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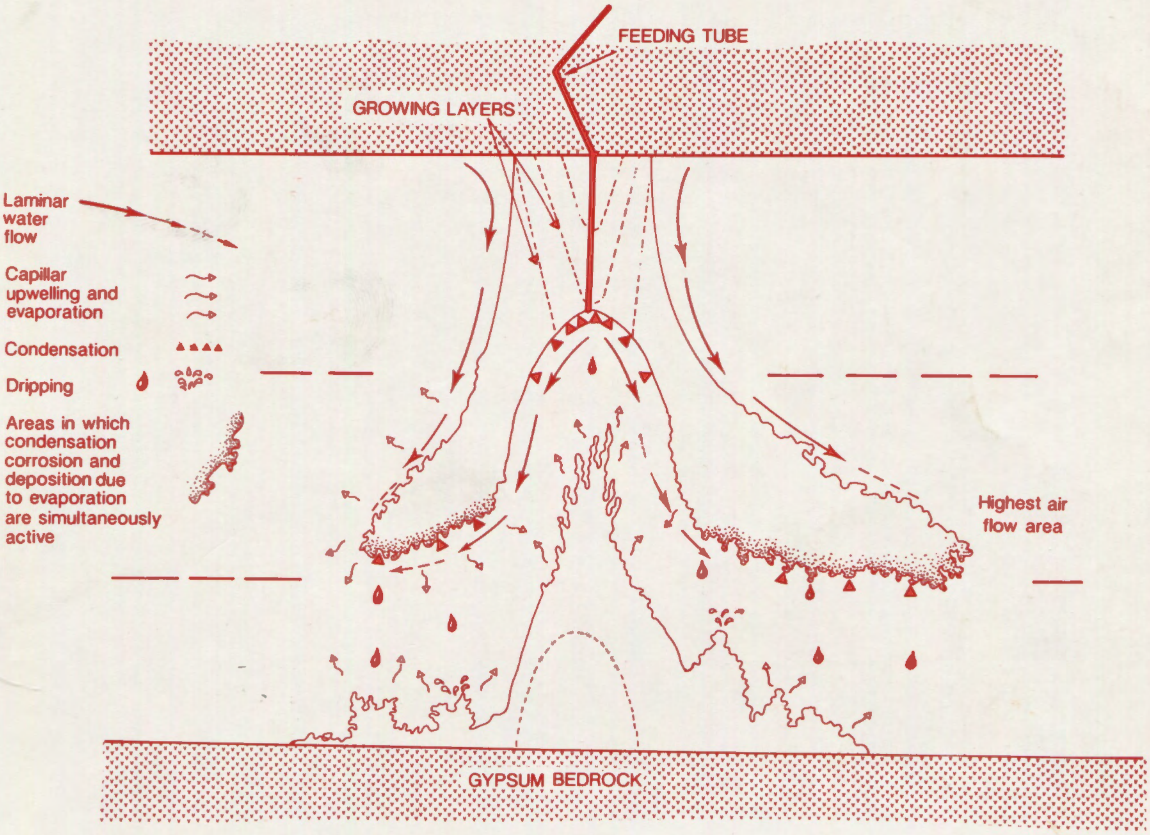

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Reinbacher, W. Rudolph—Is It Gnome, Is It Berg, Is It Mont, Is It Mond?: *NSS Bulletin*, **56**: 1-13.

IS IT GNOME, IS IT BERG, IS IT MONT, IS IT MOND? AN UPDATED VIEW OF THE ORIGIN AND ETYMOLOGY OF MOONMILK

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An analysis of the origins of words used to describe the white speleothem known as Mondmilch (moonmilk) produced etymologic incompatibilities, misconceptions in translations, and hypotheses. These led to terms based on the perceived consistency (flour or meal, paste, chalk, rock), on ancient medical uses, on peddlers names (Milk of the Holy Mary), and on belief in gnomes and alchemy. Terms relating to the moon are the oldest and most appropriate, born out of medieval literature and the influences of alchemy. The first printing of the word "Mon-Milch" was in a treatise by Gesner (1555). Montmilch, which was used between 1863 and 1975 is a now discarded spelling of Mondmilch (itself pronounced Montmilch). Montmilch is not a hybrid translation into French. The German term "Bergmilch" (hardly used since 1975) is correct only if the appropriate meaning of the word "Berg" as a mining term is applied. It became confusing in other languages when authors translated the inappropriate meaning, namely that of mountain. An etymology based on gnomes (little earth men) lacks continuity and has no basis for old, wizened, evil spirits. Mondmilch, in its dialectic variations in a fragmented Europe without unified languages, is a correct term based on the ancient connection between the moon and silver in the form of a white sublimation, and it is backed by an unbroken etymology. While nothing prohibits the use of personally favored words, reference should be made to Mondmilch (moonmilk) to clarify the international meaning in any language.

