup-like" structures (i.e., gemmae cups) that we have observed on the fossil bryophyte tissue from the Upper Mississippian Barnett Shale (mudstone), in the Mitchell Energy W.C. (Bill) Young No. 2 well in Wise County, Texas.

Plate 5, Figures A-B illustrate a bryophyte-like tissue fragment with a cluster of gemmae cups. Figure B is enlarged to show the circular nature of the gemmae cups. Figure C is another fragment of bryophyte-like tissue also showing the presence of a gemmae cup. Compare these photographs with that of the extant liverwort, *Marchantia berteroana* in Plate 4.

Plate 6, Figures A-G are various pieces of bryophyte-like tissue fragments with gemmae cups. In some instances, the gemmae cup appears to have been completely torn away from the thallus (as in Figures C and G).

Plate 7, Figure A is a photograph of the extant liverwort *Lunularia cruciata.* Figures B-C are photomicrographs of fossil material that we interpret to be related to the genus *Lunularia*. *Lunularia* can be identified, in part, by its lunate or crescent-shaped gemmae cups. The photograph of *Lunularia cruciata*, taken by Mr. Heino Lepp, who is currently associated with the Australian National Botanical Gardens and the Australian National Herbarium, can be found online (http://www.anbg.gov.au/bryophyte/photos-captions/lunularia-cruciata-42.html) (accessed January 10, 2011).

Plate 8, Figure A is a photograph of the extant liverwort *Asterella australis*. It was taken by Dr. Clive Shirley. Plate 8, Figure C is a photograph of the liverwort *Asterella drummondii* in a dried state. Note the spore capsules ("hanging baskets") extending off the carpocephalum (the umbrella-shaped sporophyte). Compare these photographs to the fossil specimen shown in Plate 8, Figure B. The arrows in Figures A-C point to the spore capsules. Figures C-D were taken by Mr. Heino Lepp. Figure D is a photograph of the extant bryophyte *Reboulia hemispherica*. Note its similarity in morphology to those liverworts shown in Figures A and C.

Figure E, on Plate 8 is a photograph of the extant liverwort *Conocephalum conicum* (http://bryophytes.plant.siu.edu/imconocephalumconicum.html) (accessed January 10, 2011). The bryophyte *Conocephalum*, taken by Dr. Li Zhang, exhibits some external morphological similarities (though vague in some of our photographs) to some of the fossil bryophyte-like forms observed in the lower Barnett Shale (mudstone), as illustrated in Plate 8, Figure B; Plate 9, Figures A-F; and Plate 10, Figures A-F.

For a good introduction and review of the extant liverworts, the reader is advised to read the following online articles; The Bryophyte Groups, by Mr. Heino Lepp, (http://www.anbg.gov.au/bryophyte/bryophyte-groups.html) (accessed January 10, 2011), and Bryophytes; Mosses, Liverworts and Hornworts, an online article by Dr. Raymond E. Stotler and Dr. Barbara J. Crandall (http://bryophytes.plant.siu.edu/bryojustified.html) (accessed January 10, 2011).

A recently published textbook, *Introduction to Bryophytes*, written by Vanderpoorten and Goffinet (2009), provides an excellent beginning for those who are interested in a more detailed analysis of the bryophytes. Also, Susan C. Munch's article, Outstanding Mosses and Liverworts of Pennsylvania and Nearby States, is a valuable handbook supplemented with excellent photographs and a short illustrated glossary of terms. Drs. Bernard Goffinet and Jonathan A. Shaw (2008) also have written a book, *Bryophyte Biology*, that provides an extensive overview of the liverworts, hornworts, and mosses.

What appears to be lacking in the literature, and sorely needed, is the compilation into a single volume of all the fossil bryophytes found to date. While there appears to be a fairly good number of reported occurrences of fossil bryophytes, they need to be synthesized into a single document that reports when and where they were found, who found them, their geologic age, and the lithology of the rocks with which they are associated.

Present-Day Bryophyte Ecology

According to Vitt and Wieder (2010, p. 357-391) bryophytes are small plants that are closely tied to the substrate to which they are attached. They are extremely sensitive to the available nutrients of the substrate, acid and alkaline gradients of the soil, and water levels. In their studies of bryophytes, Vitt and Wieder found that these plants have difficulties handling large variations in water-level fluctuations, typical of wetland swamps and marsh environments, where the seasonal variation in water levels is highly variable. In these conditions, bryophytes were found not to be the dominant form of vegetation. Vitt and Wieder (p. 369) also state that these wetland types, which are non-peat-forming environments, are generally dominated by vascular plants that produce large concentrations of organic litter and have high rates of decomposition (degradation).

Regarding the landscape, Vanderpoorten and Goffinet (2009, p. 156) state that "community patterns tend to parallel variations in environmental conditions, such as geology, soil conditions and land use". At present, in North America, bryophytes (especially the mosses) seem to be far more abundant in northern peatlands, associated with acidic-rich fens (see Vanderpoorten and Goffinet, 2009, p. 158). Here decomposition is slow, the substrate is water-saturated, and anaerobic conditions prevail. The cool moist growing season is beneficial to bryophyte growth, thereby allowing organic matter to accumulate over extremely large areas. In northern peatlands, the peat that accumulates is often composed of high percentages of detritus derived from bryophytic material.

The writers assume that under these conditions, a high acidity in the environment of deposition, higher vascular land plants would be at a disadvantage and therefore a rarity within the floral cover. This may also have been the situation during Late Mississippian time within the Fort Worth Basin of north-central Texas. It may help explain why little to no higher land plant fragments (trilete spore, pollen and woody tissue) were observed by Schwab and Bayliss in their examinations of the visual kerogen samples from the Mitchell Energy W.C. (Bill) Young No. 2 well.

The Oldest Hepatic Bryophytes

Bryophyte-like constituents have been reported from the Cambrian of China (Yang et al., 2004) and the Ordovician of Saudi Arabia (Strother et al., 1996; Wellman et al., 2003). The oldest recognizable and verifiable fossil bryophytes, however, are the liverworts *Metzgeriothallus sharonae* from Middle to Upper Devonian (Givetian) sediments of Albany and Green counties in eastern New York State (Hernick et al., 2007) and *Hepaticites devonicus* (Huber, 1961), from the lower Upper Devonian of Schoharie County, also located in the eastern part of New York State.

Specimens of *Metzgeriothallus sharonae* occur as carbonized remains in black shale and siltstone lenses that crop out in the foothills and topographically higher elevations of the Catskill Mountains. According to Huber, the specimens of *Hepaticites devonicus* occur as compressions that are found associated with other plant fragments in a fine-grained, dark-gray shale.

Hernick et al. (2007) interpret the black shale and siltstone lenses at the locations in Albany and Green counties to have been deposited in either a dysoxic-anoxic lacustrine or estuarine facies in oxygen-stratified water masses or in rapid accumulations on floodplains. The bryophytic debris was incorporated in the mud, probably at the sediment-water interface. It is assumed that this rapid deposition and entrapment in mud helped to preserve them from aerial oxidation and degradation after deposition. This interpretation may also hold true for those sediments containing the fossil *Hepaticites devonicus*.

As pointed out by Huber, the fossil record of the bryophytes, especially in the Paleozoic, is not understood as well as that of the algae and higher land plants. Some of the reasons for this may be because of their size, extremely delicate and fragile nature, and/or their chemical composition. [NOTE: To our knowledge all bryophytes have a basic skeleton composed only of cellulose. This is considerably different from algae, which can be composed of a variety of chemical compositions and/or higher vascular land plants, which are chiefly composed of lignin bound together by complex polymers.]

Specimens of fossil bryophyte thalli, especially those that have retained their gemmae cups, are rare and probably have been overlooked in extracted organic-matter residues. One reason for this may be because the rock material is first crushed to a very fine particle size (between a Tyler Equivalent Mesh Fraction of 75 micrometers and 841micrometers) prior to it being processed with hydrochloric and hydrofluoric acid. Once the rock material has been digested by the acid solutions, the remaining acid-resistant organic and mineral debris is centrifuged in a heavy liquid of zinc bromide, having a specific gravity of 2.2. By doing this, the mineral debris is separated from the lighter organic constituent (i.e., the lighter fraction floats to the top while the heavy fraction sinks to the bottom). Any large pieces of bryophyte-like material that might be recovered during processing (greater than 1mm in size), will be represented only as fragments. Therefore, anatomical features, such as gemmae cups, may or may not be found attached to the fragmented debris. If present, they may be easily overlooked, as these particular structures tend to be compacted and compressed onto the thallus (of which they are a part) and blend into the overall structure and color of the tissue fragment. The writers have not found any articles that discuss this particular morphologic feature (i.e., gemmae cups) in fossil bryophytes. In the extraction process used by these writers, virtually 100 percent of the organic material is recovered.

