PHOLEOS

Journal Of The Wittenberg University Speleological Society

Volume 26 (1,2) May, 2008

PHOLEOS

Pholeos (**Greek - cave**) is a biannual journal of the Wittenberg University Speleological Society (WUSS), an internal organization of the National Speleological Society (NSS).

Purpose

The Wittenberg University Speleological Society is a chartered internal organization of the National Speleological Society, Inc. The Grotto received its charter in May 1980 and is dedicated to the advancement of speleology, to cave conservation and preservation, and to the safety of all persons entering the spelean domain.

WUSS Web page

http://www4.wittenberg.edu/student_organizations /wuss/

Subscription rates are $10 a year for two issues of *Pholeos*. Back issues are available at $5.00 an issue.

Exchanges with other grottoes and caving groups are encouraged. Send all correspondence, subscriptions and exchanges to the grotto address.

Membership

The Wittenberg University Speleological Society is open to all persons with an interest in caving. Membership is $10 a semester or $20 a year and comes with a subscription to *Pholeos*. Life membership is $150.

Meetings

Meetings are held every Wednesday at 7:00 p.m. when Wittenberg University classes are in session. Regular meetings are in Room 319 in the Barbara Deer Kuss Science Hall (corner of Plum St. and Bill Edwards Dr. - parking available in the adjacent lot).

Submissions

Members are encouraged to submit articles, trip reports, artwork, photographs, and other material to the Editor. Submissions may be given to the Editor in person or sent to the Editor at the Grotto address. Guidelines for submitting research papers can be found on the inside back cover of this issue.

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A group of happy WUSSes peer into the entrance of Kindt's Cave I after a long trip of identifying critters on South Bass Island. Photo by K. M. Kissell.

EDITOR'S NOTE

Hey everyone!

We here at WUSS hope you all had an eventful year underground! Our numbers have grown quite a bit this year and we have kept ourselves very busy… hehehe. Inside this busty issue we have a variety of reports about all the research (and there is a lot) WUSSes have been conducting throughout the year. Our own Alex Silvis has undertaken the large (and vital!) task of entering all of our GPS points into a more accurate (very accurate, thank goodness!) GIS database. He is making us more gear-whorish than we already are. You may also notice as you peruse our pages that we have conducted many a survey trip this year. Our summer was fun and jam packed with taking bio-inventories- see Erin's article! I hope you enjoy reading this (or just looking at the pictures, admit it) as we had putting our hearts into creating it. See you underground!

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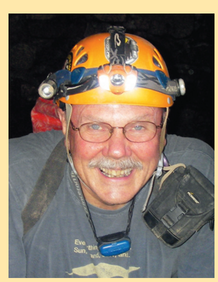

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MESSAGE FROM THE PRESIDENT

Hi, my fellow muddy people!

Goodness. Right after our last issue of Pholeos was postmarked, WUSS set out for summer, the first of a two year project. We are expanding the "complete" database of caves and their critters in Ohio, in association with WUSS alumna Erin (Athy) Hazelton and Ohio Department of Natural Resources. We traveled all over the western half of the state, staying with old (and very accommodating) friends or at state parks, usually for a couple weeks at a time. Summer was over in a heartbeat.

With the end of summer comes fall, and school, and new projects. We wooed a few new members with a bat costume (maybe you saw it at convention- light up eyes, generally amazing?) during the Activities Fair, but most of our rookie WUSSes have, from all places, come to us through Facebook! Besides our annual pilgrimage to OTR, where we suffered a crushing defeat in the Doo-Dah parade, we went on our intro trip, helped Hobbs with his Cave Ecology classes and surveyed at Carter until we were blue in the face. Dick Maxey and Ron Fulcher came to share caving stories and survey information with us. Three of our members began or continued research projects. Some overly-dedicated people caved at Gory Hole over Christmas break with our friends from the IUCC.

Spring is passing in the same way, with things going on nearly every single weekend. During Crawlathon, Dani, our VP, made a connection in the Boundary system during her very first survey. We heard back from the critter identifier- we've expanded the ranges on a bunch of species (we still don't know how many, the results trickle in slowly) and discovered a couple new ones! We've had clinics for survey and vertical work, and hope to stuff a speaker, a Sloan's trip, a vertical clinic, another trip to Carter, and an NCRC weekend course into the remainder of the year. We've even managed to update our website. Unfortunately, something had to suffer during all this, and that ended up being Pholeos. We promised a second issue for last year, and it just didn't happen. I hope this issue makes up for it.

This has been an awesome year, for WUSS, and for me, too. Presidential responsibilities were heavier than I expected, though, and I'd like to thank all of you who've taken them on in the past. Though we're not celebrating it officially until 2010, this year is the actual 30th anniversary of WUSS. I'd like to dedicate this issue to all the WUSS alums- without you, your work and dedication, we wouldn't be here. Thanks.

With much love,
Kate Ferguson, President
WUSS#0544, NSS#56925

Ohio Caves Revisited

Erin Hazelton (WUSS #0397)
Ohio Department of Natural Resources

Studying caves is a specialized science, one that many geologists and biologists have no interest in exploring. It also is well known that cavers tend to steer clear of Ohio, opting for the vast karst lands in neighboring states. But the fact remains: Ohio has caves! If cavers don't take an interest in Ohio's caves, who will? Thanks to a dedicated group of WUSS members, Ohio's caves are getting another look.

Although generally not extensive or highly decorated, Ohio caves still are an important resource. They play a vital role in the life history of many organisms, some of which are endemic to Ohio. For this reason, the Ohio Cave Protection Act, initiated by WUSS, was passed in 1988. It protects caves, cave speleothems, and cave biota from harm. As stated in chapters 1517.21 to 1517.26 of the Ohio Revised Code, the Division of Natural Areas and Preserves (DNAP) is responsible for the implementation of this law.

Unfortunately, there is so little current information about Ohio caves and cave organisms that DNAP can not effectively implement such a law. The last biotic survey of Ohio's caves was performed by Dr. Horton Hobbs and WUSS in the 1980's. Much of what is known about Ohio's caves was discovered at this time. For comparison, many other states had biotic cave surveys in place by the 1800's. We do know that Adams, Pike, and Ross counties, located in southern Ohio, have a high concentration of substantial dolomite caves: over 80 caves recorded to date, averaging 750' in length. Of the 12 state-listed species that have been observed in Ohio's caves, five are type localities from this area (Figure 1 & Table 1).

Table 1

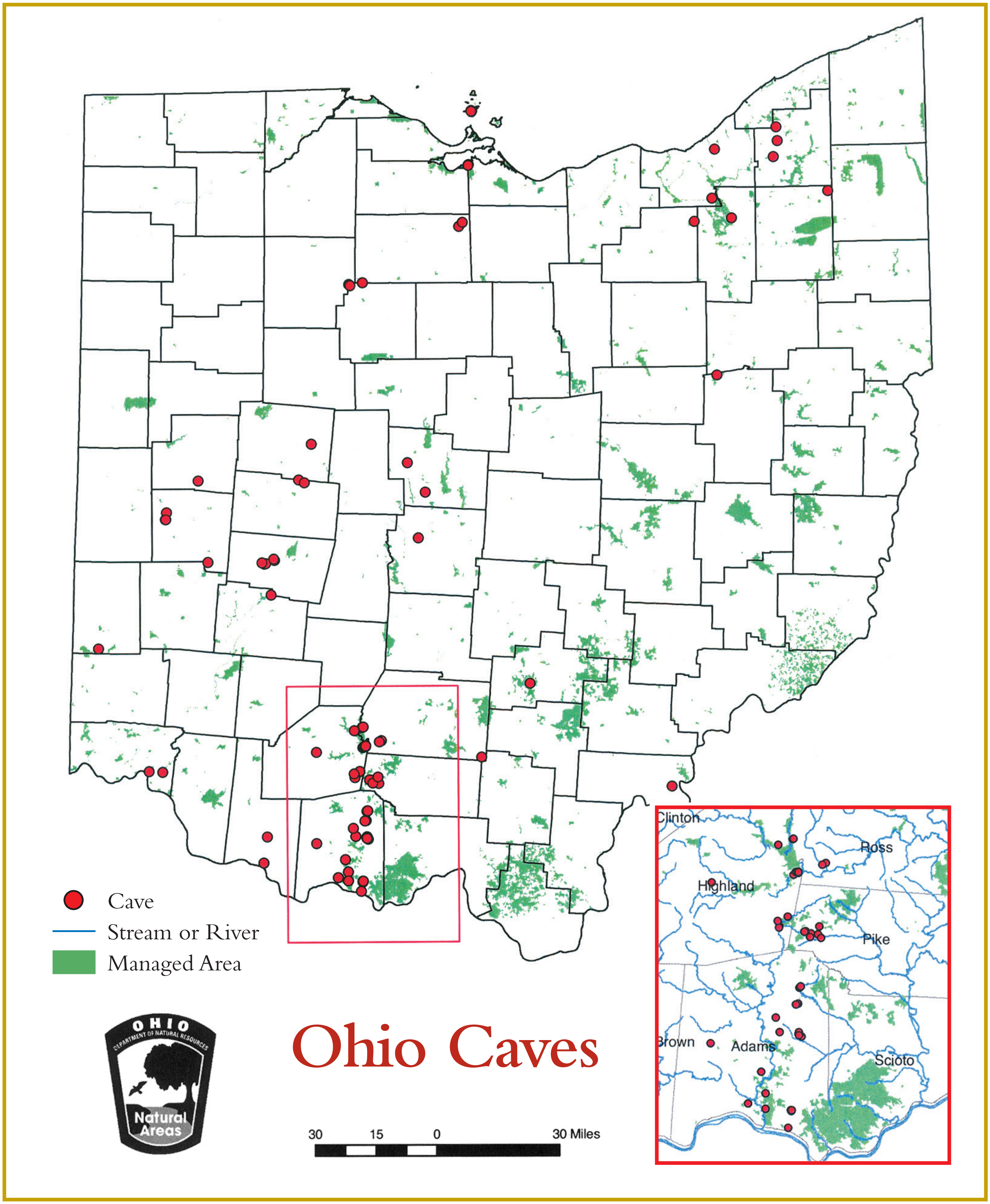
SPECIES	STATE STATUS	FEDERAL STATUS
Ohio cave beetle (*Pseudanopthalmus ohioensis*)	E	SC
Kramer's cave beetle (*Pseudanopthalmus krameri*)	E	SC
Fern Cave isopod (*Caecidotea filicispeluncae*)	SC	SC
Frost Cave isopod (*Caecidotea rotunda*)	SC	SC
Pseudoscorpion (*Apochthonius hobbsi*)	SC	SC

(E = endangered SC = species of concern)

Figure 1 *Pseudanopthalmus ohioensis*

Four of these species are endemic to Ohio, occurring in only a single cave while the fifth, *C. rotunda*, can be found in three additional caves in southeastern Indiana ground waters (Hobbs and Flynn 1981; Hobbs 1996). The Ohio cave beetle (*P. ohioensis* – Figure 2) was last studied in 1998 (Hagen and Gogolin 2001), but the remaining four species had not been assessed since 1994 (Hobbs 1996). Because all but *C. rotunda* are located in caves on private property, little was known about the current status of their populations and habitat condition. In fact, only 32 of the 130 known Ohio caves are located on ecologically-managed properties (such as state and county preserves and land trust properties).

To remedy this situation, DNAP partnered with WUSS to begin a two-year state-wide cave survey during the summer of 2007. This survey includes biotic assessment,


Cave
Stream or River
Managed Area
Ohio Caves
30 15 0 30 Miles
Clinton
Ross
Highland
Pike
Brown
Adams
Scioto
OHIO
DEPARTMENT OF NATURAL RESOURCES
Natural Areas

mapping and exploring new caves, and rekindling landowner relations. This information will be stored in Ohio's Natural Heritage Database (which is consulted for environmental reviews, but not available to the general public) and added to the Ohio Cave Survey. Additionally, the work was funded by a grant from the US Fish & Wildlife Service, which means participants had a chance to get paid to go caving!

WUSS members spent a total of 30 days in the field during the summer of 2007 and visited 89 caves. They surveyed (mapped) an additional 1100 meters of cave passags and discovered eight new caves that were not listed in the 1980 survey. Each cave was thoroughly searched for biota by sight and by use of live traps. The collected specimens have been sent to experts for identification. Initial results indicate comparatively dense populations of all state-endemic cave species except *P. krameri*, which was not documented during the survey, nor has it been observed since the 1970's. Several species including pseudoscorpions, a cave beetle, and an isopod are possibly undescribed troglomorphic species (identification pending). WOW!

This summer will surely bring more surprises as we finish up with carbonate caves in the western half of Ohio and move on to sandstone and conglomerate caves in eastern Ohio. If you are interested in joining the research team and learning more about Ohio caves, contact Dr. Hobbs (hhobbs@wittenberg.edu)or Erin Hazelton (erin.hazelton@dnr.state.oh.us) for more info.

So once again, thank you WUSS for taking on Ohio's caves! Your insatiable sense of adventure and love for all caves (even in Ohio) are marks of true cavers. I am looking forward to another exciting summer!