INTRODUCTION

Research into and discussion about the terminology of a soft white deposit occurring in limestone caves has often been published. In most continental European countries this speleothem has been called Mondmilch. In the English language and its colonial derivatives (such as in North America and in Australia) the overwhelming choice is moonmilk[1].

A few authors still prefer the names "Bergmilch" (Berg = mountain in German), "Montmilch" (Mont = mountain in French). One author (H. Fischer) maintains it is gnomes' milk. Personal preference seems to have a lot to do with it, because none of these terms including moonmilk can be considered scientific: They came into use as much from alchemy and astrology as from local custom and belief.

Ancient terminology was often based on the appearance or use of the white deposit. Everybody agrees on what the substance is and on where it is found: in caves (lac lunae subterraneum). The basic substance, when dispersed in water, has the consistency and color of milk. There was once strong opinion that the moon had nothing to do with it. But the moon has been associated with silver and its "calcinations, sublimations, condensations and albifications" (Burland, 1967) since the Egyptian god Djhowrey, whom the Greeks called "Thoth the thrice great," (romanized to "Hermes Trismegistrus"), bestowed on his followers powerful but obscure ("hermetically sealed") magic books about 1,000 B.C.

References in the literature spread over two millenia[2], in dozens of publications and many countries. Exceptional work on the entire subject was done by Bernasconi (1959), Heller (1966) and Fischer (1988, 1989). An excellent summary is found in Shaw (1992).

MINERALOGY (BRIEFLY) REVISITED

The moonmilk in caves is generally a secondary mineral deposit of calcium carbonate dissolved from surrounding limestone by dripping or percolating water. Carbon dioxide carried in the water is released as the water encounters cave air. The depositing fluid can build up on stalactites and stalagmites, build cave curtains and walls and floors. As moonmilk thickens due to loss of water, either inside or when taken out of the cave, it takes on successive consistencies of paste (milk marl), plasticity (creta, chalk), rock-like hardness (lapis galactis), or dry powder (flour or meal, farina fossilis).

Prehistoric people carved ritual pictographs on cave walls. Cave bear hunters left their footprints and stone-age tools in limestone caves. Humans at all times found medicinal properties in these white deposits, which is why caves were destroyed by indiscriminate harvesting or mining, much to the regret of anthropologists and climatologists and rock-art specialists. Even today ardent cave explorers can often destroy cave-sediment evidence by careless visits.

HISTORY AND USES OF MOONMILK

About the first century AD, brilliant men such as Pedacius Dioscorides, Pliny the Elder, and Galen of Pergamon, wrote treatises on medicine, nature, botany, mineralogy, and pharmacology, and included myths, demonology, and alchemy, which remained accepted science until well after Europe awoke from a long period of intellectual slumber.

With the advent of the Renaissance, a veritable profusion of eager scientists produced new discoveries and revised Neo-Platonic theories, but also gave rebirth to superstition and renaissance to fables (Borstin, 1985). Their manuscripts were readily printed after Johann Gensfleisch (also called: zum Gutenberg) invented interchangeable type. Many copied from many others, including mistakes and dubious translations, and added mistakes of their own. With humanistic naturalism, astrology supplanted demonology and created a favorable environment for occultism: One needed to learn the occult powers of herbs, stones, and minerals (Bréhier, 1965). Alchemists in the 13th and 14th century listed the materials they needed[3]. Genesis of metals was associated with solar system bodies then known, even precious stones with the fixed stars. Be it rays or pressure from the moonlight or other cause, moon and silver were intertwined when scientists had no ready explanation for the cause or replenishment of metals on the earth—it was commonly assumed that metals replenish themselves, that the moon kept producing silver (Agricola, 1556; Halleux, 1974).

In his Canterbury Tales, Geoffrey Caucer (1342-1400) put these words into the mouth of the Canon's Yeoman, who was an ardent, true student of alchemy, whereas his boss, the Canon, was more of a shabby friend:

> "The first spirit quycksilver called is: The second orpiment, the thriddle I wis Sal armoniac, and the ferth bremstoon[4]. The bodies seven, eek, lo heer anon: Sol gold is, and luna silver we declare; Mars yron, Mercurie is quycksilver; Santurnus leed and Jubiter is tyn, And Venus coper, by my fathers kyn."