The features that these writers interpret as being gemmae cups occur as circular or elliptical structures. Due to fossilization, the thin, semi-erect, fleshy veil that surrounds the "circular form" of gemmae cups (and is part of the gemmae cup itself) is usually compressed and appears as a flattened, circular or semi-circular disk-like, or halo-like, structure around the opening of the cup. It is reminiscent of the appearance of the "suckers" on the arm of an octopus. What we believe are the fleshy veil-like structures surrounding the cup itself often are observed as only a subtle change in color intensity. This may be the only clue the analyst observes as to their possible existence. Gemmae cups, or what we interpret as being gemmae cups, may occur as a single structural feature on a thallus or in groups (Plate 4, Figures A-C; Plate 6, Figures A-B, D). Occasionally, a single specimen of what might have been a gemmae cup (possibly torn from the surface of a thallus) can be observed in the organic matter residue (Plate 6, Figures C, E-G). Whether these in fact are gemmae cups, as we suspect some of them to be, is debatable. We have not seen any literature regarding how gemmae cups in extant forms look once they have been torn from the thallus. We assume they would appear as circular to round objects, much like what we have found in the core samples from the Mitchell Energy W.C. (Bill) Young No. 2 well (Plate 6, Figures C and G). [NOTE: In the liverwort *Lunularia,* one would probably not see isolated gemmae cups since they would appear only as a thickened "U"-shaped ridge, or ridges, on the thallus and not as the "disk-like" structures which are characteristic of the liverwort *Marchantia*.]

The lower Barnett bryophyte-like flora in the Mitchell Energy W.C. (Bill) Young No. 2 well, is associated with fossil specimens of algae, including cyanobacteria (trichomes of *Anabaena*-like forms), desmids (*Staurastrum* sp.), *Tetraedron* sp. and *Boytrococcus* sp., cf. *B. braunii*.

Several bryozoan fragments (not illustrated), surrounded by a fine-grained, dolomite-rich matrix, were observed by Nelson Yoder and Karl W. Schwab in some of the thin sections that were initially prepared by Nelson Yoder for the Lewis Energy Group in 2006. Since modern bryozoans can be found in fresh water and marine environments, we can only assume that those that lived during the Mississippian occupied the same type of habitat. Their presence in the lower Barnett Shale (mudstone) adds little to being able to differentiate between a marine and nonmarine environment. More conclusively, the writers did not observe any palynomorphs of a marine nature in any of the visual kerogen preparations made of the lower Barnett section of the Mitchell W.C. (Bill) Young No. 2 well. Trilete spores (from vascular plants) and gymnosperm pollen are also rare to absent.

[NOTE: The algal cysts belonging to the genus *Tasmanites* sp., reported by Loucks and Ruppel (2007, p. 593) to be a major constituent in the Barnett Shale, were, we believe, incorrectly identified. The fact that the identifications were based on what are thought to be steinkerns, found in thin sections, makes them, in our opinion, unreliable. If *Tasmanites* sp. really is a common constituent in the Barnett Shale (mudstone), especially in the numbers shown in the photomicrographs taken by Loucks and Ruppel (2007, p. 592), we surely would have found them in our visual kerogen preparations. In all the core samples that these writers have examined, including some of the same core sample material examined by Loucks and Ruppel, *Tasmanites* sp. has never been observed and/or identified. Algal cysts belonging to the genus *Tasmanites* sp., because of their chemical composition, are easily preserved and readily preserved in sediments. The Devonian Black Shale of the Appalachian Bain is a classic example of a sediment containing abundant and well preserved *Tasmanites* sp.]

Methane, Wet Gas and Gas Condensate in the Lower Barnett Shale

Although no geochemical extractions or gas-chromatography analyses were conducted on the core samples from the Lower Barnett Shale (mudstone) in the Mitchell Energy W.C. (Bill) Young No. 2, the stratigraphic section is similar in lithology and organic matter content to the lower portion of the Barnett core taken in the Mitchell Energy T.P. Sims No. 2 well. The latter is about 10 to12 miles east-northeast of the W.C. (Bill) Young No. 2, also in Wise County, Texas (Figures 1a, b). Based on a detailed geochemical extraction, gas chromatography and visual kerogen study of the Sims No. 2 and Blakely No. 1 wells, conducted by Dr. Geoffrey Bayliss and Karl W. Schwab, (presented to Stephen Ruppel and Bob Loucks, with the University of Texas, Bureau of Economic Geology in late 2007), it was determined that the biological metagenesis and geothermal (time-temperature) diagenesis of the organic matter (defined as a Type 1 and Type 2 kerogen mix which was at a moderately mature stage of thermal alteration) was the principal source for the methane, wet gas, and gas condensate being produced in the Wise County area of the Fort Worth Basin.

The writers were unaware of the presence of bryophyte-like fossils in the Barnett Shale (mudstone) section at that point in time. We have since looked again at our visual kerogen slides, and now we believe that bryophytes are present, although not in the numbers observed in the Mitchell W.C. (Bill) Young No. 2 well. This being true, the writers suggest that some of the methane gas, wet gas, and gas condensate, may have been generated from bryophytic tissue and that the bryophyte-like organism itself, being cellular and porous in nature, might also be serving as a possible trapping mechanism for the gaseous hydrocarbons.

Conclusions

These writers were not able to find any reports (published or unpublished) on the internet, or in any of the major geological journals, regarding the occurrence of bryophytes in the Upper Mississippian strata of Texas. To our knowledge this article represents the first documented occurrence of bryophyte-like fossils found in the Upper Mississippian of Texas. We consider that the photographic illustrations of the fossil bryophytic forms, or fragments, shown on Plates 7, 8, and 9, are among the first to be reported from strata of this age that show such a striking resemblance to the conical-shaped carpocephalum heads (sometimes referred to as carpophores) of extant genus *Asterella* (and possibly genera *Reboulia* and/or *Conocephalum).* Other bryophyte-like fragments observed in the lower Barnett Shale samples, perhaps not as easily recognized as those considered to be related to Aytoniaceae and/or Conocephalaceae, are tentatively interpreted as being related to *Riccardia* sp., *Marchantia* sp., and *Lunularia* sp. (Plates 2, 5, and 6). In summary it is our contention that:

- Bryophyte-like fossil fragments and other fresh water algal constituents are common to abundant in the core samples taken between 6,891.0 and 7,211.0 feet in the Mitchell Energy W.C. (Bill) Young No. 2 well, Wise County, Texas.
- No marine organisms, especially *Tasmanites* sp., were observed in any of the eleven core chip samples taken between 6,891.0 and 7,211.0 feet in the Mitchell W.C. (Bill) Young No. 2 well.
- Trilete spores of vascular land plants (ferns) and gymnosperm pollen are extremely rare or absent in the core chip samples from the lower Barnett Shale (mudstone).
- We interpret the lower Barnett Shale (mudstone) in the Mitchell Energy W.C. (Bill) Young No. 2 well as representing a sedimentary sequence that was deposited, at least in part, on a broad, gently sloping, coastal floodplain, near the shoreline and ocean interface, in a shallow, possibly semi-restricted, basin.
- Deposition of the lower Barnett muds were associated with a wetlands type of environment (i.e., fresh-water ponds, contiguous lakes, marshes, bogs, swamps, fens). We suggest that much of the fresh water associated with the bryophyte-like habitat may have been derived from springs and seeps, the water coming from the underlying karst Ordovician Ellenburger Formation. The springs and seeps may also be the source for much of the calcium carbonate associated with the shale itself.
- The preserved fragile parts of the liverwort-like fragments in the lower Barnett Shale (mudstone) is an indication that the majority of the organic constituents are *in situ* and may never have been carried any great distance prior to their deposition and fossilization. Burial of the flora was rapid with a minimal amount of degradation.
- The dwarf size of the bryophyte-like constituents is possibly an indication that the flora, during Late Mississippian time in north-central Texas, was experiencing a great deal of stress due to severe climatic conditions. This may have been the result of extreme weather changes, poor soil conditions, lack of necessary nutrients, and/or prolonged periods of flooding or drought.
- The Mitchell Energy W.C. (Bill) Young No. 2 well never penetrated the Ordovician at 7,168.0 feet as initially thought.

Measurements

The size range of the extant bryophytes in the photographs presented in this manuscript (shown as numerical values within the white bars on the photograph itself) are approximate measurements only. The size range of the fossil material, shown within the black bars, represent measured values recorded from a stage micrometer using a micrometer eyepiece. The numerical values, within the bars, are the lengths of that particular bar for that particular fossil. To alleviate concern regarding incorrect measurement calculations, Mr. Schwab had Dr. Gordon Wood, formerly a palynologist with Amoco, calibrate and check the microscope measurements for accuracy. In the single specimen that was measured by Dr. Wood and Mr. Schwab, the measured value was exactly the same.

Acknowledgements

The authors thank each of the individuals, along with their institutions, who supplied us with their personal photographs of bryophytes (and/or other data) used in this study. Without comparative material, in this instance the superb photographs and illustrations of living material, it would be next to impossible to illustrate and understand the importance of the bryophyte-like fossil fragments found in the lower Barnett Shale (mudstone).