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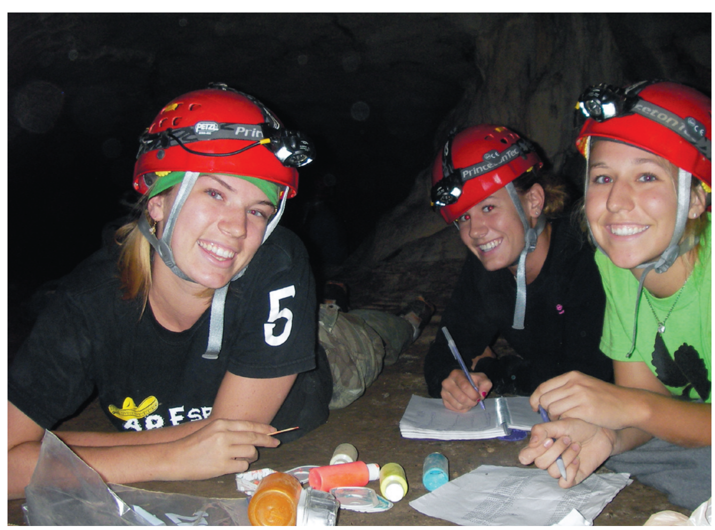
MISCELLANEOUS



A Progress Report of a Study of the Reproductive Cycle of the Cave-Dwelling Crickets, *Hadenoecus cumberlandicus* and *Ceuthophilus stygius* (Orthoptera, Rhaphidophoridae), in Northeastern Kentucky

Danielle Carey (WUSS #0551, NSS #59092), Kevin M. Gribbins, Lauren Butch, Justin L. Rheubert, and Horton H. Hobbs III (WUSS #0001, NSS #12386 HM, CM, FE)

Cave cricket research has been focused primarily on *Hadenoecus subterraneus* and various species of the genus *Ceuthophilus* during the last 30 years (e.g., Lamb & Willey 1975, Hubbell & Norton 1978, Studier et al. 1986, Caccone & Sbordoni 1987, Studier & Lavoie 1990, Northup et al. 1993, Taylor et al. 2005). These cavernicolous crickets are wingless grasshoppers, phylogenetically, that migrate periodically from the cave to forage typically in ground-level epigean vegetation. These trogloxenic cave crickets often are keystone species in the cave(s) in which they dwell since they provide fecal material to the community while some species support specialized egg-predator communities (*Hadenoecus subterraneaus* and the cave beetle, *Neaphaenops tellkampfi* - Norton et al. 1975, Kane & Poulson 1976, Griffith 1991), and dead carcasses yield varied forms of energy to maintain diversity within these food-limited ecosystems (Lavoie et al. 2007). *Hadenoecus cumberlandicus* is a parthenogenic species in many of the caves in its northernmost range, including Coon-in-the-Crack I and II caves in Carter County, northeastern Kentucky (Hobbs & Lawyer 2003).

Since little is known about the life history of *H. cumberlandicus*, we propose to study the histology of the reproductive cycle within the parthenogenic species of *H. cumberlandicus* found in Coon-in-the-Crack Cave I. This cave is somewhat isolated on the south-facing side of a limestone ridge capped with sandstone. Several of the caves within this ridge as well as others in Carter County, Kentucky host populations of parthenogenic *H. cumberlandicus* (Fig. 1). The females undergo what seems to be normal oogenesis, however eggs are activated and laid without interaction with sperm, resulting in female progeny that are genetically identical to their maternal parents. A histological evaluation of this process for this species has never been done and the population size of *H. cumberlandicus* within this cave was estimated by Hobbs and Lawyer (2003) to be greater than 5,500, which would provide a sufficient number of individuals to carry out an intricate histological evaluation

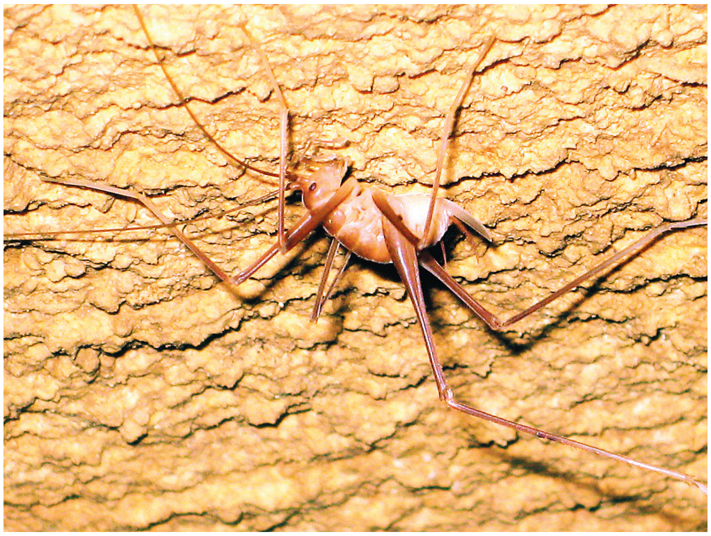


Figure 1: *Photograph of a smaller sized mature female* H. cumberlandicus.

Figure 2: *Danielle Carey searching for a fallen cricket,* H. cumberlandicus, *on the cave floor of Coon in the Crack Cave I (photo by Erik Poldemann).*

Figure 3: *A normal ovipositor (Left) showing serrations that most likely aid the insertion of this reproductive organ into sediments found in these cave systems. A damaged ovipositor (Right) mostly likely broken during recent deposition of eggs.*

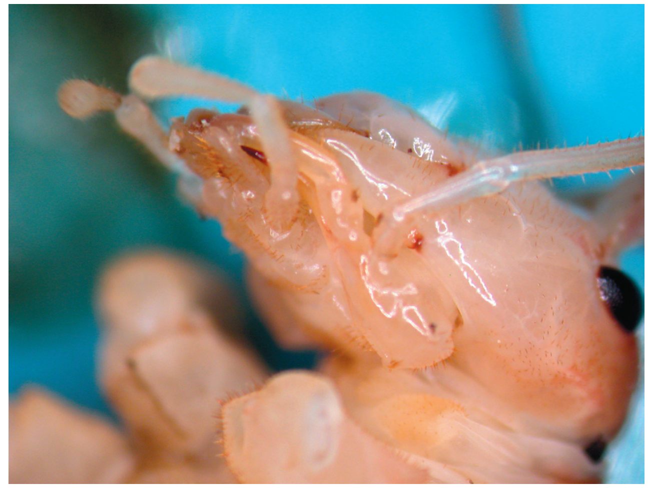


Figure 4: *Mouthparts of* H. cumberlandicus *may have phylogenetic implications based on their anatomy compared to other cave cricket species.*

of the process of oogenesis. This study will not only help elucidate the histological events of parthenogenic oogenesis in these crickets but will hopefully give insight on whether *H. cumberlandicus* is a seasonal or continual breeder and what time of the year they may prefer to deposit most of their eggs.

This study is taking place during this calendar year, with monthly collections of 5-7 crickets from the cave (Fig. 2) and then immediate dissections conducted within three days. During the dissection the length (mm) of the cricket body and hind femur (mm) is taken, along with the weight (g) and relative distance (mm) between the eyes. Pictures are taken pre-dissection, during dissection, and post-dissection of the internal anatomy (ovary and oviducts), cloacal structure, ovipositor structure (Fig. 3), and mouth parts (Fig. 4).

An incision on the crickets is made using a midsagittal cut from the opening of the cloaca, through the abdominal cuticle, and ending at the base of the head. The sides of the abdomen are pulled back and the ovaries can then be viewed anterodorsally (Fig. 5) to the cloaca. Large developing vitellogenic ootids and rice-sized mature ova are visible during the months of July through September. Though our preliminary results are not conclusive, we have seen a trend of broken ovipositors (Fig. 3) during the months of August and September. This may indicate that the females have recently laid their eggs, causing damage to the ovipositors during egg deposition. Nymphs of *H. cumberlandicus* (Fig. 6) also have been observed during the months of August through November. Future collections will be made each month until May 2008.

Once the dissection is complete, the samples are then fixed in Trump's fixative and refrigerated for future histological procedures. Cricket samples containing visible and adequately sized ovaries are then dehydrated through a graded series of ethanol, infiltrated, and embedded in

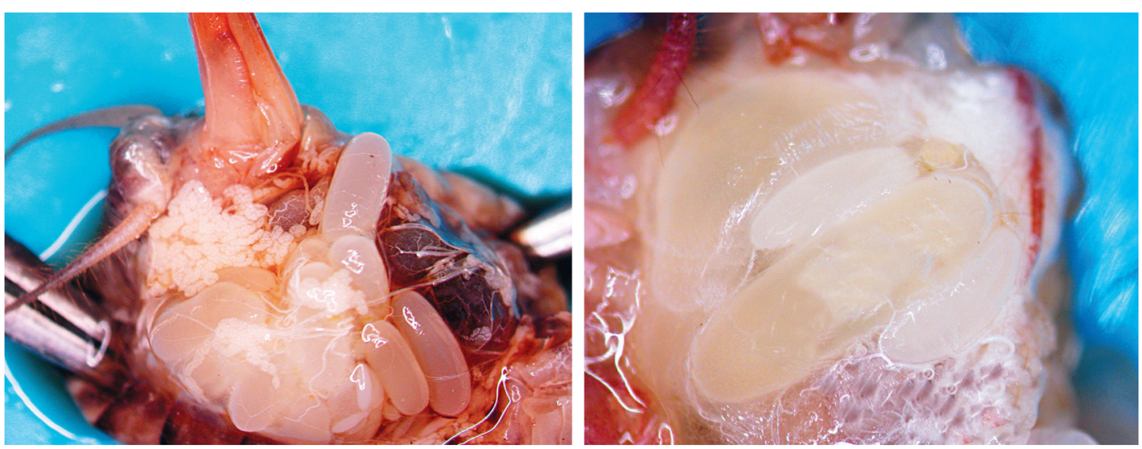


Figure 5: *Left Micrograph: Exposed ovary showing a number of mature ova. Right Micrograph: Higher power of a mature ova and two smaller vitellogenic ootids within the ovarian sac of H. cumberlandicus.*

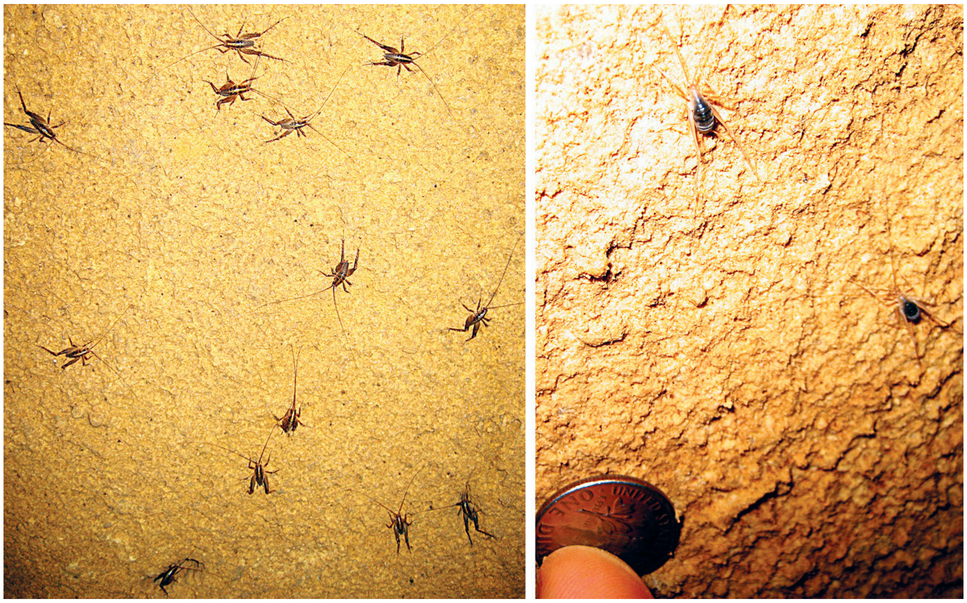


Figure 6: *Photographs of adolescent* C. stygius *from Upper Laural Cave (Left) and nymphs of H. cumberlandicus from Coon-in-the-Crack-Cave I (Right) taken during the September 2007 collecting trip (photographs taken by Erik Poldemann).*

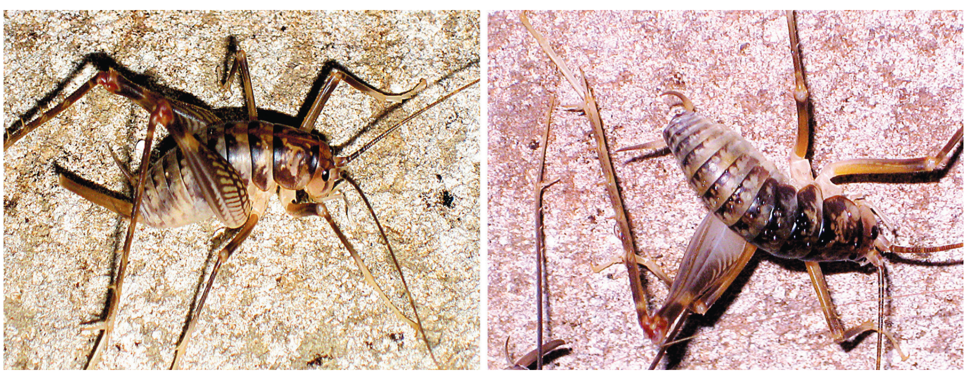


Figure 7: *Female (Left)* C. stygius *and male (Right)* C. stygius. *Note the location of the ovipositor on the female vs. its absence on the male.*

Spurr's plastic. Thin (3-6μm) sections are cut using an ultramicrotome and slides are then made, stained with toluidine blue, and viewed using a light microscope to elucidate reproductive structures and general internal anatomy.

In addition to the work with *H. cumberlandicus*, we are conducting a histological study of the reproductive cycle in the bisexual camel cricket, *Ceuthophilus stygius* (Fig. 7), found in Upper Laurel Cave as well as Coon-in-the-Crack Cave I. Testes and ovaries were removed (same location as the ovaries found in *H. cumberlandicus*) and embedded using the same procedure employed for *H. cumberlandicus* crickets. Slides have been made from these embedded tissues and pictures were taken of the testes/ovaries of *C. stygius* and ovaries of *H. cumberlandicus* using a Zeis light microscope with an attached digital camera and SPOT software (Model 25.2, Version 4.6.4.6/4.6.4.6). Their ovaries are similar anatomically and histologically to that found in *H. cumberlandicus*. The ovaries consist of a follicular epithelium with oocytes undergoing proliferation and maturation at the basal portion of the ovum (Fig. 8).

The testes consist of sperm tubes or lobes typical of orthopterans. Germ cells develop within cysts, which make up these lobes. Immature cysts containing mostly spermatogonia and spermatocytes are located basally within a lobe (Fig. 9). Cysts, which have completed spermiogenesis, are found apically within the lobes and eventually rupture to deliver sperm to the vas deferens (Fig. 9).

The results of this study will provide vital information about the reproductive cycles of two species of trogloxenic crickets, one of which lacks males in the population. The understanding of the histological aspects of reproduction in a parthenogenic species will provide us with a better understanding and comprehension of the intricate mechanisms females use to produce all clonal female progeny. This study also will lead to a more complete knowledge of the reproductive strategies of male and female crickets in parthenogenic versus sexually reproducing populations. Furthermore, these results will answer the question concerning the time when eggs are being laid in these caves. If there is a time of year when more mature ova are present in the ovaries then we can start to look for eggs at logical sites of ovodeposition. If deposited eggs can be located then future experiments can be performed that may help elucidate the embryonic development of these crickets.