Aristotle has been cited for "exhalations from the earth" that were wet steam and dry smoke and had nothing to do with the rays of celestial bodies until Avicenna (980-1037) put them under astral influence. Fortunately the old philosophers are not needed for this analysis, even though their superstitions long haunted science: Narwhale tusks (in the guise of unicorn horns) sold as medicine at 20 times their weight in gold "to protect from the arrow that flies by day and pestilence that walks in darkness, from the craft of poisons, from epilepsy and ills of the flesh" (Lopez, 1986).

By the time of Albertus Magnus (1200-1280), three substances (salt<of ammonia>, sulphur and quicksilver, the descendants of earth, water, air and fire) were believed to turn into the seven metals by influence of the respective planets, When bismuth was discovered, an astral orphan, it was added to Jupiter's tin burden as the most likely relative, since tin was also called "white lead" and bismuth "grey or ashen lead" (Halleux, 1974).

In any event, the age of Martin Luther, John Calvin, Leonardo da Vinci, and Christopher Columbus arrived. Learned men added -ius to their names and wrote in appallingly bad personal versions of Latin, but still better than the multitude of parochial dialects and idioms then prevailing. George Bauer became Georgius Agricola who refuted the ancient philosophers as well as the 10th and 13th century alchemists (Agricola 1546, 1558) with an explanation that metals are congealed juices of the earth.

A Swiss professor of Greek at age 21, later on also a physician, compiler of dictionaries and encyclopedias, naturalist, mineralogist, zoologist, botanist, and pharmacologist was Konrad Gesner (1516-1565)[5]. In 1555 he made the first written reference to moonmilk as "Moon-Milch," later printed "Mon-Milch," and "lac lunae," and he compared it to a long popular medication, the ground powder of a fungus called Lärchenschwamm[6].

Moonmilk was used in veterinary and human medicine. It was a cattle-feed additive and cure for poorly lactating cows, also "Ammenmilch" for the same purpose in humans (wet-nurse milk). It was the first antacid and cure for ulcers, it was used to induce a sweat, to treat broken bones (Shaw citing Hertodt v. Todtenfeld, 1669), to bewitch loved ones, as a cosmetic for face and hands (Shaw citing Binder, 1963b), as a remedy for diarrhea or dysentery (Shaw citing Baier, 1708), and as a dressing to dry bleeding wounds. It apparently also made a good cleanser for dishes and flatware, it worked even as mineral axle grease (Axungia; Major, 1667). If a person required it as a remedy, moonmilk was believed to be much more efficacious if the patient's name was shouted in the cave where the moonmilk was mined (Sidler, 1939/40). Usually moonmilk was taken mixed with wine or honey (a theriac or electuary) or as eclegme (a medicine to be licked off in a spoon).

Not much later, several probably promotional or peddlers' names were in use: Milk of the Holy Mary, Mary's Milk, Lac Lunae Bethlehemiticum[7], Himmelsmilch and Himmelsmehl (heavenly milk and heavenly flour). Votive figures carved of solid moonmilk were sold to thousands of the devout on pilgrimages to Austria's most revered shrine of the Holy Virgin[8]. They even had "latte della madonna," apparently for visitors from Italy. In England, at the Shrine of Walsingham (Norfolk), "lac virginis" was sold: Erasmus of Rotterdam reported in 1511 (cited by Girgson, 1957) that it tasted like chalk with egg added[9].

An appellation of "nothing, worthless" (Nichts, Nihil, Nihil album nativum) and the German dialect version "Nix" appeared by the 17th century, possibly so called because dry moonmilk was very light in weight. Almost certainly, it was not considered worthless, inasmuch as it was commercially mined by local peasants in Nix-Bergwerke[10]. Trimmel (1968) reports that the Germanic word "Galmey" (and variants) was used to describe moonmilk, whereas Galmey actually is calamine (G. W. Moore, pers. comm.), and the substituted substance was moonmilk instead of calamine for either zinc carbonate or zinc oxide ointments for eye infections. Heller (1966) doubted (correctly) that Galmey was moonmilk. Heller also recorded the word "pompholyx" and did not see it as a proper appellation for moonmilk; indeed pompholyx (from Greek pomphos) has a geologic meaning of "contaminated zinc or arsenic oxide." Both calamine, also called cadmia[11], and pompholyx were encrustations or effluents from early smelting ovens and usually consisted of a whitish substance, either zinc or arsenic oxide or a mixture of both. Moonmilk may well have been a pharmacological substitute for these ointment ingredients.