The interpretations and conclusions presented herein, are strictly those of the writers, and are not necessarily shared by any of the above-noted individuals or organizations. Though somewhat controversial in nature, it is the intent of the writers to inspire the petroleum industry and paleontological community at large to get more involved in the search for fossil bryophytes.

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References

Goffinet, B. and J.A., Shaw, 2008, Bryophyte Biology 2nd edition: Cambridge University Press, New York, 580 p.

Hernick, L., E.L., VanAller, and K.E., Bartowski, 2007, Earth's oldest liverworts *Metzgeriothallus sharonae* from the Middle Devonian

(Givetian) of eastern New York, USA: Review of Palaobotany and Palynology, v. 148/2-4, p. 154-162.

Hueber, F.M., 1961, Hepaticites Devonicus, A New Fossil Liverwort from the Devonian of New York: Ph.D. Thesis, Cornell University, published in Annals of the Missouri Botanical Garden, v. 48/2, p. 125-132.

Lepp, H., 2008, The Bryophyte Groups, *in* Australian Bryophytes: Australian National Botanical Gardens and the Australia National Herbarium: Website accessed 7 January 2011, http://www.anbg.gov.au/bryophyte/bryophyte-groups.html

Loucks, R.G. and S.C., Ruppel, 2007, Mississippian Barnett Shale: Lithofacies and depositional setting of a deep-water shale-gas succession in the Fort Worth Basin, Texas: AAPG Bulletin, v. 91/4, p. 579-601.

Mishler, B.D. and D.G., Kelch, 2009, Phylogenomics and early land plant evolution, *in* B. Goffinet and J.A. Shaw (eds.), Bryophyte Biology 2nd edition: Cambridge University Press, New York, p. 173-197.

Munch, S.C., 2006, Outstanding Mosses and Liverworts of Pennsylvania and Nearby States: Sunbury Press, New Kingston, Pennsylvania, 89 p.

Oliver, M.J., 2009, Biochemical and molecular mechanisms of desiccation tolerance in bryophytes, *in* B. Goffinet and J.A. Shaw (eds.), Bryophyte Biology 2nd edition: Cambridge University Press, New York, p. 269-297.

Raven, J.A., 1999, The Size of Cells and Organisms in Relation to the Evolution of the Embryophytes: Plant Biology Journal, v. 1/1, p. 2-12.

Schopf, W.J., 1999, Fossils and Pseudofossils: Lessons from the hunt for early life on Earth, *in* Size Limits of Very Small Microorganisms, Proceedings of a Workshop: Steering Group for the Workshop on Size Limits of Very Small Microorganisms Space Studies Board, Commission on Physical Sciences, Mathematics, and Applications: National Research Council: National Academy Press, Washington, DC, p. 88-93.

Steward, D.B., and F. Paniszczyn, 2007, The Barnett Shale Play, Phoenix of the Fort Worth Basin: A History: The Fort Worth Geological Society and the North Texas Geological Society, 202 p.

Strother, P.K., S. Al-Hajri, and A. Traverse, 1996, New evidence for land plants from the lower Middle Ordovician of Saudi Arabia: Geology, v. 24/1, p. 55-59.

Vanderpoorten, A. and B. Goffinet, 2009, Introduction to Bryophytes: Cambridge University Press, New York, 303 p.

Vitt, D .H. a nd R .K. Wieder, 2010, The structure and function of bryophyte-dominated peatlands, *in* B. Goffinet and J .A. Shaw, (eds.) Bryophyte Biology: Cambridge University Press, New York, p. 357-391.

Wellman, C.H., P.L. Osterloff, and U. Mohiuddin, 2003, Fragments of the earliest land plants: Nature, v. 425, p. 282-285.

Yang, Rui-Dong, Jia-Ren Mao, Wei-Huia Zhang, Li-Jun Jiang, and Hui Gao, 2004, Bryophyte-like Fossil (*Parafunaria sinensis*) from Early-Middle Cambrian Kaili Formation in Guizhou Province, China: Acta Bontanica Sinica, v. 46/2, p. 180-184.

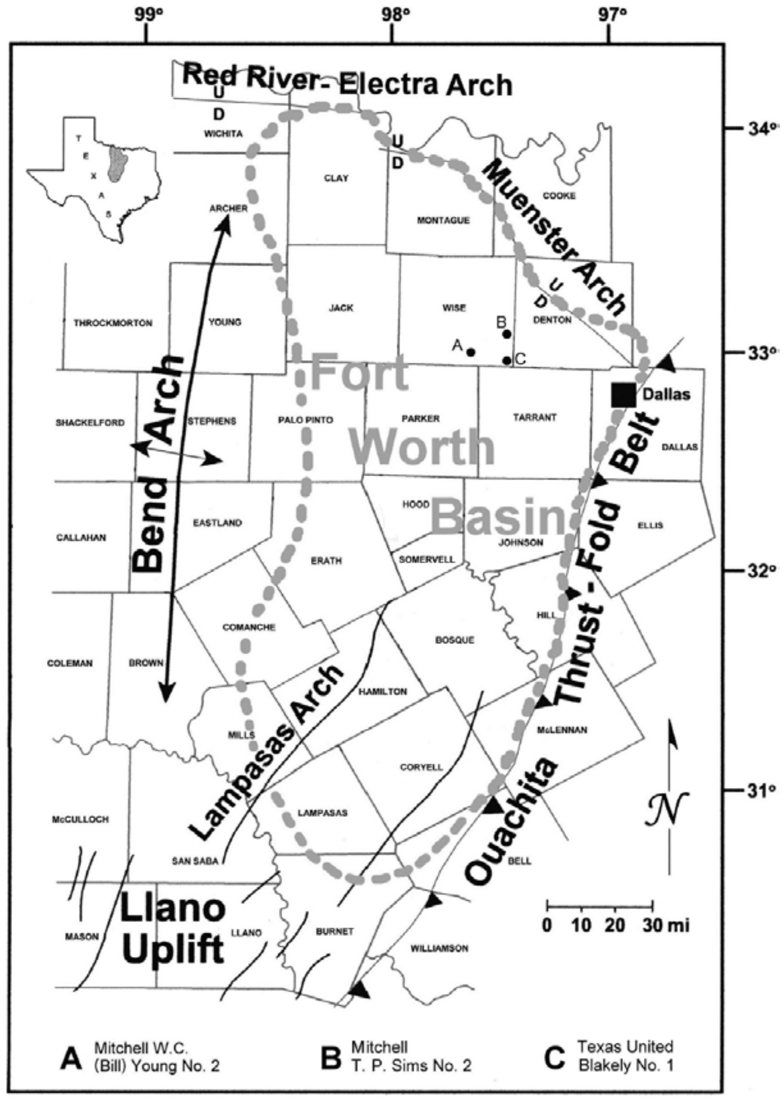

Figure 1a. Diagrammatic illustration showing the approximate location and configuration of the Fort Worth Basin in north-central Texas.