It is too early in this study to draw definitive conclusions, but we do note trends over the past seven months. We have found a significant decrease in population

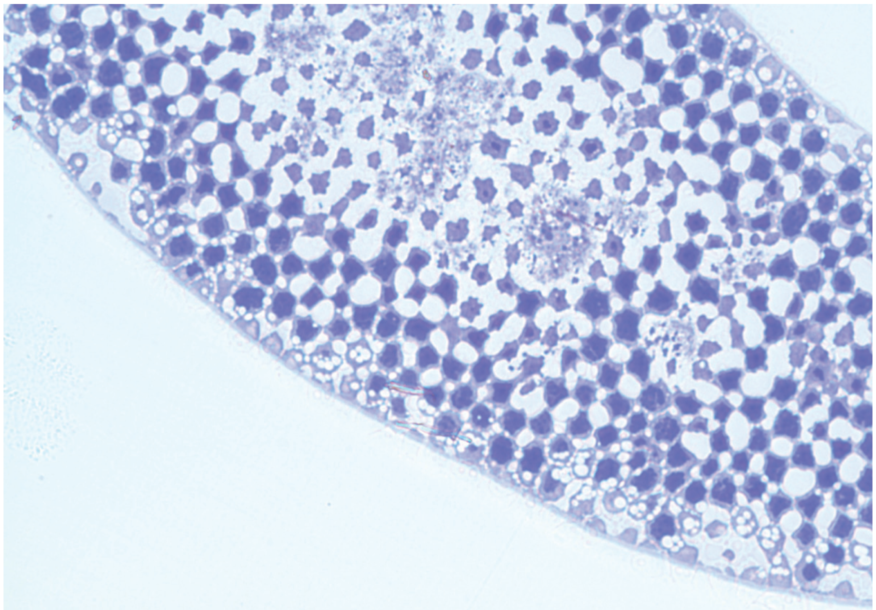


Figure 8: *A transverse view of an ovary from* H. cumberlandicus *with early developing previtellogenic oocytes located at the base of an ovariole.*

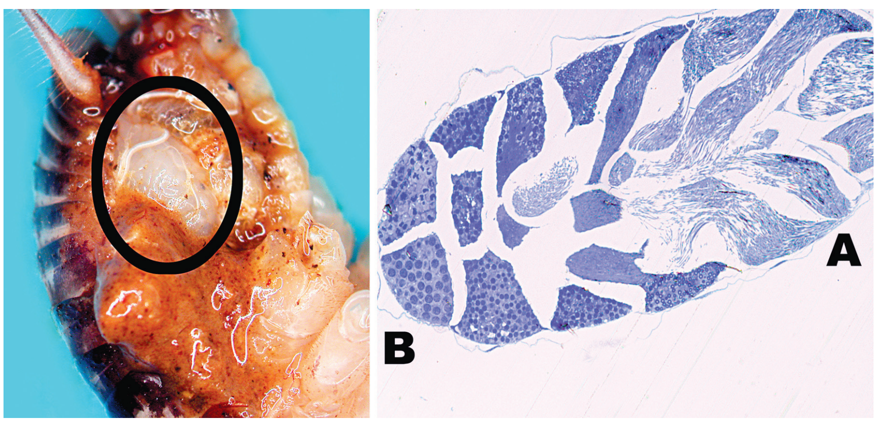


Figure 9: *Left Micrograph: Gross dissection showing the location of the testis (black circle) in* C. stygius. *Right Micrograph: A sagittal view through a sperm tube of the testis of* C. stygius *showing developing germ cells. Spermatogonia and spermatocytes are found basally (B) and mature spermatozoa are located apically (A).*

size of cave crickets in both caves during mornings after humid, warm nights. We hypothesize that during these nights, crickets exit the caves and forage in the epigean undergrowth for food. Yoder et al. (2002) suggested that crickets migrate from the cave during humid nights when the air is near saturation, preventing a large loss of water from their bodies and thus dehydration. We have also seen a trend of physically damaged and broken ovipositors for *H. cumberlandicus* in Coon-in-the-Crack Cave I during the months of July through September. This may be the result of ovoposition of eggs in compacted sediments within the cave. There also has been a significant increase in the number of nymphs in this cave, ranging from 2mm to 6mm in length, during the months of September and October. This provides additional evidence that eggs may be deposited slightly before and during these months of peak ova development within our histological samples. The large number of nymphs and adolescents (Fig. 6) observed also indicates that the populations in both caves are healthy and continue to produce offspring and suggests our work is not affecting the population size significantly.

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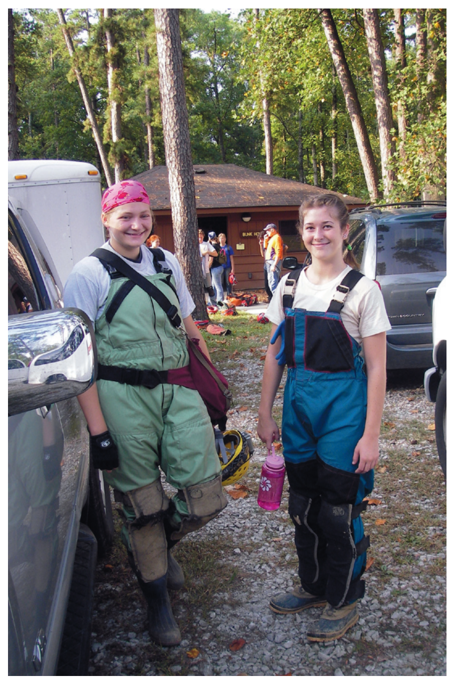
MISCELLANEOUS



A Consideration of Possible Biological Components Connected to the Formation of the Speleothem, Moonmilk

Polly A. Barger (WUSS #0556)

Moonmilk is a curious speleothem substance found in caves throughout the world and in most climates. Historically, the word "moonmilk" has been used not only as a name for the speleothem, but also as a means to describe physical textures and depositional attributes found in caves. According to Hill and Forti (1997), there are 79 different synonyms for moonmilk. Its morphology continues to be the subject of numerous papers (Chirienco 2004).

Moonmilk in its physical form is a very fine-grained material that has a high plasticity and contains a large percentage of interstitial water. In wet environments, moonmilk remains soft and does not harden into a mineral deposit. In dry environments, it desiccates into a crumbly material similar to powdered chalk. Occasionally, moonmilk will form in association with fragile cave balloons. About 95% of all moonmilk deposits are carbonates, while the remaining 5% are represented by sulphates, phosphates, and silicates (Chirienco 2004). Found in some speleothems are biologic-like attributes, suggesting that something in addition to mineral composition is being deposited.

Speculation about the medical lore surrounding moonmilk and its use as a healing agent eventually led to scientific analysis of the substance. The scientific reasons behind the "curative powers" of moonmilk did not have to be understood for humans to use it medicinally. Historical records dating to seventeenth century Europe show that moonmilk was administered to lactating livestock and wet-nurses to encourage milk production, and it was also prescribed for wounds and aliments including stomach burn, diarrhea, ulcers, surface cuts, and broken bones. (Hill and Forti 1997).

Moonmilk from a Missouri cave (area of view approximately 0.4m² - photo by H. Hobbs III

Intensive studies in Europe and North America over the past thirty years (Moore and Sullivan 1997) have shown that certain moonmilk deposits contain microbial or microbe-like elements, with some species playing an active role in formation of the speleothem (Chirienco 2002). Research by several individuals indicates that the list of microorganisms associated with moonmilk includes algae (unknown species), Actinomycetes*, Macromonas bipunctata* (Moore and Sullivan *1997),* Cyanobacteria*,* fungi (Roth 1995, Perrone et al. 2004), nitrifying bacteria (Ohde and Takii 1978), *Anthrobacter*, *Flavobacterium, Pseudomonas* (Hill and Forti 1997), *Bacilli* spp., *Micromonas* spp., and *Streptomyces* spp. (Boston 2001).

Thus far, the majority of identified microorganisms are bacteria normally found in soils, surface and subsurface waters, and cave environments. Actinomycetes are a primarily aerobic group of bacteria often found in soils. In cave systems, they are a chief contributor to the decomposition of cellulose, chitin, and lignocellulose matter. The eleven genera of Actinomycetes include *Actinomyces, Arthrobacter, Micromonas,* and *Streptomyces,* a group of bacteria that display antibiotic properties (Stackebrandt et al. 1997, Groth and Saiz-Jimenez 1999) and most likely were contributors responsible for the "healing powers" in early moonmilk prescriptions.

Pseudomonas is a metabolically diverse genus. Biofilm production by these bacteria enables some strains to survive in caves and other similarly unexpected locations. Specific species have been used as biocontrols in the fruit, greenhouse, and turfgrass industry since the 1980s, but little to no research has been done to measure the impacts this use may have in karst areas, on leached waters entering caves, cave speleothems and deposition, or cave ecosystems.

Flavobacteria are commensal bacteria that function globally in aerobic or anaerobic soil and water environments. In fishes and other animals, they can be opportunistic pathogens. A study of moonmilk deposits near Moscow, Russia, suggests that the bacteria may work in combination with others to corrode bedrock and produce the speleothem (Hill and Forti 1997). It is unknown if flavobacteria occurring in conjunction with moonmilk have any direct or indirect effect on the health of stygobiotic fauna.

Macromonas bipunctata is a recently classified chemolithotrophic bacterium. Current research suggests that it is partly responsible for precipitating calcite crystals in caves and metabolizing organic acids. It may also work in combination with other microorganisms to degrade cave wall minerals and produce the solids found in moonmilk (Moore and Sullivan 1997).

Cyanobacteria are aquatic, photosynthetic bacteria that reduce carbon and nitrogen in aerobic conditions. In anaerobic conditions, they make use of electron donors (other than water) to complete cyclic photophosphorylation. In dark environments, they are able to reduce elemental sulfur through anaerobic respiration (Anonymous, 1995). Their versatility and tenacity enables them to survive in cave environments and is speculated that these microbes also aid in the breakdown of cave wall minerals.

Nitrifying bacteria are chemolithotrophs that convert ammonia to nitrite, and nitrite to nitrate. They are common in soil, freshwater, and marine water. Large colonies in lakes and streams are indicators of anaerobic conditions and high ammonia concentrations, often found in association with sewage or wastewater. Samples analyzed from two shallow caves in Japan suggest that nitrifying bacteria are necessary for the formation of moonmilk (Ohde and Takii 1978).

Although research does seem to point to the need for microorganisms (or other organic substances) to be involved for the formation of some moonmilk deposits, this idea is still being debated. One biologically based theory considers moonmilk to be a precipitate or byproduct formed from microbial activity (in single species or in combination). In one study, samples of "Crisco" moonmilk were taken from Spider Cave, located in Carlsbad Caverns National Park, New Mexico. Microbes derived from the samples were cultured on four types of media with an incubation time varying from two to seven months. Low magnification analysis with a scanning electron microscope showed bacterial and fungal growth, as well as smooth curd-like biofilm textures. High magnification showed calcite rhombohedrons as well as organic filamentous fabric with calcite coatings, which are typical of many moonmilk deposits. The preliminary results suggested that a biotic component is associated with this particular moonmilk form (Perrone et al. 2004).

In another study involving Crisco, DNA-binding fluorescent dyes showed that calcite was precipitated on filaments that were, or recently were, living. Broken filament ends stained, while the calcite did not. The range of bacteria and fungi culturable from Crisco demonstrated the presence of an active biological community that included *Bacilli* spp., *Micromonas* spp., and *Streptomyces* spp. (Boston 2001).

Moore and Sullivan (1997) also note that microorganisms are involved in the development of moonmilk deposits. Formation occurs where water may reasonably be inferred to move through the substance to its surface, where deposition takes place through carbon dioxide degassing. Life processes of individual microorganisms cause a microvariation of the chemical environment, which leads to deposition of discrete mineral grains.

A second biologically based theory regarding moonmilk suggests that the speleothem is formed from the biochemical corrosion of bedrock by organic acids produced by microorganisms. Bacteria are known to break down the crystalline structure of calcite, forming moonmilk (Hill and Forti 1997). Calcite moonmilk found in Oregon Caves contains microorganisms which likely assist in breaking down minerals in the cave wall, adding them to moonmilk (Roth 1995). In catacombs near Moscow, Russia, evidence through luminescent microscopy has found that moonmilk is the product of organic acid corrosion of bedrock (Hill and Forti 1997).

Other factors or variables that may affect the organic content of moonmilk include mineral composition of the cave and the subsurface filtration of microorganisms. For example, moonmilk deposits composed of calcium carbonate contain microbes, but moonmilk deposits composed of magnesium minerals do not (Hill and Forti 1997). Roth (1995) conducted research in caves located at Oregon Caves National Monument and determined that the longer it takes water to reach the cave, the more likely it is that organics will be consumed enroute. In general, epikarst water dripping into the deeper parts of Oregon Caves has less organic content than water in shallower parts and, therefore, less organic material is available to contribute to or affect moonmilk formation. Agricultural use and human disturbance near and in cave systems also can play a significant role in the infiltration and deposition of microbes in moonmilk. As Hill and Forti (1997) suggest, the occurrence of microorganisms in some deposits does not show conclusively that they are essential to its genetics.

A factor not thoroughly considered in this review, which, in some irony, may become a serious thread of future health research, is rediscovering the antibiotic properties of moonmilk and comparing them to present antibiotics used (which are increasingly becoming ineffective against certain diseases). Barton (2006) noted that cave microorganisms have the potential to harbor unique antibiotics and cancer treatments. That same year, a student in California tested freshly formed moonmilk samples taken from Oregon Caves National Monument for the antibacterial properties suggested by European folklore. Four samples were tested against *Rhodospirillum rubrum* and *Micrcoccus luteus* and compared with Neosporin and a bacteria-only control. In his results, one dish inoculated with moonmilk showed a bacterial growth inhibition ring. Hardened moonmilk tested similarly showed no bacterial inhibition rings. One drawback to this study, unfortunately, was an eight day delay between collection and inoculation. Until shipment, samples were stored at cave temperatures (Faust 2006). Perhaps if the entire experiment was able to be conducted within the cave, moonmilk cultures would have shown a different set of results.