Half a millenium later it is reported (George W. Moore and Bro. G. Nicholas [Sullivan] 1964, 2d ed. 1978) that moonmilk occurrence is aided by bacterial breakdown of limestone. When mineral constituents of moonmilk are removed, organic residue remains, including bacteria such as *Macromonas bipunctata* and also actinomycetes, which have promise as an antibiotic substance. The ancients must have realized the healing qualities of moonmilk without knowing why. The Swiss pharmacist Sidler (1939/40) previously had sensed that it might be interesting to examine moonmilk for its organic substances and their suspected healing effects.

Some of the recorded terminology (and we are by no means assured that it always was the "real" moonmilk and not other deposits or sediments) had to do with the consistency of the substance: "Mar(c)k, Marga, Lithomarga" (marrow as in bone marrow), "medulla" (as in plant milk), usually followed by a descriptive "fossilis," "mineralis" or "petr(a)eus" (all meaning mineral). Other local terms were Swiss "Bergzieger" (cheese, like creamy cottage cheese), "Bergbutter," "Steinmehl" or "Bergmehl" as in rock or stone flour or meal, farina creta (See Table 2), but by far the oldest name referring to the *moon* was moonmilk. Other previous appellations referred to the relationship to the mushroom called agaricum, if indeed they referred to the speleothem under discussion and not to a different substance[12]. Many "earths" are mentioned in classic and medieval literature as medications which might have had moonmilk-like healing promises. One, terra sigillata, was dispensed during the Black Death in London as such or as Mithridate[13]. Agricola's "galactite" (Agricola, 1546), dispensed to poorly lactating women, may have been a solid version of moonmilk.

ETYMOLOGY

Milk

The term "Milch" (milk) is not an aberration and has never been questioned by the speleologic or geologic community in any language. Milk has been used to donate color, consistency, or both: Cows' milk, fish semen, botanical plant milk, milk of lime (calcium hydroxide), and we all know milk of magnesia before they made it pink. It has been used in "milk glass" as a fake substitute for translucent porcelain since the early 16th century in Florence and Venice. It is used in "milk quartz." Pretty girls in Germany have a face of "milk and blood," referring to rosy cheeks over a white teint[14]. The word "milk" has been used in many languages with the same meaning of color and consistency (e.g., Laguna de leche, Cuba).

Berg

The German word Berg (Latin: mons), when used by itself or with a proper-name prefix, means mountain, or at least something higher than a hill. It stems from berac, beirg, baurg, berc, closely related to the later Burg, a fortress on a high point, often used interchangeably with Berg. The other major meaning of Berg derives its origin from the verb "bergen": to protect, to hide, to salvage, to harvest, to exploit. Together with other nouns as suffix, Berg has developed two broad meanings: mountain and mine, but the meaning can only be discerned in context.

In old German, a Bërgwërc was a place to do organized work, a mine. Georgius Agricola (1546) used Berckwerck. "Bergbau" (mining) is the sum total of all activities by which useful minerals are located in the earth's crust, mined, and brought to the surface.

Another meaning of Berg is a partial synonym for Erde (earth) and describes many mined substances: Bergöl–Erdöl (oil), Bergpech–Erdpech (asphalt), Bergwachs–Erdwachs (earth wax, talcum), Bergteer–Erdteer (tar). In miners' language, "Berg" always referred to a non-ore-bearing accumulation of rock. The meaning of Berg changes subtly: "Ich gehe *in den Berg*" means "I climb this mountain," "Ich gehe *unter Berg*" means "I go down into the mine" (See Table 3).

While there is no doubt that the Pilatus near Lucerne in Switzerland, whose slopes contain the type-locality cave for moonmilk, is a Berg in the sense of mountain, the term "Bergmilch" means "mined milk." The Mondmilchloch (Loch: hole, cave) in the Pilatus was one of the first caves commercially mined for moonmilk which was exported throughout Europe. Heller cites Scheuchzer (1708)[15]: ". . . so that our Switzerland can be proud, and especially our Canton of Luzern, of having been the originator of this name [i.e. Mondmilch] now so common in usage in all of Europe."