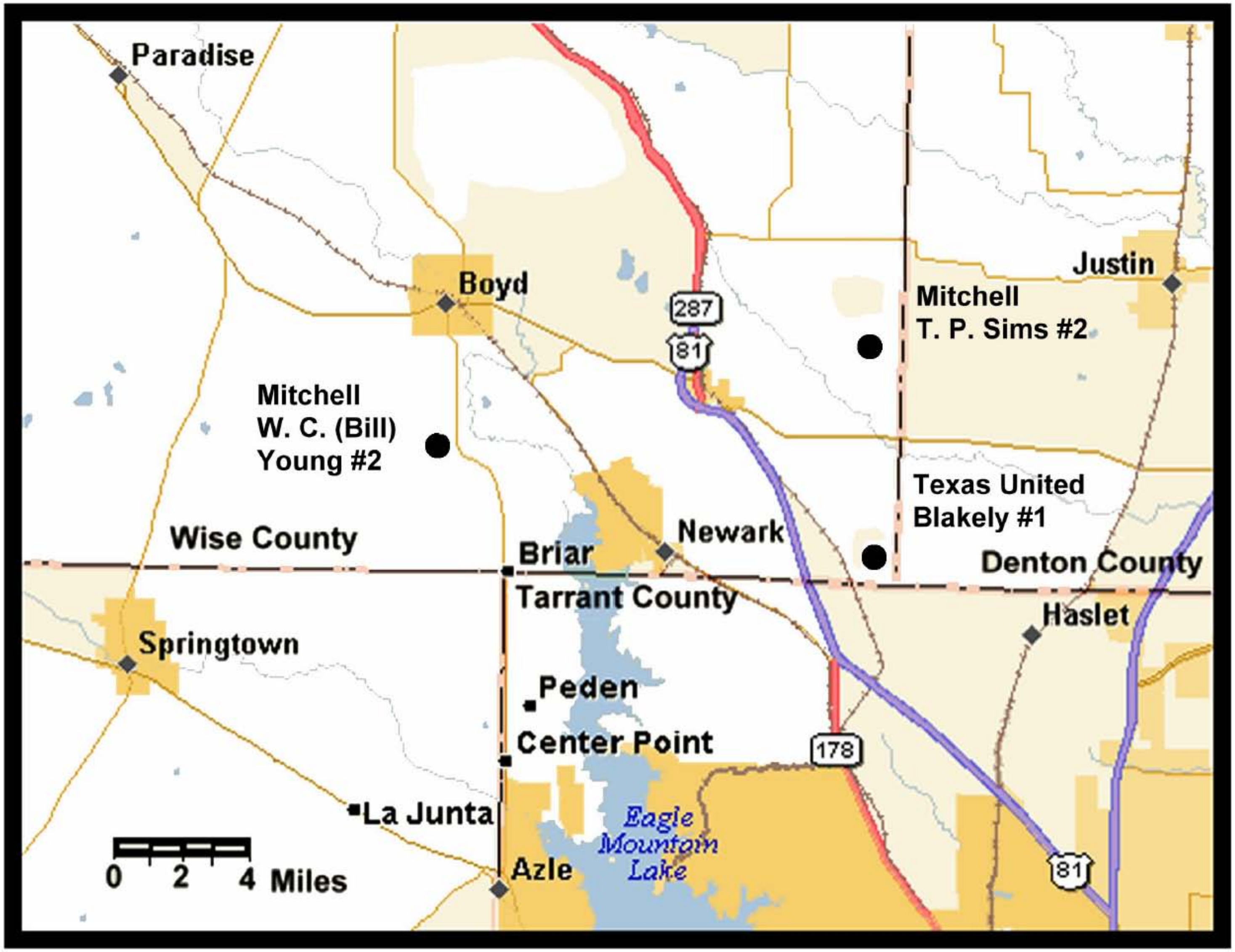

Figure 1b. Map of southeast Wise County, Texas, showing the approximate locations of Mitchell W.C. (Bill) Young No. 2, Mitchell T.P. Sims No. 2, and Texas United Blakely No. 1 wells.

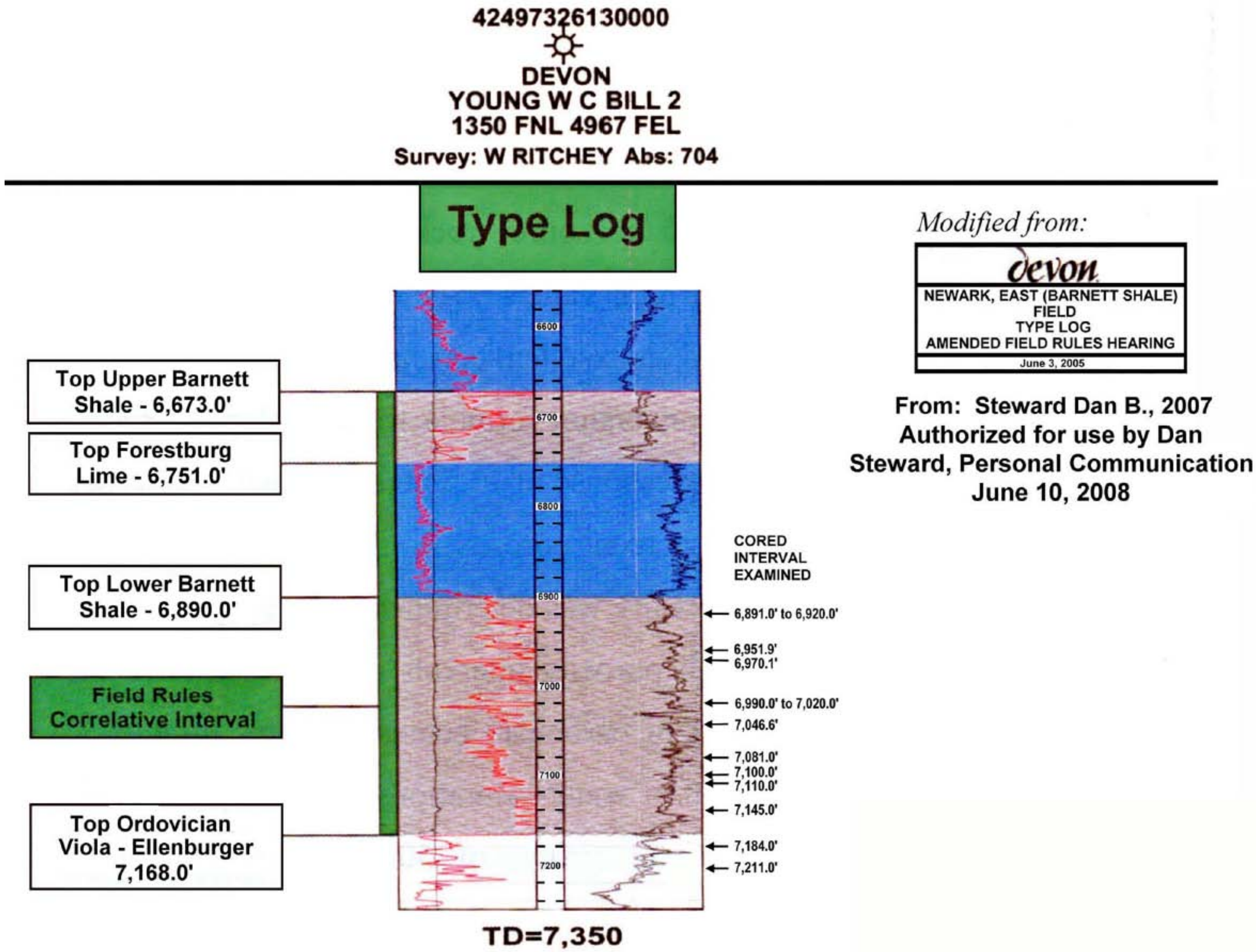

Figure 2. Type log of the Mitchell W.C. (Bill) Young No. 2, showing the positions of the core chip samples that were examined in this study (after Steward and Paniszczyn, 2007).

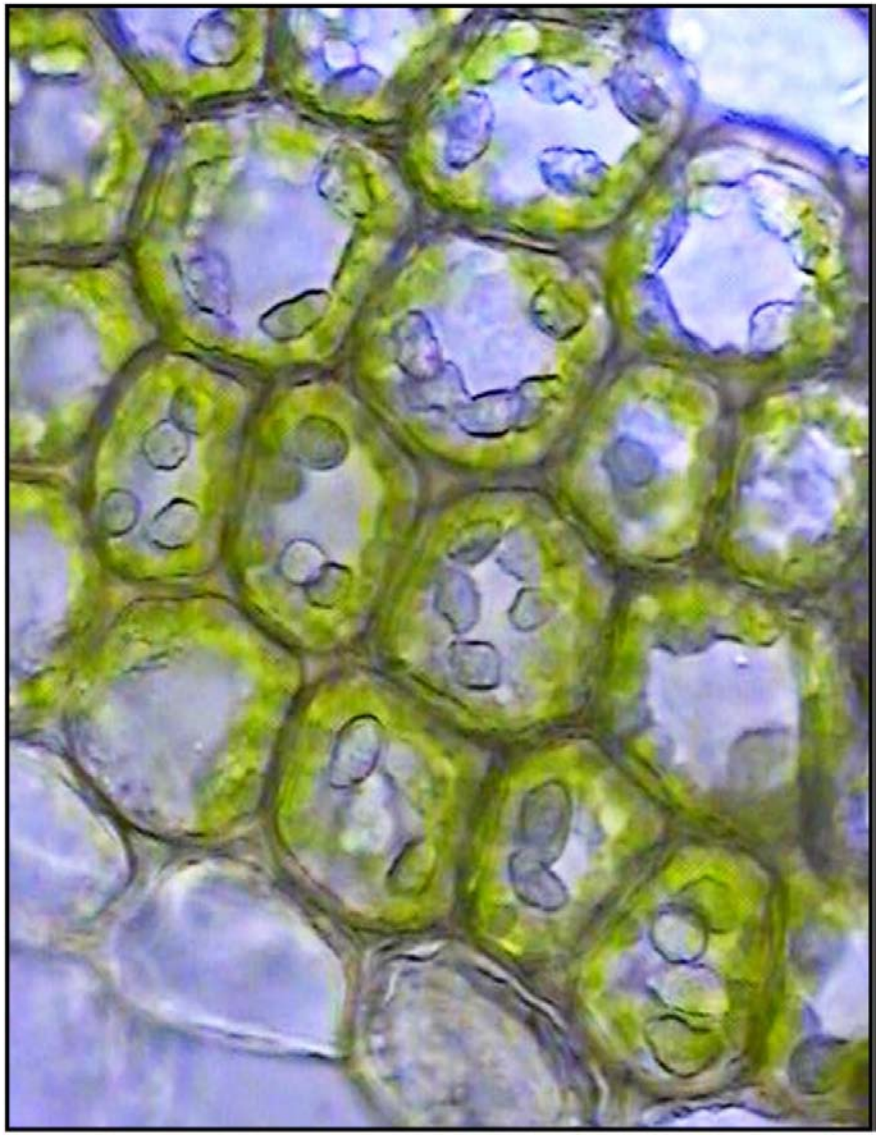

Figure 3. Oil bodies in the leafy tissue of Anastrophyllum or possibly a highly reduced form of a *Lophozia*. The cells containing the oil bodies are approximately 20 to 25 micrometers in diameter. Photograph courtesy of Dr. Steven L. Jessup.