One thing became apparent in this literature review: some scientists reasonably conclude moonmilk speleothems are biogenic, while others have identified non-biological formation mechanisms and presume moonmilk results from mineral deposits that inadvertently contain microbes; it is comparable to insects trapped and preserved in amber. If both biological and abiological formation mechanisms are indeed possible for moonmilk formation, then it is critical to distinguish between the two (Boston 2001). Knowing the cave atmosphere parameters, solution chemistry, and flow velocity in connection with crystal morphology can help reconstruct the environments of moonmilk (Moore and Sullivan 1997) and perhaps demonstrate it to be a speleothem with several subcategories of deposition, formation, and influence in cave ecosystems.

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Adaptive Troglomorphic Evolution

Adam Morrison

Abstract

The purpose of this manuscript is to demonstrate that animals living in caves are direct decedents of ancestors dwelling on the surface. The only explanation as to how this is possible is through troglomorphic evolution. The organisms go through either regressive or progressive troglomorphy, according to natural selection, which in turn leads to efficiency of energy use, thus stretching the amount of available energy for consumption, prolonging life.

Many hypogean (underground) troglomorphic animals are derived from epigean (above ground) animals through evolution; this indicates that the troglomorphic features observed are naturally selected and are adapted over periods of time. The term "troglomorph" was coined to designate phenotypic features that are characteristic of cave animal evolution (e.g., reduced pigments and eye structures) (Christiansen 1962). Troglomorphy is not universal among cave organisms yet is displayed commonly by fauna within invertebrate and vertebrate phyla (convergence). In order for this to occur two factors have to be present: (1) a strong selection pressure for the developments of a particular characteristic, and (2) the genetic and physiological or behavioral ability of the organisms to respond to this pressure (Christiansen 1965).

Darwin himself took a somewhat ambiguous position in the first edition of *On the Origin of the Species by Means of Natural Selection*, where he explained troglomorphism as a combination of both natural selection and use vs. disuse (Romero 2001). Evolution is opportunistic, and that helps explain why life is ubiquitous on earth. The total number of troglomorphic species has been estimated to be between 50,000 and 100,000 (Culver & Holsinger 1992) This is considerable, given that most hypogean habitats: (1) are very reduced in space; (2) generally lack primary producers (plants); and, (3) have not been thoroughly explored, particularly in tropical regions where caves can contain a very diverse fauna (Deharveng & Bedos 2000).

No other animals on the planet have a more intimate environmental adaptation than those inhabiting caves. Light provides energy for all life forms, and primary production is a source of biodiversity; however, life still exists in the darkness of caves (Aden 2005). The deep cave (beyond the threshold zone) is completely aphotic; it is comparable to the darkness of the deep ocean. Hence, there is no photosynthesis and thus nor organic molecules assimilated in caves except in those few subterranean settings where chemolithoautotrophic microbes contribute energy to the subterranean ecosystem (Engel 2007).

The term adaptation is applied to several different biological phenomena. Generally, three different types of responses of organisms to their environment have been termed adaptive: in behavior and evolutionary and physiological adaptation (Aden 2005). Behavioral changes usually precede external morphological evolution. Behavioral flexibility is thus the first condition for success in cave colonization. Only after colonization has taken place do morphological and physiological changes begin to occur (Romero 2001). Adaptation is a progress of genetic change resulting in improvement of a character with reference to a specific function or a feature of a selective advantage that has become prevalent in a population (Aden 2005).

The main environmental factors influencing physiological adaptations in cave organisms are darkness, lack of food (energy), and in some rare cases hypoxic conditions. These factors have a high selective value in regard to adaptive features such as drastic reduction in eye size and function and a reduced metabolic rate compared with that of surface-dwelling relatives (Romero 2001). During periods of hypoxic stress, hypogean crustaceans possess a lower critical oxygen partial pressure than epigean ones, which may indicate that these organisms are better adapted to low oxygen levels (Hervant, 1998). When starvation begins, the respiratory-- but also locomotion and ventilation--rates are drastically reduced in hypogean species (Hervant, 1997).

Behavioral traits play a big role in determining the ability of a group of individuals to survive during colonization of a subterranean (hypogean) environment. Numerous animals colonize the hypogean environment by developing entirely new behaviors such as echo-location (bats), bioluminescence (New Zealand glow worm); however, these are the exceptions, not the rules. Most behaviors can be grouped into one of the following categories: feeding, reproduction, social behavior (aggression, responses to alarm substances, and antagonistic behavior), photo responses, and circadian rhythms (Romero 2001).

Morphological adaptation is any evolutionary modification of the morphology of lineages of organisms associated with their existence in caves (Peck 1988). Peck usefully divided these changes into two groups: regressive and progressive. Regressive adaptations involve reduction or loss of systems that occur in surface-dwelling organisms. Progressive adaptations involve enlargement, modification, or development of systems not seen in most surface-dwelling organisms. Recall the definition of the term troglomorphy (Christiansen, 1962); it designates both regressive and progressive evolutionary traits associated with cave life. The term was originally used only for morphological qualities; further study has shown that it applies equally to behavioral and physiological features (Romero 2001). Some troglomorphic characteristics are considered universal, specifically, elongation of appendages and loss of pigmentation. These traits are absent in fauna living in cave environments that contain guano piles or large masses of organic debris which are extremely energy rich. Troglomorphy should not be expected in these cases since it has a tendency to occur when organisms are exploiting large volume spaces such as the surface of cave walls or floors (Peck 1988).

Regressive troglomorphy is commonly found in troglophilic forms, but progressive troglomorphy is nearly limited to troglobionts or stygobionts. Progressive troglomorphy is, however, not universal among cave organisms. In order for it to occur, three factors have to be present: (1) selection pressure for the development of a particular characteristic, (2) the genetic and physiological or behavioral ability of the organism to respond to this pressure, and (3) sufficient time evolving in caves to develop the adaptations (Christiansen 2002).

"Pre-Adaptations" have been described as features, such as nocturnal habits and hyper development of sensory organs in epigean species, that are considered useful and even necessary in hypogean environments (Langecker 2000). The two characteristics most closely correlated with light conditions are eyes and pigmentation. Animals that have been raised under conditions of total darkness display a lower degree of eye and pigment development. On the other hand, when some troglomorphic animals are exposed during certain periods of time to light, they may redevelop, to a certain extent, both pigmentation and the visual apparatus (Romero 2001). This strongly agrees with the fact that many troglomorphic animals are derived from epigean species characterized by phenotypic plasticity, which is the ability of a single genotype to produce more than one alternative form of phenotype in response to environmental conditions (Romero 2001). Lack of light can trigger heterochrony, the change in timing of the development of features. Examples are paedomorphs (animals that do not reach morphological maturity, reproducing as juveniles) and neotenes (animals with an unusually slow rate of growth). Many cave organisms are either paedomorphic or neotenic (Romero 2001).

The recessive allele can be considered the "troglo-morphic gene" because it manifests a morphologically and ecologically differentiated phenotype that is reproductively isolated from the epigean ancestor. This is supported by the convergent nature of troglomorphic characteristics. Convergent evolutionary patterns are strong evidence of adaptation via natural selection. Isolation would later lead towards speciation (genetic differentiation from the epigean ancestor). Some troglomorphic organisms are believed to have invaded the hypogean environment recently, since their epigean ancestor is easily recognizable and can even interbreed with them to produce fertile hybrids (Romero 2001).

Speciation is the process by which one species evolves into a different species or splits over time into two or more new descendant species, and has been effectively reviewed in cave animals (Barr & Holsinger, 1985). There is very strong evidence that even when large surface populations of the same species exist, rarely is there significant gene interchange between the surface and hypogean populations (Kane & Culver 1992). Some evidence shows that while the forces of selection have much to do with morphological or phenotypic speciation, they have little to do with genetic speciation (Sbordoni et al. 2000). Genetic speciation studies almost never involve genes associated with morphological features of adaptive importance and thus cannot be subject to selection, which is the final determinant of lineages (Romero 2001).

There are two types of speciation in cave organisms: the first is phase 1 which involves the evolutionary changes that a species makes when it first successfully invades a cave, and phase 2 involves changes made in established cave lineages. The first phase produces often unclear changes in physiology, little or no troglomorphy, and has a heavy association with pre-adaptations. The second phase usually involves clear morphological, physiological, and behavioral changes and often results in increased troglomorphy (Romero 2001). It is believed that troglobites evolve from pre-adapted forms that actively invade caves to exploit new niches and are evolved from native fauna (Holsinger, 2000). During the Pleistocene many tropical environments went through major shifts. In addition, there was a high degree of troglomorphy in cave fauna where the surface conditions made movement between caves improbable, and troglomorphy was low or absent where such movement was easy (Sbordoni et al. 2000).

Speciation within troglobitic lineages is almost certainly due to allopatric speciation (Sbordoni et al. 2000). The spatially limited distribution of troglobionts, the degree of subdivision of populations, and isolation of these from each other all lend themselves well to the process of allopatric speciation. Furthermore, the distribution pattern of troglobionts and primarily troglophiles further supports the idea that allopatric speciation is dominant (Christiansen & Culver 1987).

It is quite clear that many hypogean cavernicoles are descendants of their epigean ancestors; because of troglomorphic evolution these animals demonstrate regressive and progressive adaptations (e.g., lost pigmentation and eyes; elaborated appendages) but they are still related to each other. It is necessary for species to adapt to the vagaries of the spelean environment through natural selection in order to preserve energy and to survive in their limited and extreme subterranean ecosystem.

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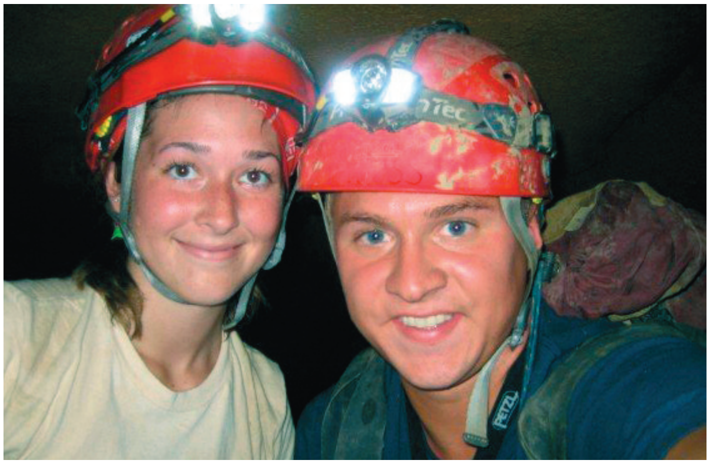
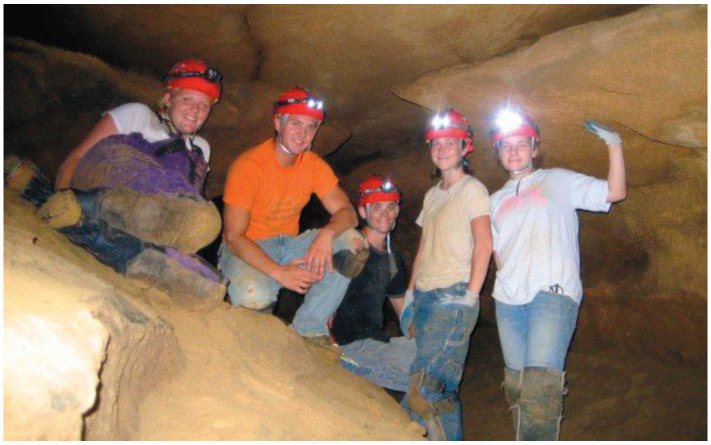
MISCELLANEOUS





A Short Guide to Linking the Cave Mapping Program *Compass* to *ArcGIS*

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Since its development, geographic information systems (GIS) have become an efficient and popular management tool for natural resources with public land management agencies, such as the United States Forest Service and Fish and Wildlife Service, state departments of natural resources, and many colleges and universities offer GIS as a major or minor concentration of study. Major applications of GIS are typically grouped into three key categories: spatial and geographic databasing, map viewing/creating, and model viewing/creating, all of which are useful in management, both natural (i.e., forest, water, fisheries, wildlife) and human (e.g., population density, political boundaries, utilities) sectors (http://www.gis.com/whatisgis/). Despite its demonstrated benefits in forest, water, wildlife, and soil resource management, use of GIS in cave management has been understandably slower, given the limitations of geographic positioning system (GPS) devices, which require a view of the sky to receive coordinates from GPS satellites. GIS has however, made its way into cave management, due in large part to the integration of cave survey maps with GIS, and has been featured as a special issue by the Journal of Cave and Karst Studies [April 2002,Volume 64 (1)]. Some examples of cave resource management that appear in the issue include Timpaganos Cave National Monument, where GIS has been used to make maintenance decisions and for resource management; the city of San Antonio, that employed GIS to address development issues on karst lands; and Wind Cave National Park, where GIS has been used to identify surface level features of concern to Wind and Jewel caves through the integration of cave survey maps. The articles featured in that issue of the Journal of Cave and Karst Studies are but a few of the possible uses of GIS in cave resource management.

At the most basic level for any of the three categories of GIS use, cave resource management is greatly facilitated by possessing both cave locations and passage orientation. This basic information can then be used at higher levels to create sophisticated 3D and stochastic models, and spatial databases. For these purposes, it is fundamental that cave passage layout data be included. Obviously, there are a variety of cave survey mapping programs available; of these, the *Compass* cave mapping program is particularly useful because it has the capability to export cave maps directly in a number of formats, including GIS acceptable shapefiles (one of the basic GIS spatial data files), and is supported by ESRI, the producers of the *ArcMap* GIS program. Furthermore, *Compass* is a useful extension outside of GIS that displays cave passages in a number of different formats, including spline curve and 3D polygon, provides statistical information on surveys, and can be obtained at low cost. There are other mapping programs, however, that are available and are supported by *ArcMap*, such as *WALLS* and *WinKarst*, though *Compass* will be the only one addressed in this discussion. Because the process of importing *Compass* maps into a GIS map is a less than intuitive process, this article is intended as a manual to guide *Compass* and GIS users in the integration of the two programs for basic mapping purposes.

To display a *Compass* survey map in a GIS map requires several things- 1) a GPS device (the more accurate the better), 2) cave survey data, 3) *Compass* cave mapping software, and 4) ArcMap GIS software. Addition of cave survey maps created in *Compass* to *ArcGIS* maps consists of seven major steps; 1) physical location of caves, 2) recording of GPS coordinates for the cave mouth, 3) cave surveying, 4) entering of coordinate and survey data into *Compass*, 5) export as a shapefile, 6) assignation of a projection layer (based on the desired datum), 7) and addition to a GIS map.