The use of "Bergmilch" appeared first about 1863. By 1900 it became the choice for moonmilk in Germany and Austria. The major lexica "Brockhaus" and "Meyer" just before 1900 show "Bergmilch" (and a reference Mondmilch or Montmilch); just after 1900 the reference to Mondmilch was dropped. Lais (1941) used Bergmilch (and referenced Mondmilch and Montmilch), Trimmel (1965 and 1968) used Bergmilch, but explained the other terms[16]. Now, however, in scientific literature "Bergmilch" has disappeared, whereas "Mondmilch" has grown to an international standard. Contrary to Fischer (1988) who decries the use of Bergmilch, I do not find Bergmilch etymologically inappropriate, but indeed it is outdated by about 25 years of later science.

Mont

The only claim to fame for Montmilch is that it is a translation of Bergmilch. At a superficial first glance it seems plausible. Kyrle in1923 (cited by Heller, 1966) flatly said that the moon has nothing to do with the sediment, so it must be Montmilch meaning Bergmilch. This is a double fallacy, because the moon does have something to do with moonmilk, and linguistically the move in either direction from Berg to Mont or from Mont to Berg is not available for three compelling reasons:

1. The French word "mont" (meaning mountain) does not exist in conjunction with anything but a name. Wherever there is a Mont+, such as Montmartre, Montpélier, Montluçon, it is exclusively the name of a department (district) of France, of a region, of a noble estate, of a city or part of a city, whether there is a mountain or hill near it or not.

2. The French word "mont" plus the name of a mountain is always separated by a space or by a hyphen: Mont Blanc, Mont-Blanc[17]. Even if there were a word like Montmilch, it reverses the meaning into milk mountain instead of mountain milk. Not a single German expression Berg+noun is Mont+noun in French: Bergakademie–école des mines (school of mining), Bergarbeit–travail des mineurs (miners' work), Bergbahn–chemin de fer de montagne (mountain railroad), Bergkegel–cône d'une montagne (cone of a mountain).

3. The Mondmilchloch in the Pilatus is in the Swiss-German speaking part of Switzerland[18]. They use "Berg," not Mont: Pilatus-Berg, Rigi-Berg, Rütliberg. They also use terms like Bergzieger and Bergzuhr and Bergbutter for variants of Mondmilch, without any attempt at calling it Montzieger or Montzuhr or Montbutter. Bergmehl (flour, meal) was never made into Montmehl.

Neither the Swiss German population nor Germans nor Austrians had any reason whatsoever to translate Berg into Mont. Common sense would raise an eyebrow anyhow at mining a substance called Montmilch from a Mondmilchloch on the Pilatusberg.

In Latin, mountain is "mons, montis." It has been used as "lac montis" (Bruckmann, 1728), but mons, montis has never been used with the German word Milch (milk). Gesner (1555) used the medieval Latin name for the Pilatus-Berg, mons fractus, germanized to "Frakmont" (the rugged mountain). Investigated as a possible source of "Montmilch," it seems certain that Montmilch was not written until 1863, well into the fourth (modern) Germanic language period which began about 1650 AD.[19]

The Latin word "montanus" means "of or belonging to a mountain." In German it is "montan" and in English "montane." The German word strictly refers to ore- and coal-mining enterprises. The English word refers to a subalpine surface environment (usually forest). French does not have an adjective montane or montaine, only the noun montagne or the adjective de montagne. Southern Austria uses some Montan+noun words (Montanstrasse = alpine road), but no Mont- prefixes. Mont and Mond are the same German word, meaning moon, but nowadays uniformly and correctly spelled Mond, pronounced Mont.

Gnome

Gnomes, dwarfish spirits seen or imagined as old men the size of a 2-year-old boy, have been part of mythology since the Icelandic Elder Edda, the Völsund saga, and the Nibelungenlied. They were, aside from forest and hidden-valley fairies, usually inhabitants of mountains and mines. They were said to live in gem-filled halls and to forge magic swords. They were heard by miners in lower levels of mines. If observed too closely by miners, or if miners withheld gifts of food, the spirits would cause mine fires, break tools, or pull down the roof of a mine.

Mythology divided gnomes into good house ghosts, helpers doing work overnight, and into the more malevolent kind. There were Heinzelmännchen (little work men), Männchen, Männlein, Mandl, Mannli and Mandli (all meaning little men), Erdmännchen or Erdmännli (little earth men). Agricola (1556), who had abandoned reliance on classic "dry and wet vapors" as origin of metals, still believed in mine spirits in his de re metallica: "In some of our mines, however, though in very few, there are pernicious pests. These are demons of ferocious aspect about which I have spoken in my book de animantibus subterraneis: Demons of this kind are expelled and put to flight by prayer and fasting." Agricola gave them Latin names, *daemon subterraneus truculentus* (the bad ones, called mine devils), and *daemon subterraneus mitis* (the benevolent ones, called Gutli, the good ones), also cobelt = Kobold = gnome, Trulli = trolls in northern European areas. None of these are associated with a specified mined substance.