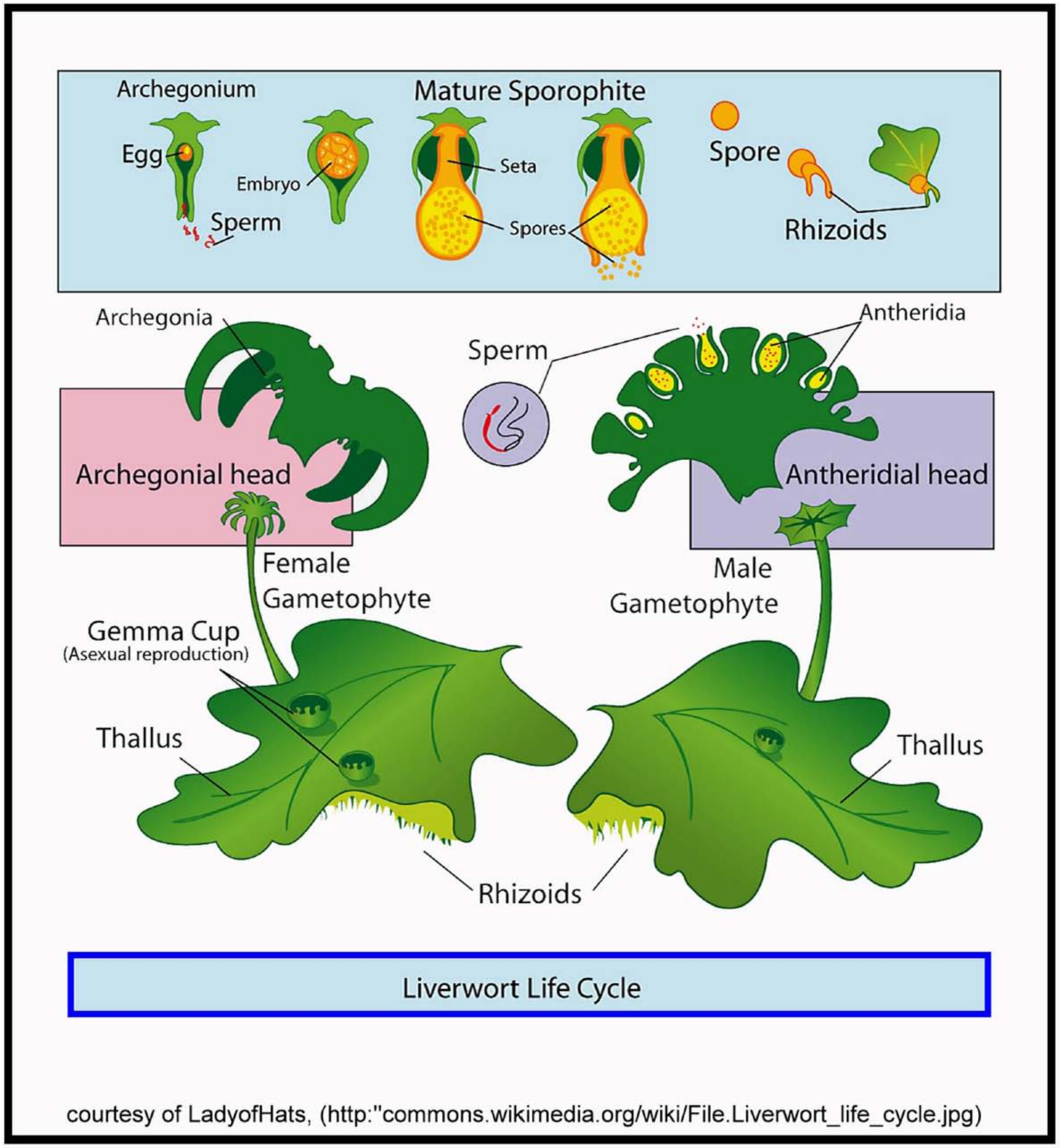

Figure 4. Liverwort life cycle (courtesy of LadyofHats) (http://en.wikipedia.org/wiki/File:Liverwort_life_cycle.jpg).

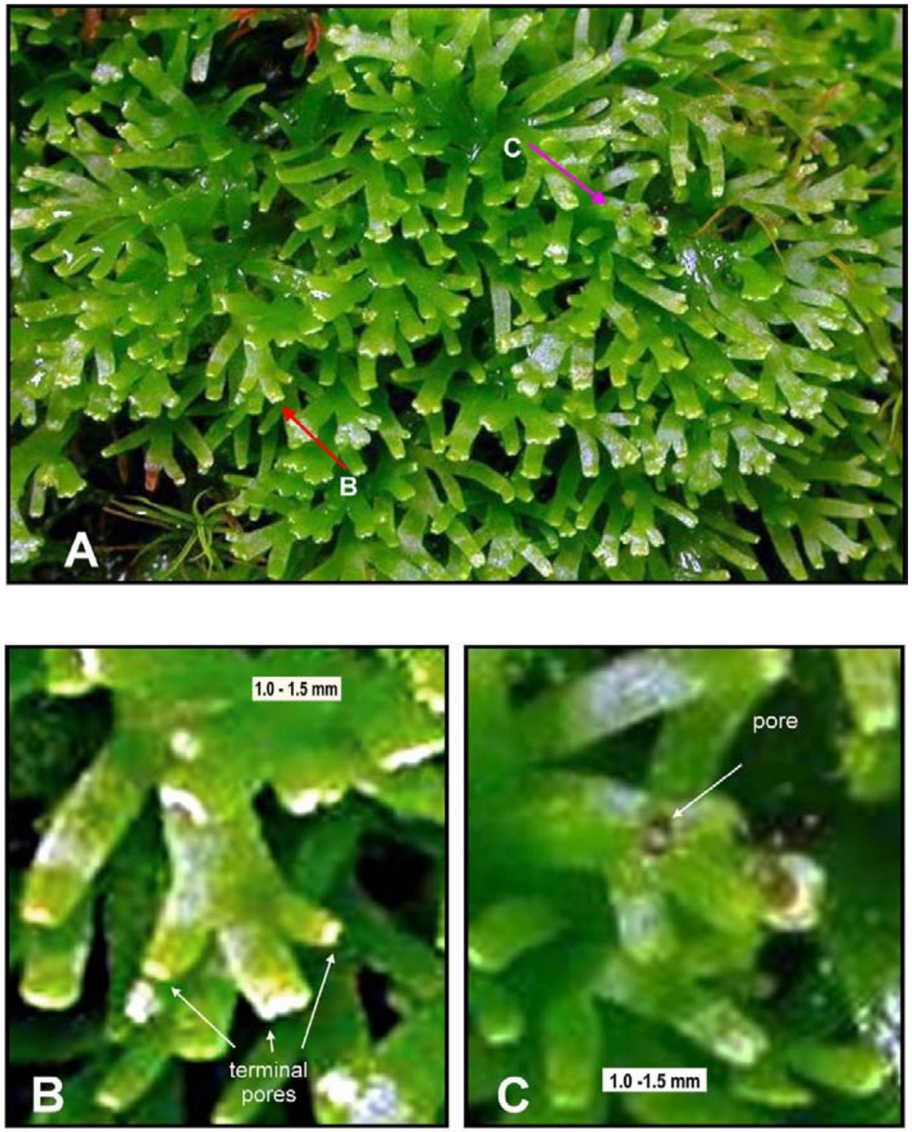

Plate 1. Figure A. Photograph of the liverwort *Riccardia* sp. (from Sichuan, China) by Li Zhang. Figures B-C. Enlarged portions of Figure A (see arrows) illustrate the "Y"-shaped terminal ends of the thalli. This is one of the morphological characteristics of *Riccardia*.