Before progressing into the actual methodology of integrating *Compass* and *ArcMap*, it is first important to understand that *Compass* is divided into three portions– **Cave Editor**, **Project_Manager**, and **Cave Viewer**, which are used in that order to produce cave survey maps. With basic entrance location and passage survey data and *Compass* opened, cave surveys can be entered into the **Cave Editor** portion of *Compass*. For accurate mapping in GIS, declination should be calculated in this portion of *Compass*;

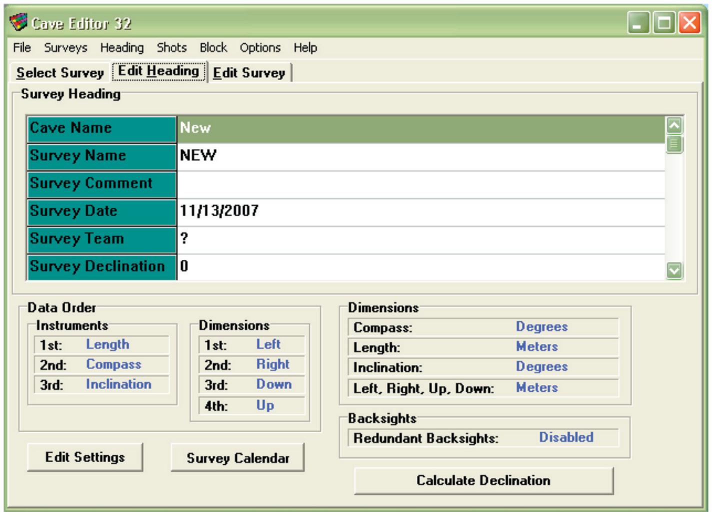


Figure 1. *The* Compass ***Cave Editor*** *window, under the 'Edit Heading' tab, also displaying the 'Calculate Declination' button.*

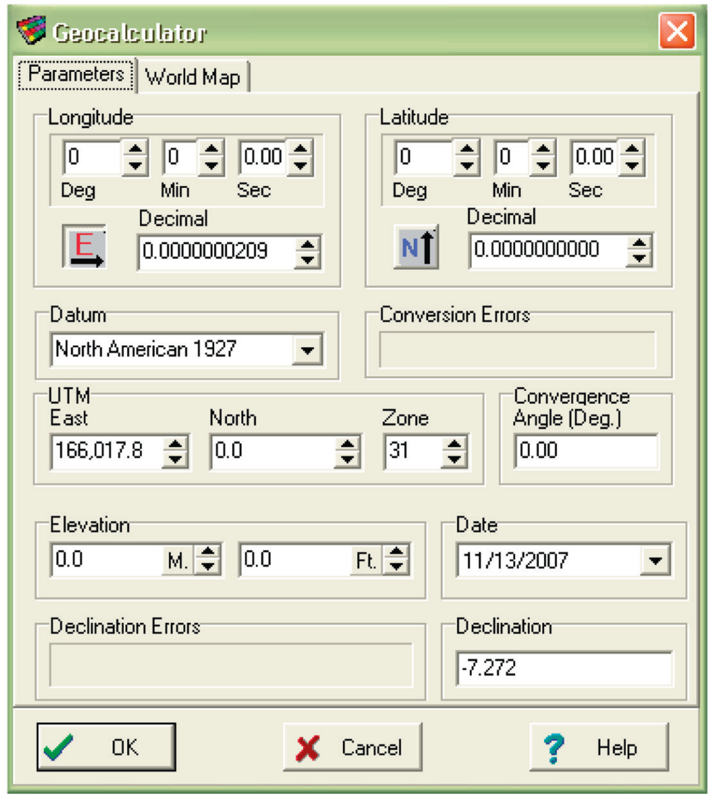


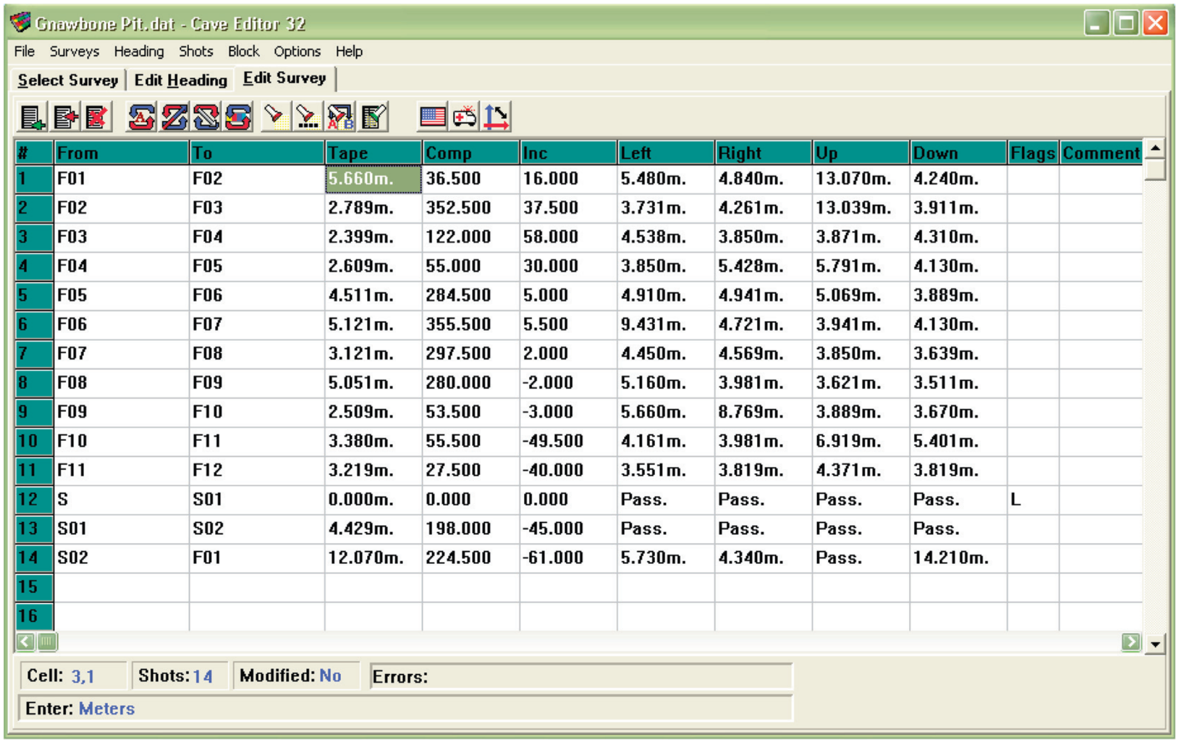
Figure 2. *The Geocalculator window. Datum and coordinates are added at this point to calculate declination.*

if declination has been set on the survey compass, this step will not be necessary. Calculating declination at this step ensures that the directional orientation of the cave will be correct in the GIS map. Briefly, this is due to the offset of the magnetic poles from true north and south; traditional magnetic compasses read north as magnetic north rather than true north. *ArcGIS* mapping software uses true north, therefore, calculating the declination improves the accuracy of the map. Those interested in learning more on declination and the magnetic fields of the United States should refer to Heck (1941) and Constable et al. (2000). Declination is calculated in **Cave Editor** under the 'Edit Heading' tab, where there is a 'Calculate Declination' button (Figure 1).

When clicked, a geocalculator window appears, prompting for geographic coordinates, datum, and elevation (Figure 2). Geographic coordinates can be entered as either UTM (universal transverse mercator), degrees minutes seconds, or decimal degrees. Entering coordinates in any form will automatically generate the coordinates in the remaining two reference systems; for UTM coordinates, the zone will automatically be selected. Clayton (1971) provides a useful overview of geographic coordinate systems for those interested in more information on this subject. Accurate mapping requires that the datum used in the GPS device be used at this point in *Compass*. Selecting the correct datum, the one used in the GPS device- whatever it may be (e.g. NAD 1927, NAD 1983, WGS 1984), ensures that the correct type of coordinate grid is used. More detailed information on this subject is available in Bowie (1928), Schoewe (1948), and Wood (1996). Specifically, Wood (1996) focuses on the difficulties and calculations associated with generating coordinates on earth with planar, spherical, ellipsoid, and geoid surface models. Schoewe (1948) and Bowie (1928) focus on triangulation and the datum of North America.

Entering the cave coordinates and selecting the correct datum will automatically calculate declination which will then be displayed under the 'Edit Heading' tab. Coordinates entered into the Geocalculator under **Cave Editor** are only used to calculate declination; *Compass* will not keep these coordinates as the physical location of the cave. In addition to calculating declination cave survey information is also entered into *Compass* using **Cave Editor** (Figure 3).

To enter survey data, select the 'Edit Survey' tab; this will bring up a spreadsheet formatted for cave surveys that includes distances, inclination, and survey station names. Once the initial set of station names is entered (in the 'To' and 'From' columns), *Compass* will automatically name all following survey stations in a progressive fashion; e.g., if the first survey shot is from F01 to F02, the subsequent shot will automatically be named F02 to F03. Automatic naming in this fashion will continue unless station names are changed.



#	From	To	Tape	Comp	Inc	Left	Right	Up	Down	Flags	Comment
1	F01	F02	5.660m.	36.500	16.000	5.480m.	4.840m.	13.070m.	4.240m.		
2	F02	F03	2.789m.	352.500	37.500	3.731m.	4.261m.	13.039m.	3.911m.		
3	F03	F04	2.399m.	122.000	58.000	4.538m.	3.850m.	3.871m.	4.310m.		
4	F04	F05	2.609m.	55.000	30.000	3.850m.	5.428m.	5.791m.	4.130m.		
5	F05	F06	4.511m.	284.500	5.000	4.910m.	4.941m.	5.069m.	3.889m.		
6	F06	F07	5.121m.	355.500	5.500	9.431m.	4.721m.	3.941m.	4.130m.		
7	F07	F08	3.121m.	297.500	2.000	4.450m.	4.569m.	3.850m.	3.639m.		
8	F08	F09	5.051m.	280.000	-2.000	5.160m.	3.981m.	3.621m.	3.511m.		
9	F09	F10	2.509m.	53.500	-3.000	5.660m.	8.769m.	3.889m.	3.670m.		
10	F10	F11	3.380m.	55.500	-49.500	4.161m.	3.981m.	6.919m.	5.401m.		
11	F11	F12	3.219m.	27.500	-40.000	3.551m.	3.819m.	4.371m.	3.819m.		
12	S	S01	0.000m.	0.000	0.000	Pass.	Pass.	Pass.	Pass.	L	
13	S01	S02	4.429m.	198.000	-45.000	Pass.	Pass.	Pass.	Pass.		
14	S02	F01	12.070m.	224.500	-61.000	5.730m.	4.340m.	Pass.	14.210m.		
15											
16											

Figure 3. *Entering survey information into* ***Cave Editor.*** *Note that automatic naming changed in line 12 of the spreadsheet when new station names were entered and that this new naming scheme was adopted by the automatic naming function and that "Pass." appears when a side passage extends from the main cave passage.*

When changed, automatic numbering will continue using the new station names (Figure 3). Column headings correspond as follows:

From– the current survey point
To– the survey point being shot to
Tape– linear distance from point to point
Comp– compass bearing from survey point to point
Inc– inclination from survey point to point
Left– distance from point to left wall
Right– distance from point to right wall
Up– distance from point to ceiling
Down– distance from point to floor

Distance data should be entered in meters, while all angle and compass data should be entered as degrees. If a passage extends in any direction at a survey point, this can be denoted as "Pass.", indicating that the wall, ceiling, or floor is actually a passage; this can then be connected to the survey later with another series of survey stations extending from the passage location. When all survey data have been entered, declination calculated, and survey information recorded, the file is ready to be sent to the second portion of the *Compass* program, **Project Manager**; all that is required to prepare the **Cave Editor** file for **Project Manager** is a saved file of the survey. Saving the **Cave Editor** file can be

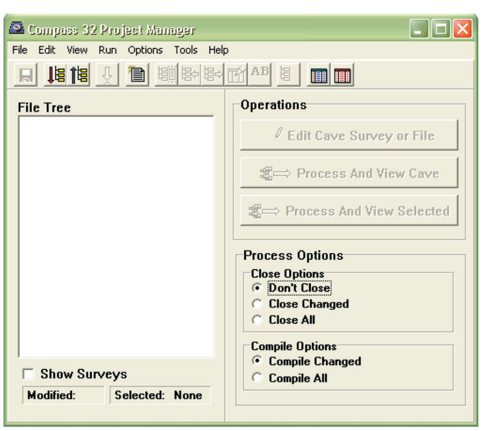


Figure 4. Project Manager *will open with inactive buttons, indicated by lack of color.*

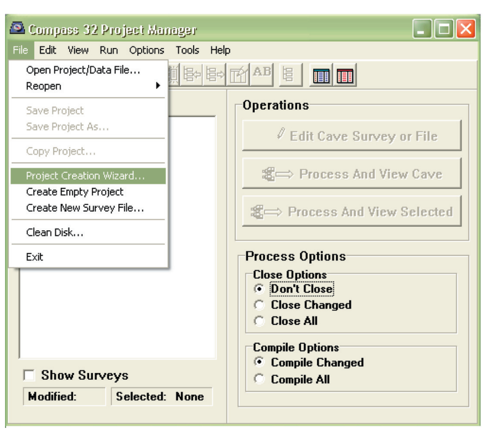


Figure 5. *Project Creation Wizard is located under the File button at the top of the* ***Project Manager*** *window.*

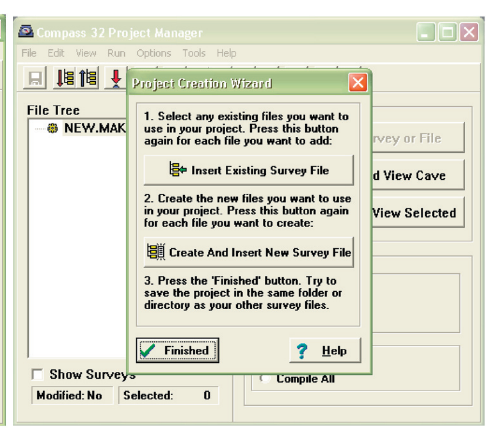


Figure 6. *Project Creation Wizard popup window.*

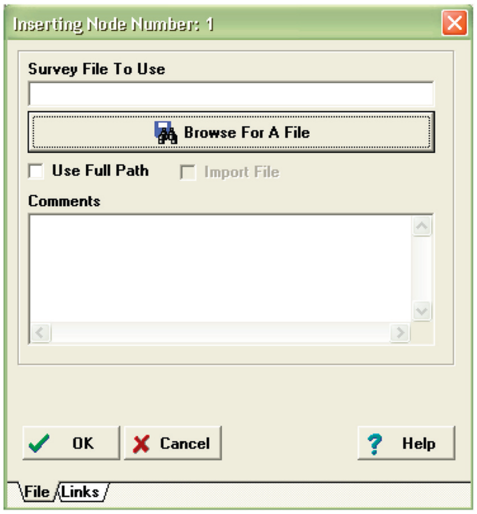


Figure 7. *Survey files can be selected using the Browse for a File button.*

done following the standard 'File > Save As' method.

With the survey data entered and saved, **Project Manager** is capable of processing the data for viewing, assigning GPS coordinates to survey stations, linking multiple survey files, and calculating survey statistics. To do this, **Project Manager** first must be opened; when opened, most **Project Manager** buttons will be inactive (Figure 4). Buttons will become active when a **Cave Editor** file is opened or the Project Creation Wizard is used to create a **Project Manager** file. Opening a **Cave Editor** file (.dat files) will not allow coordinates to be assigned, but will allow for quick viewing.

To add geographic coordinates, Project Creation Wizard must be used to create a **Project Manager** file (.MAK files) from a **Cave Editor** file; Project Creation Wizard is located under the 'File' button (Figure 5). After selecting 'Project Creation Wizard', a new window will appear with two options, 'Insert Existing Survey File', and 'Create And Insert New Survey File' (Figure 6).

Selecting 'Create' and 'Insert New Survey File' here will create a blank **Cave Editor** file that can be accessed by selecting the Edit Cave Survey or File button. Selecting the 'Insert Existing Survey File' button automatically converts a previously created cave survey file into a **Project Manager** file; the desired survey file can be selected by navigating through the browse file button to the location of the desired survey (Figure 7).

After the survey file has been selected, it can be added to **Project Manager** by pressing 'OK', and 'Finish'. Once the survey file has been added to **Project Manager** it will become a .MAK file that can be saved along with the original .dat file. At this stage, geographic coordinates can be assigned to any desired survey station. To do this, the .dat portion of the .MAK file must be opened. This can be accomplished in either of two ways: using the mouse to click the node symbol next to the file name, or by pressing the 'Expand Tree' button on the top left of the **Project Manager** window (Figure 8). Selecting either will cause the tree to expand and display the .dat file. (Figure 9). With the .dat file selected, it can be edited by selecting the 'Edit File Node' button. Pressing the 'Edit File Node' button will

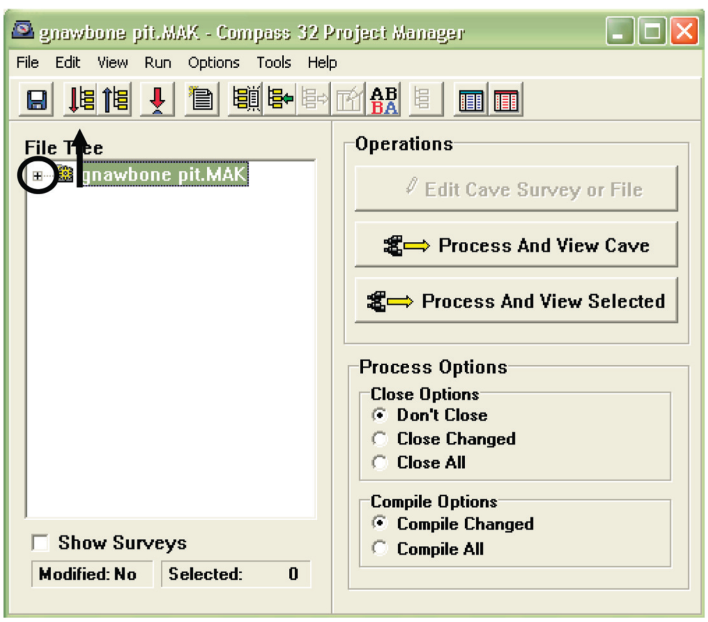


Figure 8. *Both options for opening the .dat file in the .MAK file; the Expand Tree button is indicated by an arrow, the node symbol by a circle.*

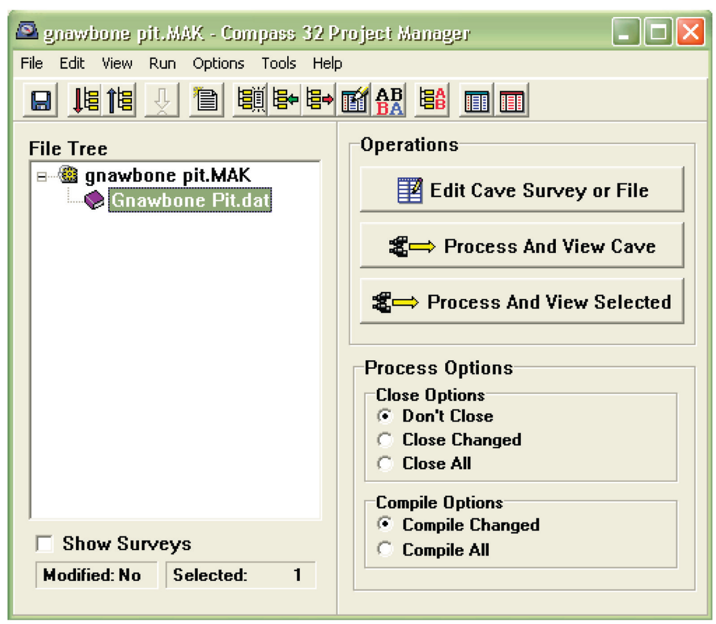


Figure 9. *The .dat portion of the .MAK file becomes visible after opening the file tree.*

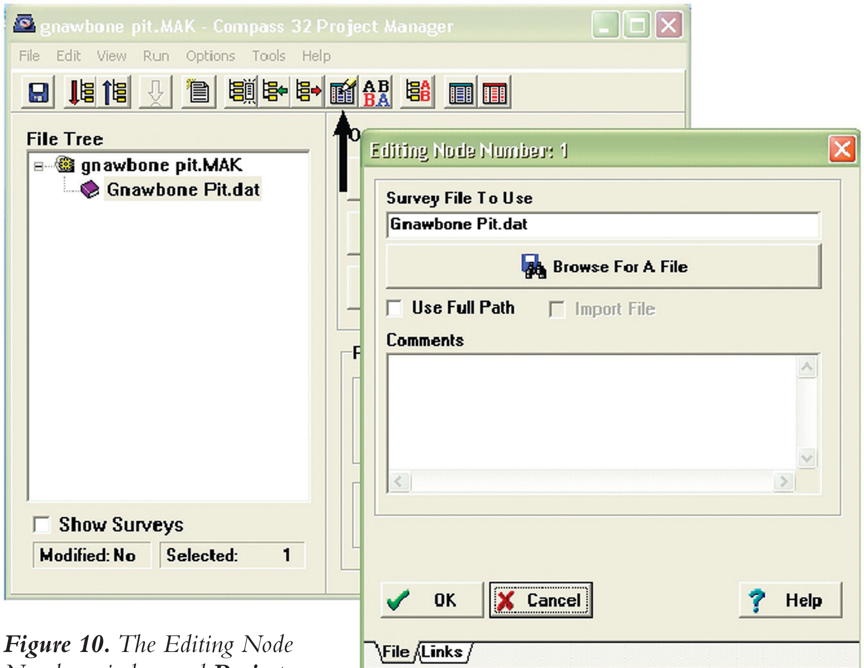


Figure 10. *The Editing Node Number window and **Project Manager** window. The Edit File Node button on the **Project Manager** window is indicated by an arrow.*

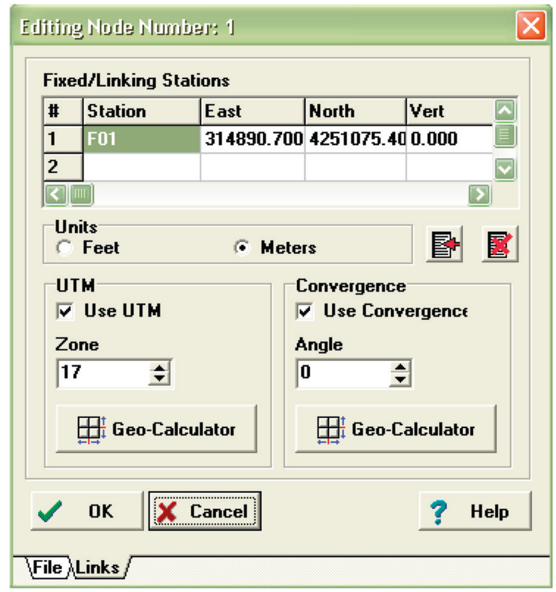


Figure 11. *The Editing Node Number window under the Links tab, displaying geographic coordinates and the survey station to which they are attached.*

open the Editing Node Number window (Figure 10).

In the Editing Node Number window, select the 'Links' tab at the bottom left. Selecting this tab will bring up a new display that includes a small spreadsheet under the Fixed/Linking Stations heading (Figure 11). Geographic coordinates are assigned to survey stations in this window, and can be alloted manually as UTM coordinates or calculated as UTM coordinates. To allocate coordinates manually, enter the survey station to which the coordinates are to be attached in the Station portion of the spreadsheet, then enter the Easting and Westing coordinates of the point. When deciding the correct survey station to which coordinates are to be assigned, remember to select the station nearest to the point where the geographic coordinates were recorded.

To have UTM coordinates automatically calculated, begin by checking the 'Use UTM' box under the UTM heading; next, select 'Geocalculator'. Selecting 'Geocalculator' will open the Geocalculator window again (Figure 12). This Geocalculator is the same as that described above, and will function in the same manner.

After the correct coordinates and datum have been selected, selecting 'OK' will close the Geocalculator window and bring the Editing Node Number window back up. Remember to select meters as the unit of measure before selecting 'OK' to return to the Project Manager window; no changes will be visible to the file but the coordinates will be retained by the chosen survey station. Once coordinates have been assigned to the survey station of choice, the .MAK file can be saved for later use. Saved .MAK files will preserve geographic coordinates that have been assigned to survey stations.

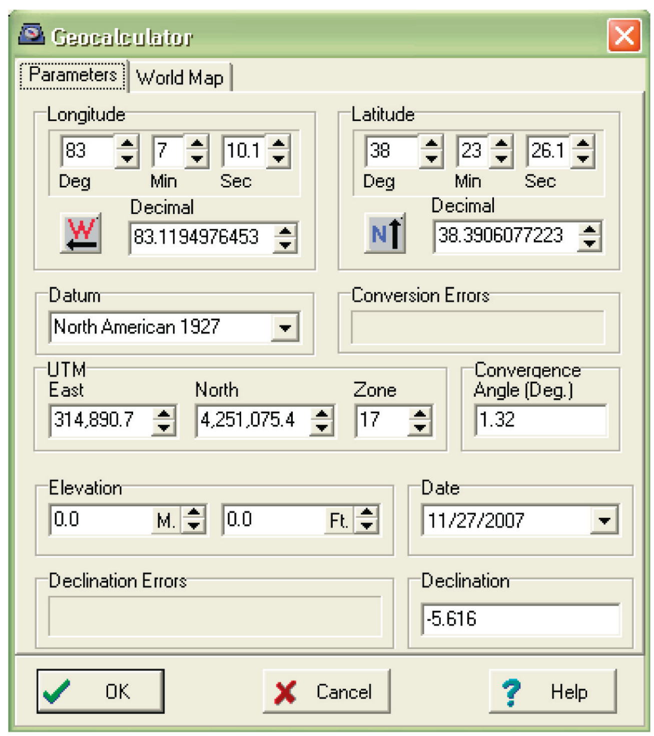


Figure 12. *The Geocalculator window.*

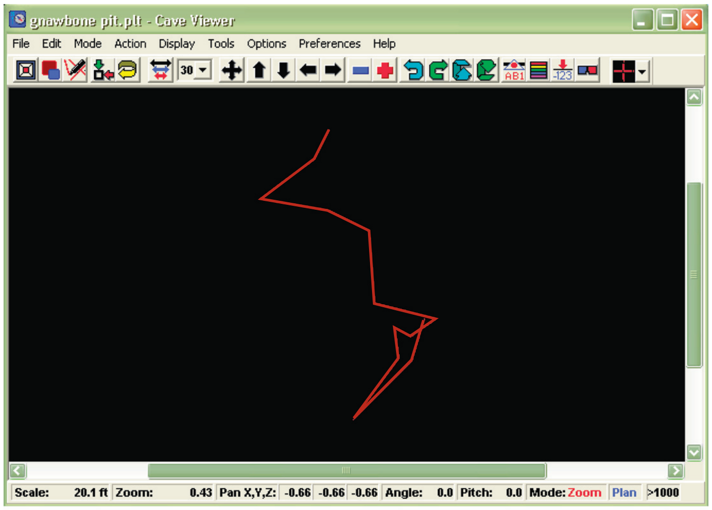


Figure 13. *The* Compass ***Cave Viewer*** *window displaying a cave line plot.*

Clicking the 'Process and View Cave' button will cause **Cave Viewer** to open automatically and display the cave survey file as a line plot (Figure 13).