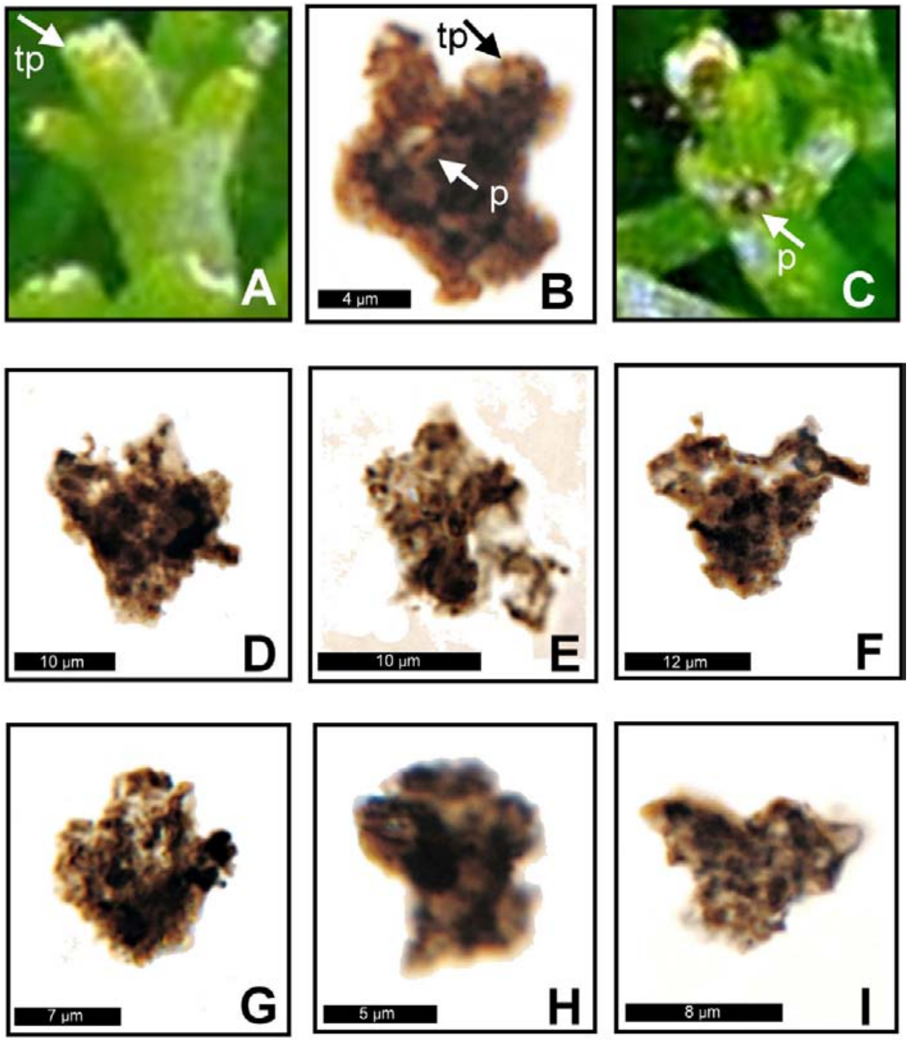

Plate 2. Figures A and C. Same figures as shown in Plate 1, Figures B-C. They are used to compare the morphology of the thallus of the extant specimen of *Riccardia* to that of the fossil *Riccardia*-like specimen illustrated in Figure B. Note the flattened terminal ends of the thalli of the thallus (the part that appears to be tubular and hollow) and the central pore on the main portion of the structure that is present. We interpret the part labeled "TP" (terminal process of the thalli) to be where growth takes place. The central pore "P" is not always well defined but does occur on a number of specimens (extant and fossil). Figures D-I, on Plate 2, are photomicrographs of fossil specimens of *Riccardia*-like fossils, each showing similar features to those illustrated by the extant material in Figures A-C.

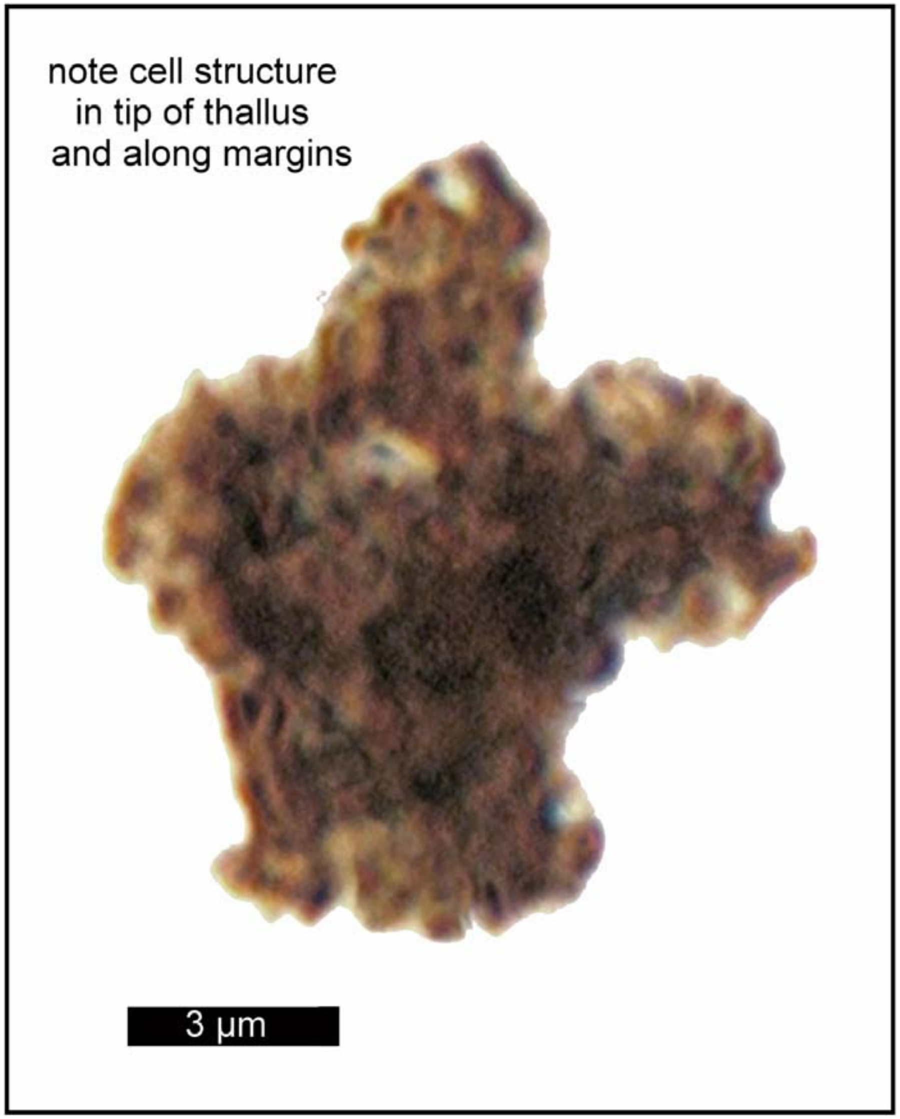

Plate 3. Enlarged fossil fragment of what the writers interpret as being a fragment of a *Riccardia*-like fossil. The specimen is the same as that shown on Plate 2, Figure B. The photograph shown on Plate 3 was prepared using a "stacked" series of photomicrographs taken at different focus levels in order to present a more detailed, 3-D type, image to emphasize the cellular structures.

Plate 4. Photographs of the liverwort *Marchantia berteroana*, by Ricardo Rozzi, showing the morphology of the thallus. The "circular" cup-like structures on the surface of the bryophyte are gemmae cups. Figures B-C are enlarged photographs of the gemmae cups. Figure B shows the details of the gemmae cup, especially the thin fleshy veil-like portion that extends above the surface of the thallus. In Figure C, the veil-like portion has been broken-off, with the gemmae cup now appearing as just a thickened rim.

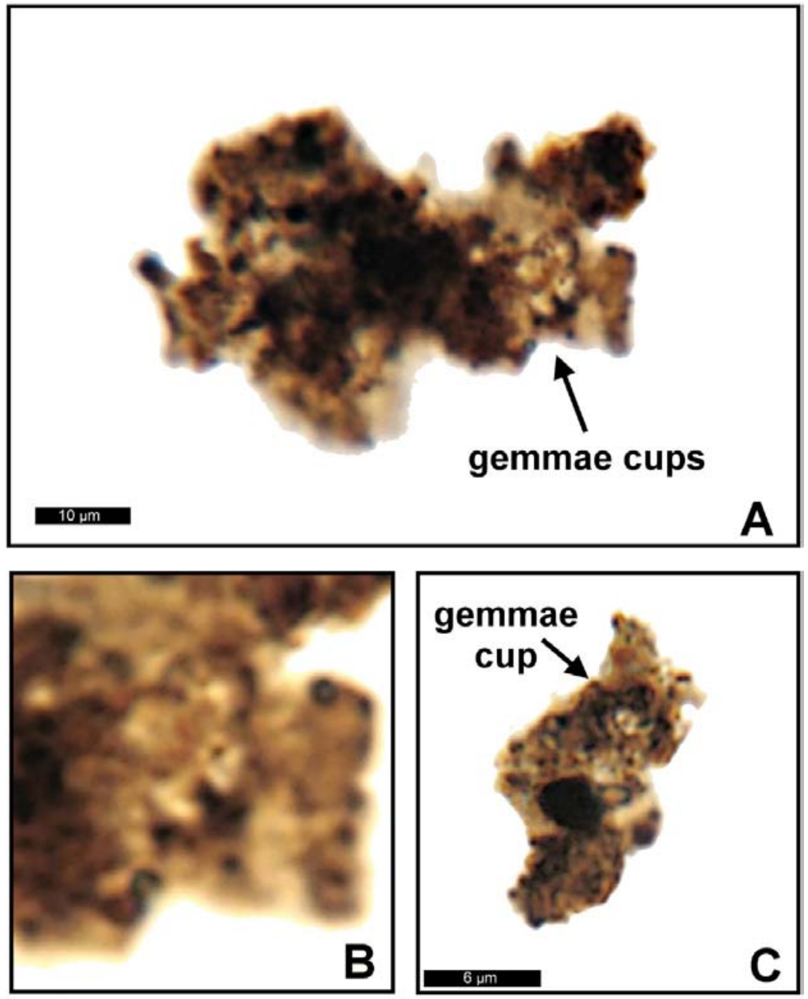

Plate 5. Figures A-C. Specimens identified by these writers to be tissue fragments from a liverwort-like fossil having a similar morphology as the extant bryophyte genus *Marchantia*. Figure A shows a series of small circular structures (center-right) that the writers interpret as being gemmae cups. That area is enlarged in Figure B. The uppermost gemmae cup is well defined and shows the fleshy, veil-like structure fully intact. Figure C is another example of a fragment of what we interpret as being a form similar to *Marchantia.* Note the gemmae cup in the upper portion of the tissue fossil fragment.