If the **Cave Viewer** does not appear and an error message is received stating that the **Project Viewer** and **Cave Editor** extensions cannot be located, the directory pathway to these extensions must be set manually. To set these, click the Options button at the top of the **Project Manager** window and select Settings (Figure 14). This will open the Settings window; in this window select the 'Directories' tab. Pathways to the **Cave Editor** and **Project**

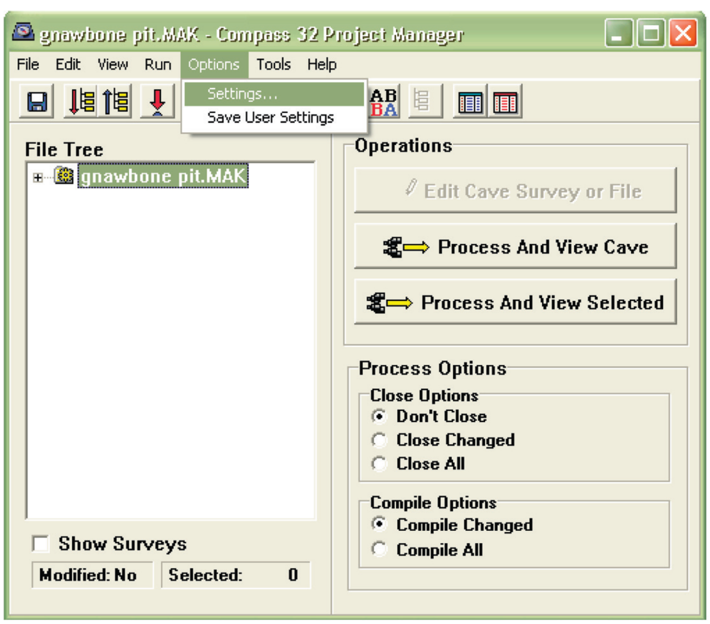


Figure 14. *The Options > Settings buttons.*

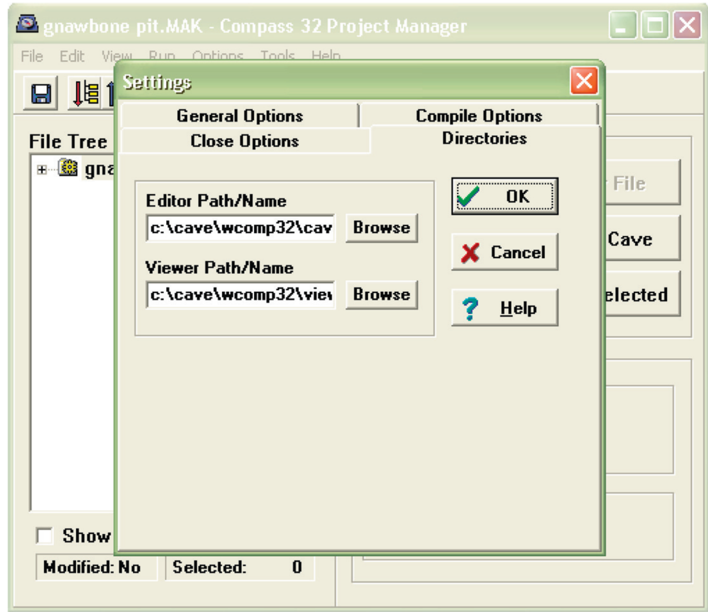


Figure 15. *The Directory tab in the Settings window where pathways to* Compass *extensions can be manually determined.*

Viewer extensions can be set by clicking the 'Browse' button and navigating to the location of the extensions (Figure 15). After the extension pathways have been set, the 'Process and View Cave' button will cause the cave plot map to display in **Project Viewer**.

Cave plot maps can be displayed in a variety of styles, including polygon, line, spline curve, and 3D cave profiles that can be manipulated about their axes. While these are useful tools, they do not play a role in exporting *Compass* cave plot maps into GIS, and therefore will not be discussed herein. However, all different styles of map views may be

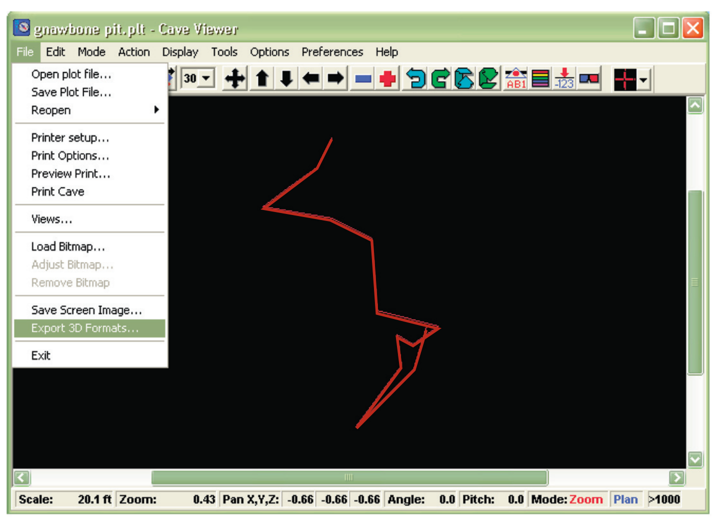


Figure 16. *The Export 3D Formats button is located in the File menu.*

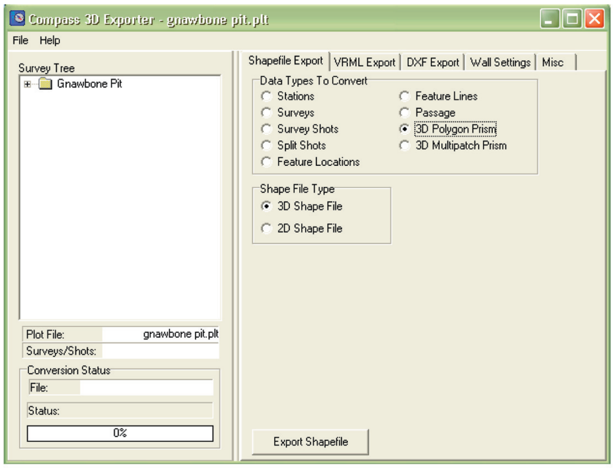


Figure 17. *The* Compass *3D Exporter window.*

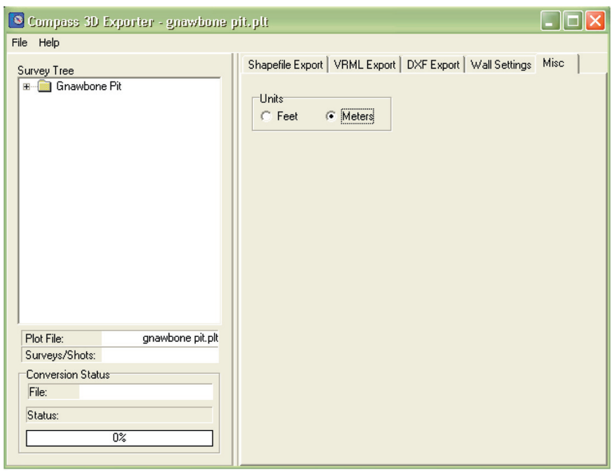


Figure 18. *Keep units constant throughout the process; make sure units are in meters since this is required for the cave map to display properly in a GIS map.*

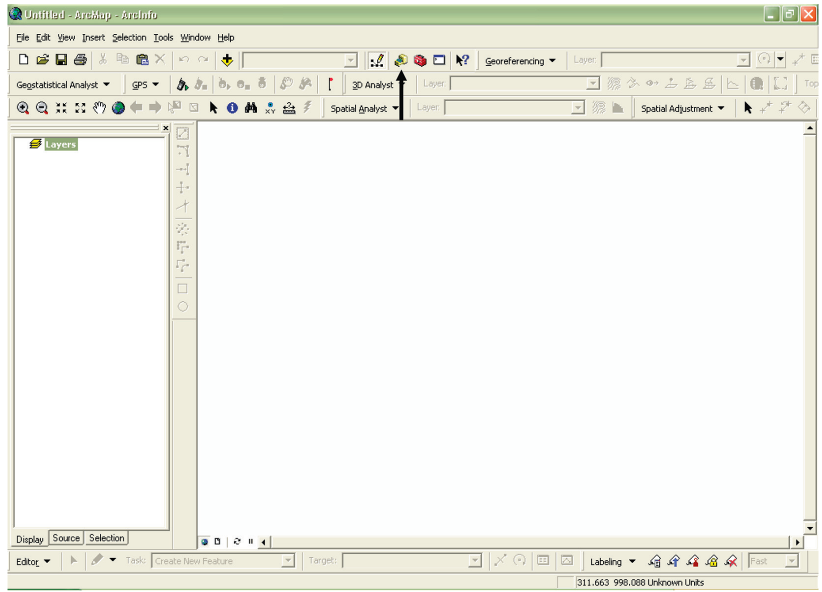


Figure 19. *The* ArcMap *window with the* ArcCatalog *button indicated by an arrow.*

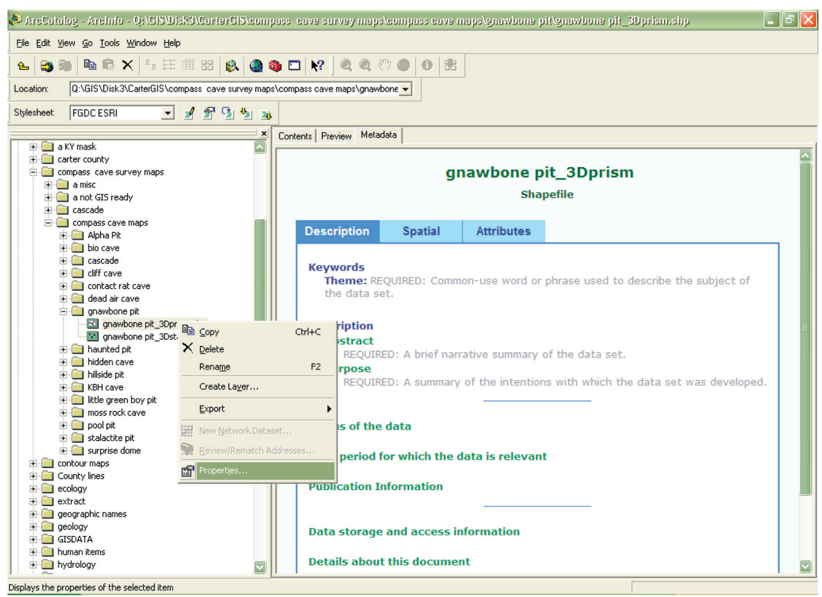


Figure 20. *Opening the properties for the shapefile cave map layer.*

exported for use as a GIS file layer.

To export ProjectViewer maps in a GIS compatible format, go to 'File' and select 'Export 3D Formats' (Figure 16). This will open the *Compass* 3D Exporter Window. At this point, the export file type must be selected; for ESRI *ArcMap* GIS programs 'Shapefile Export' should be selected. Under this tab, choose the type of data that are to be exported and shapefile type; chosing data types will determine how the map will appear when exported. It is recommended that under 'Data Types to Convert,' 3D Polygon Prism be selected and under 'Shape File Type' 3D Shape File be selected (Figure 17). Selecting these will generate whole cave maps that will accurately display passage widths. Other data types, such as Stations, will display differently. As an example, selecting 'Stations' as the export file type will result in an exported cave map that displays a collection of the survey points with no connecting lines to indicate passage widths. With the proper data type and shape file type selected under the 'Shapefile Export' tab, go to the 'Misc' tab and select meters as the unit (Figure 18). It is important to keep the unit of measure constant throughout the process and that it be meters since the map projection layer will be in the UTM coordinate system.

With the units set and the data type and shape file types selected, the map is ready to be exported. To do this, go back to the 'Shapefile

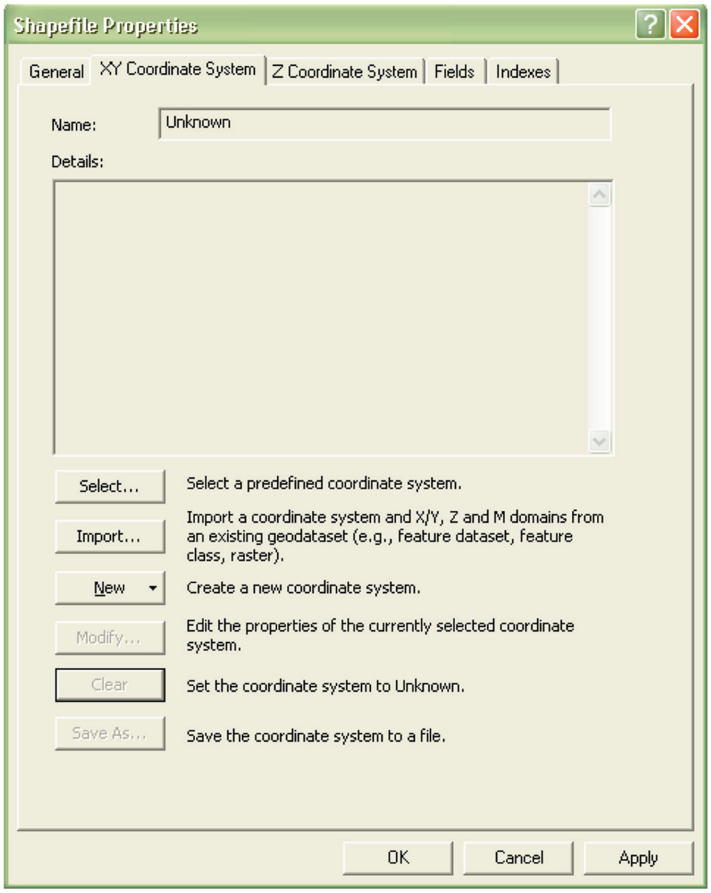


Figure 21. *The Shapefile Properties window.*

Export' tab and press the 'Export Shapefile' button. This allows the cave map data to be saved as a shapefile. When naming the shapefile, do not change the file type extension.