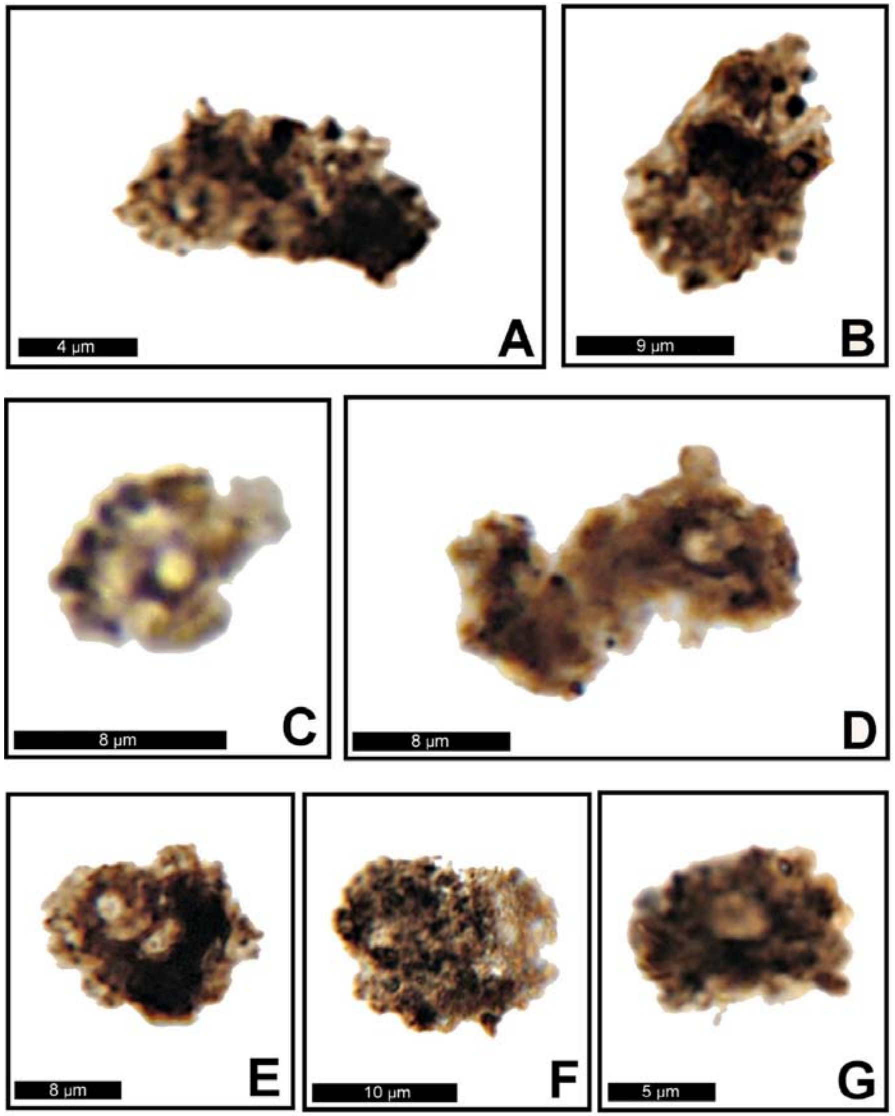

Plate 6. Figures A-G. Photomicrographs of tissue fragments of bryophyte-like fossils that the writers interpret as belonging to *Marchantia*. All the photomicrographs illustrate gemmae cups, some having been torn from the surface of the thallus (as in Figures C and G); others are still attached (as in Figures A-B and D-F) to thallus-like tissue.

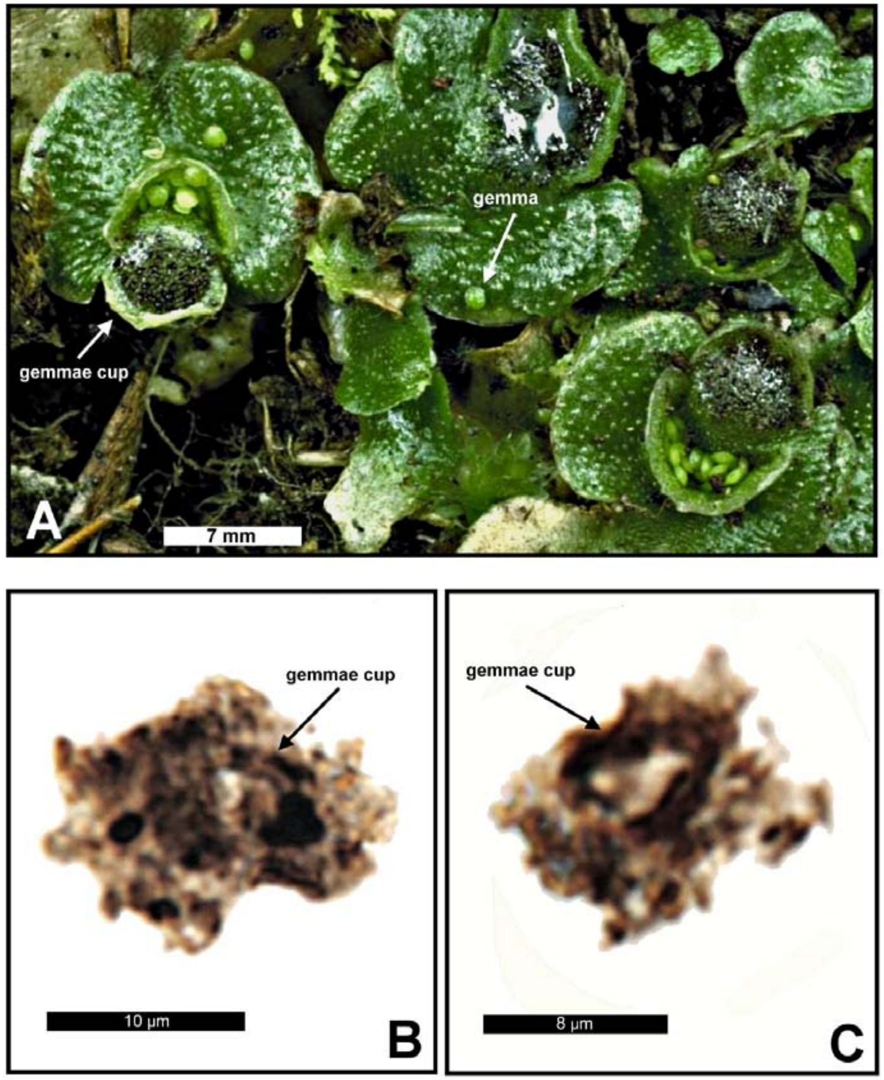

Plate 7. Figure A. Photograph of the liverwort *Lunularia cruciata* taken by Heino Lepp. This particular genus is identified, in part, by its lunate or crescent-shaped gemmae cups. The gemmae cups, rather than being "circular" in appearance, are composed of two structures, one being convex, the other concave, which unite to form the "cup-like" structure. Figures B-C. Two fossil fragments that the writers interpret as being gemmae cups from a fossil liverwort similar to *Lunularia*.