With the cave map data exported, the remaining steps will be done in GIS in the *ArcMap* extension. All steps from

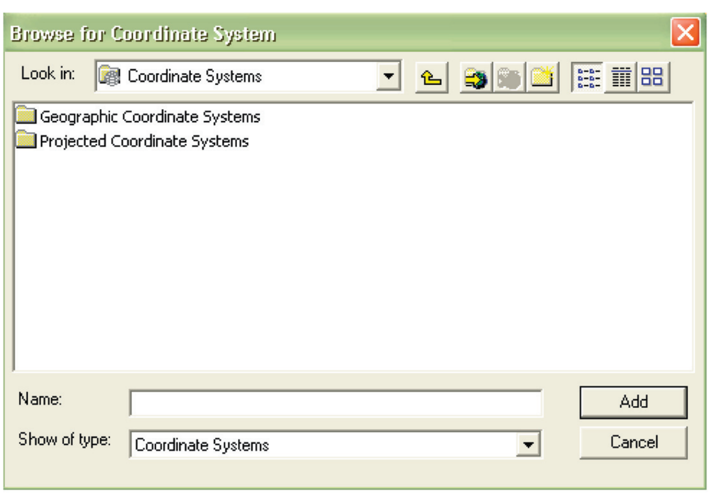


Figure 22. *The Browse for Coordinate System window.*

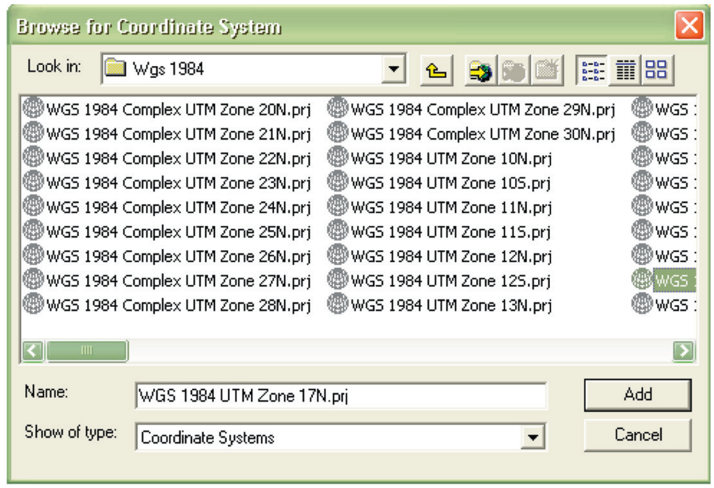


Figure 23. *Defining the correct projection layer.*

this point will be described as they are performed in *ArcMap* v.9.X. While the cave survey map is capable of being viewed using GIS directly after export by opening *ArcMap* and adding the layer, the map will not display at the correct coordinates unless the projection layer is defined. To define

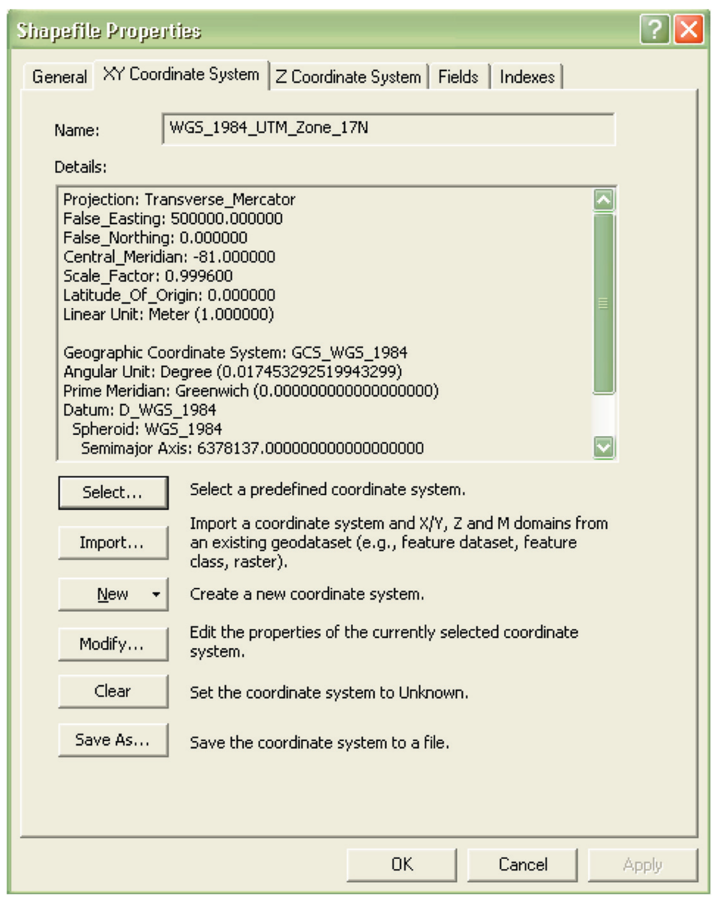


Figure 24. *The projection layer has been defined for the cave map shapefile layer.*

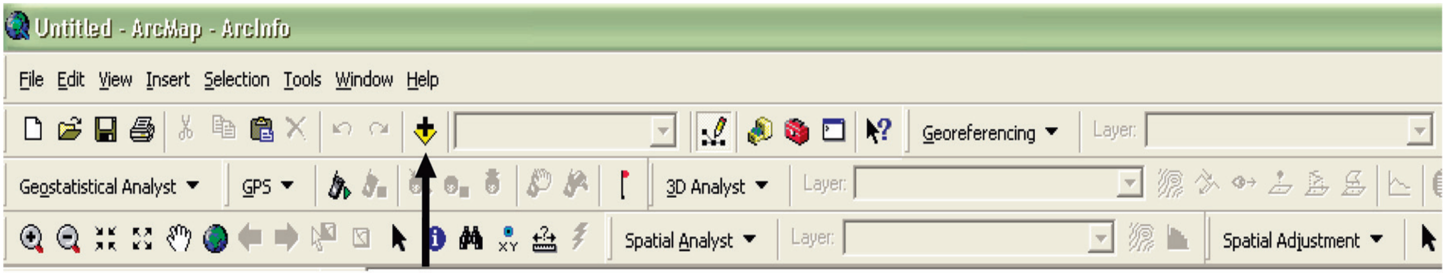


Figure 25. *Adding the map layer; the Add Data button is indicated by an arrow.*

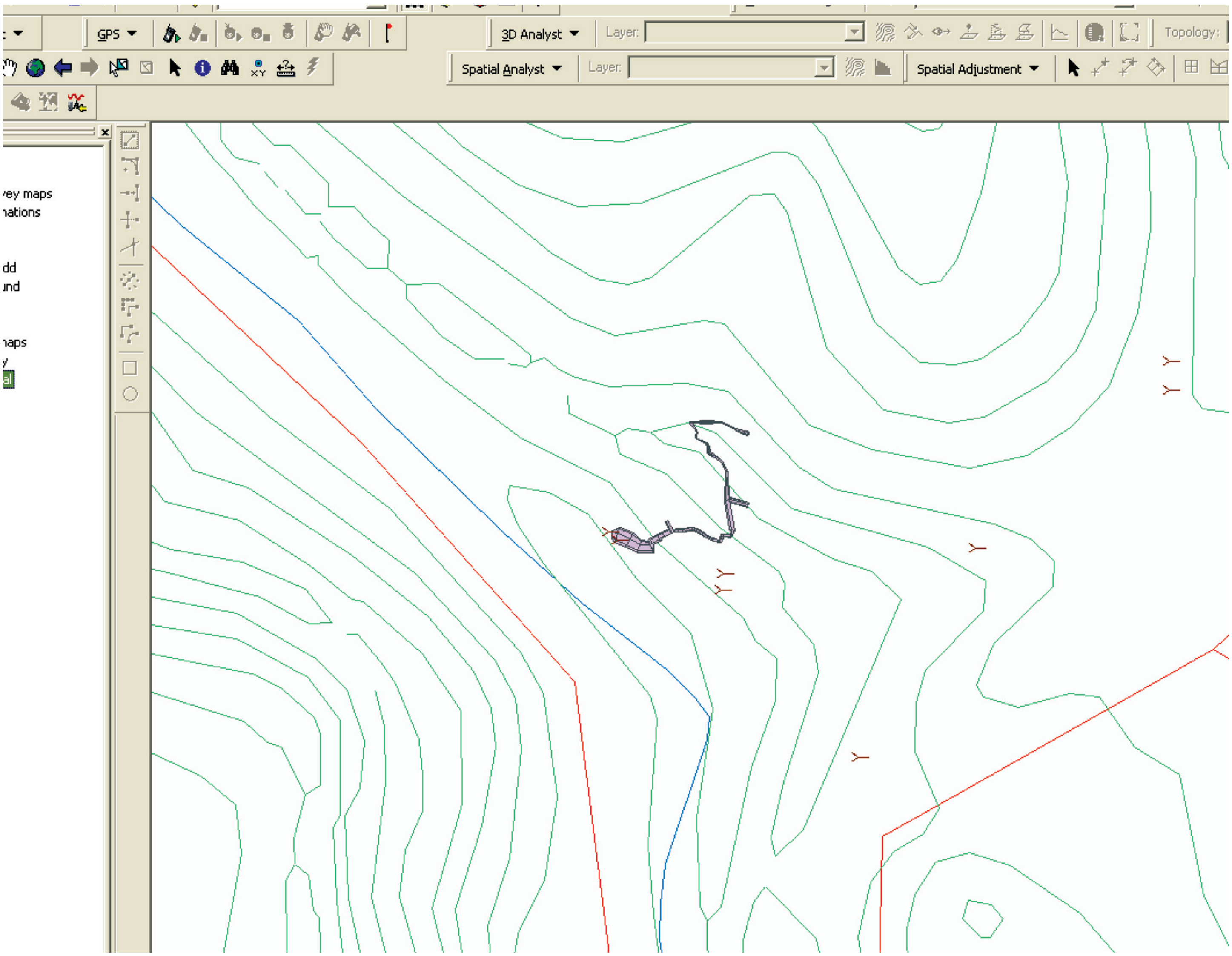


Figure 26. *A simple GIS map including a cave survey, cave entrance locations, streams, roads, and contour lines.*

the projection layer, open the *ArcMap* window and then the *ArcCatalog* window (Figure 19).

When *ArcCatalog* opens, find the cave map shapefile that was just created. Right click on this file, then on the 'Properties' button to open the Properties window (Figures 20, 21)

The projection layer is defined in the Shapefile Properties window by pressing the 'Select' button to bring up the Browse for Coordinate System window (Figure 22). Use this window to locate the proper UTM zone and projection system. If the UTM zone is unknown, open the Geocalculator window again and check which zone has been automatically selected; the calculated zone will be the zone that must be used for the projection layer. Again, when selecting the projection layer it is vital to use the **correct datum**, which must be the same datum used in the GPS device.

Once the correct projection layer has been located, pressing the 'Add' button will define this as the projection layer for the cave map shapefile layer (Figure 23, 24). In the Shapefile Properties window, pressing 'OK' will close the window and save the changes to the layer. Once this step is completed, ArcCatalog will no longer be needed and can be closed.

With the projection layer defined, the cave map will be displayed at the proper coordinates when added to a GIS map. To add the layer to the map, press the 'Add Data' button and select the desired layer (Figure 25). This will add the cave map as the top layer in the GIS project. Once the cave survey map has been added as a layer it can be manipulated in the same fashion as any other shapefile layer. Figure 26 is an example of the completed process, with a cave displayed in a simple GIS map; roads (red), streams (light blue), contours (green), caves, and a cave survey map are displayed. This example is from an ongoing project by the Wittenberg University Speleological Society in cooperation with Carter Caves State Resort Park, Carter County, Kentucky to inventory and survey caves within the park.

Acknowledgments

I thank Erin Hazelton (Ohio Department of Natural Resources) for her assistance with *Compass*, Horton H. Hobbs III (Wittenberg University) for his guidance and support, and Timothy Lewis (Wittenberg University) and Philip Huber (United States Forest Service) for introducing me to GIS.

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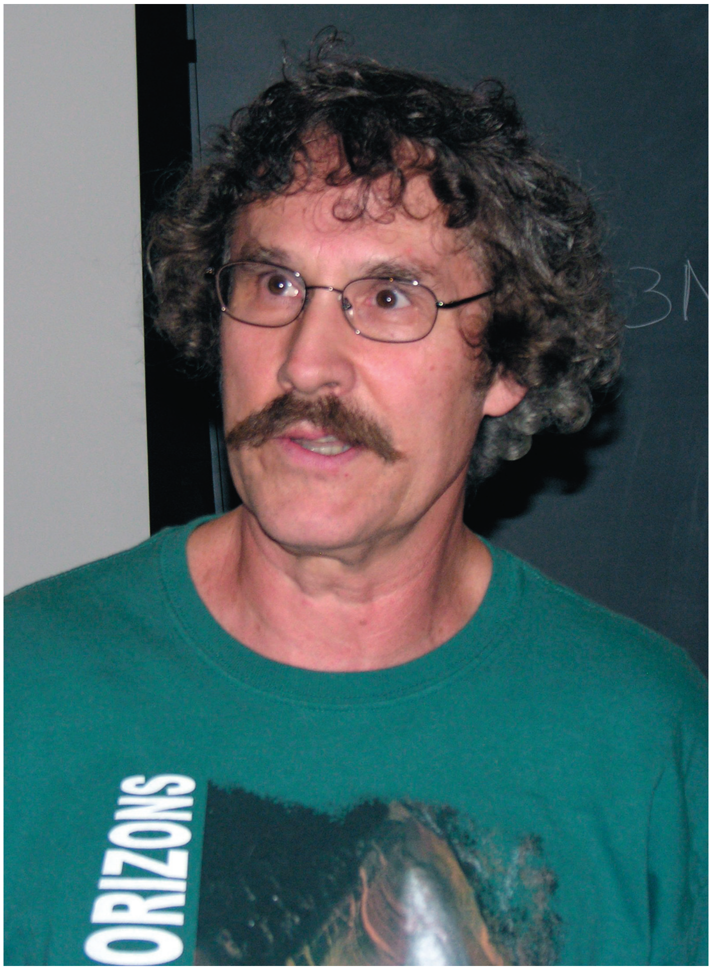

Dick Maxey and Ron Fulcher are two of the speakers who came to share caving stories and survey information with us.

MISCELLANEOUS

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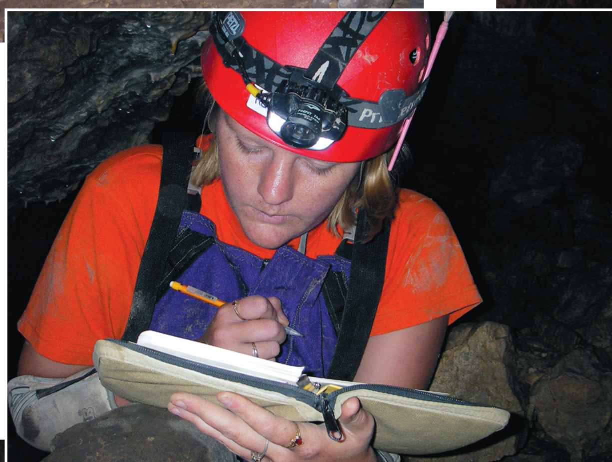

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