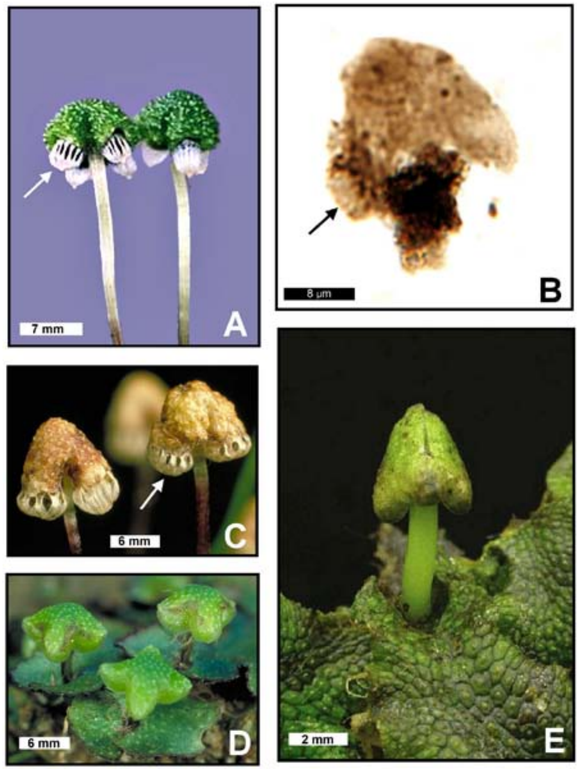

Plate 8. Photographs of liverworts whose sporophytes are born on a seta and rise above the surface of the thallus. Figure A. *Asterella australis*, taken by Clive Shirley, shows in detail the morphology of the sporophyte (the umbrella-shaped structure on top of the stalk, called a "carpocephalum") (Liverwort Reproduction-- www.hiddenforest.co.nz: www.hiddenforest.co.nz/bryophytes/liverworts/reproduction.htm). Note the "basket-like" structures (arrow) hanging down from the carpocephalum. These contain spores which, when mature, are liberated as part of the reproduction process. Figure C. *Asterella drummondii*, taken by Heino Lepp, that shows appearance of *Asterella* when the tissue of the carpocephala becomes dried-out or dies (ANBG Bryophyte website: http://www.anbg.gov.au/bryophyte/photos-captions/asterella-drummondii-8.html). Figure D. *Reboulia hemispherica*, also by Heino Lepp, that shows a lateral view of this particular genus and species (ANBG Bryophyte website: http://www.anbg.gov.au/bryophyte/photos-captions/reboulia-hemispherica-04.html). Although no "basket-like" structures can be seen hanging on the carpocephalum, the overall morphological shape of the structure is typical of what the writers see in their fossil material. Figure E is a photograph of the liverwort *Conocephalum conicum*, taken by Li Zhang. Once again the readers are asked to pay attention to the umbrella-shaped sporophyte that rises from, and above the surface of, the thallus. Figure B (Plate 9) is a photomicrograph of a fossil that the writers interpret as being related to this particular group of bryophytes, the Aytoniaceae and/or Conocephalaceae. Note the "basket-like" structure hanging down from the conical head of the carpocephalum (arrow). If the reader looks closely at the photomicrograph, even the individual "flap-like" structures that make up the carpocephalum can be seen.

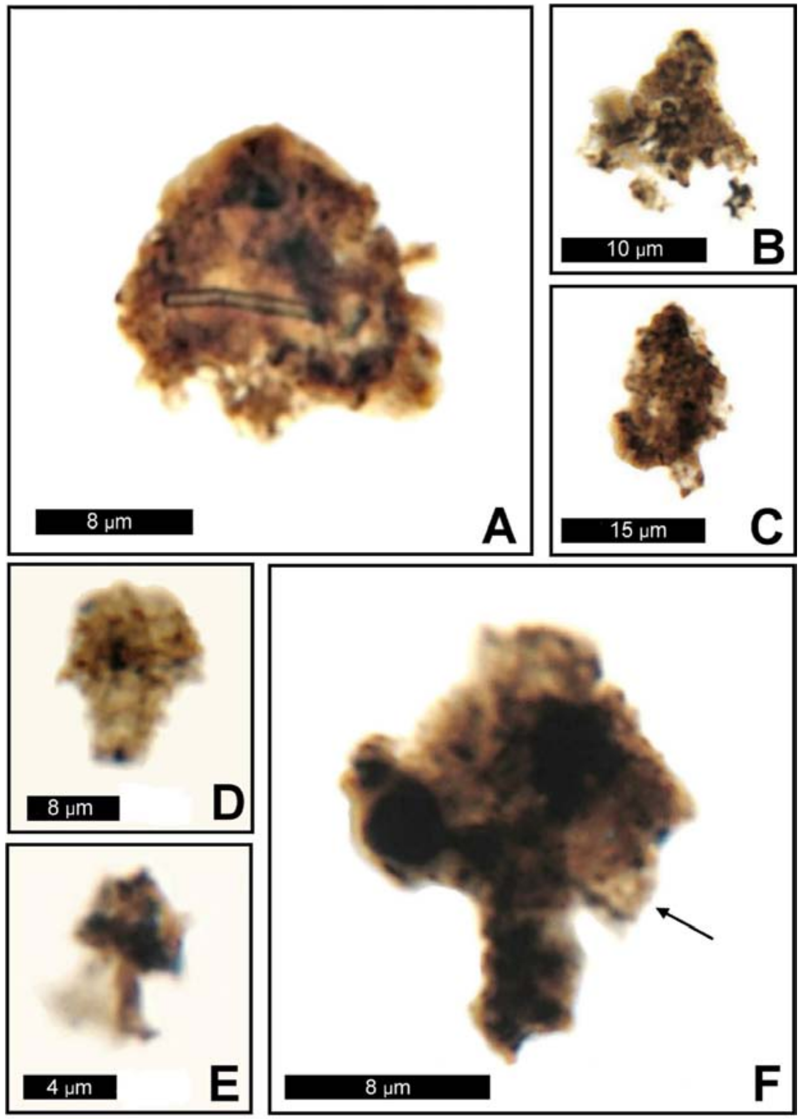

Plate 9. Figures A-F. Photomicrographs of what the writers identified as the fossil carpocephalum and seta from *Asterella*-like (possibly *Reboulia* and/or *Conocephalum*) bryophyte-like forms found in the lower Barnett Shale (mudstone) of the Mitchell Energy W.C. (Bill) Young No. 2 well, Wise County, Texas. The specimen in Figure D may belong with the fungi, rather than the bryophytes. The arrow in Figure F points to what are interpreted as the remnants of a spore capsule on the carpocephalum.

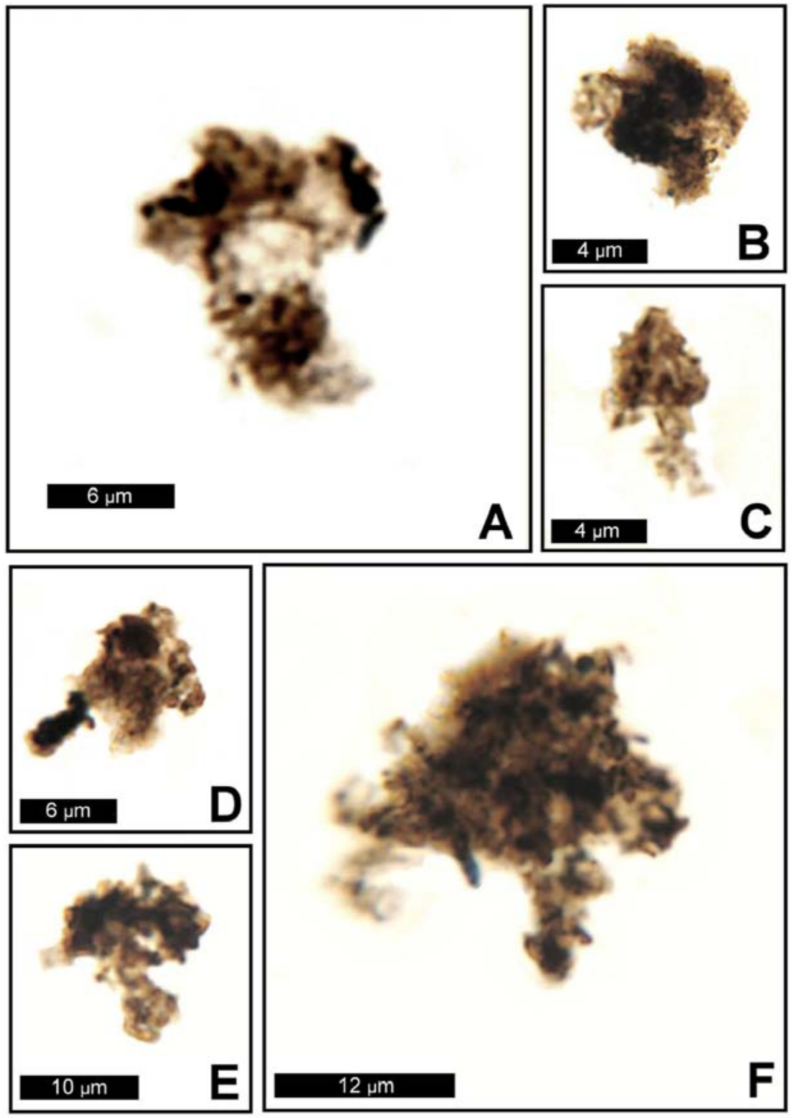

Plate 10. Figures A-F. Photomicrographs of fossil carpocephalum and seta from *Asterella*-like (possibly *Reboulia* and/or *Conocephalum*) components from the lower Barnett Shale (mudstone) in the Mitchell Energy W.C. (Bill) Young No. 2 well, Wise County, Texas. Figure A. Interpreted fossil liverwort that has a rather thick seta (stalk). We are not certain whether this specimen belongs with the fungi or the bryophytes.