In modern times, Fischer (1988, 1989) became a proponent for an explanation of the term Mondmilch via gnomes living in his Swiss mountains. Fischer proposes that Mandli turned into Mond, but he does so by an unexplained etymological skip and mixing of dialect regions as well as different cave locations. Mandlimilch or Mannlimilch was sold in the 20th century in towns near Lucerne (Sidler, 1939/40). The word "Mandli-Milch" never appeared in earlier literature; Sidler was the first to research the subject[20]. For instance, he said that in the Entlebuch district "Mamilch" and "Mannmilch" were used, but the milk came from a different cave (probably either the Baumgartenfluh or the Enziloch) and while certainly calcitic, was yellowish-grey instead of white (Bergbutter?). The Obwald dialect used Maanmilch. There are many caves (often kept secret by the people) in the local mountains where the inhabitants gathered a moonmilk-like substance by one of the many Swiss terms for a variety of different calcitic deposits from caves (Sidler, 1939/40).

Gnomes were believed to be involved in many activities in many localities. One superstition is that some local dairy farmers, every evening, gave the gnomes in their area an "English salute" with their milk funnels to keep the little men from hexing or stealing their animals (which would be returned emaciated and milked dry). In other valleys, peasants believed that the gnomes were guardians of wild game, that they helped the people find medicinal herbs, and the people would reward them with wild-berry pies. The legends are legion.

Getting moonmilk from a cave required the people's own efforts, a two-man, two-day effort and adherence to many special observances such as the phase of the moon, the time of day. It was said that the moon deposited moonmilk in a cave only during the three days of the full moon. Gesner (1555) correctly interpreted the relationship of moon and moonmilk. The moon replenished the moonmilk, not the little earth men.

While little earth men were spirits which could move through the earth the way nymphs moved through water, birds (and humans) through the air, and salamanders through fire (Blaser, 1960), wherever they were[21], they were little men denoted by the German diminutive -chen or -lein or the Swiss-German -li (approximately like an English -let as in droplet). To people anywhere, the little men, earth men or little mountain men were real. Women secretly sought them out for help with ailments; men thought they were being punished by the little earth men for sinful living[22].

But wherever you found these earth spirits, they were always little men, child size, but gnarled, wizened *old men*, called Zwerg (dwarf), nano in Italian, and nain in French (even though nano and nain derive from the Latin nanus meaning *young* little beings as compared to the Latin word pumilio for old or adult dwarf-like men). The German diminutives Männchen, Männlein, Mannli, likewise, denote dwarf-size adults. To get to Mond, Fischer had to drop the diminutive, and the little earth men were suddenly full grown male humans. Most of Fischer's etymology is the same as the for "Mond" (See Table 4). The names given in his 1989 paper (notably Mamilch, Mahmilch, Maamilch, Maanmilch) are not found in literature and do not fit the etymology of "man," diminutive or full size.

Bernasconi (1959), writing in Italian, noted that Gesner (1555) translated "Mon-Milch" as "latte di luna" instead of "latte dell'uomo." Uomo is man in Italian, nano is little man. What is important is that in the case of all gnomes (from leprechauns to Mandli) the diminutive is *not an endearment* (my little man, little friend of all the world [as used by Rudyard Kipling for Kim]), but a distinctive nomenclature for good or evil beings never physically of a grown-man's stature anywhere in mythology. Moonmilk may have been one of the treasures guarded by little men, it may in a few isolated locations have been called "little men's milk" or "little moon's milk" (even Sidler does not distinguish between Ma*nn*li and Ma*nd*li—his 20th century spelling is a subjective phonetic assumption). There is no written record of gnomes' coal or gnomes' iron—few, if any, gnome legends deal with specific treasures of the earth, but with gnomes' good or evil deeds.

Unless a plausible link between Mannli/Mandli and Mond is presented, the theory of gnomes' milk is not complete. It is not rooted in Swiss natural history. Three noted Swiss scientists, Gesner and Lang from Zürich, and Scheuchzer from Luzern, as well as other prominent writers of the 17th through the 19th century, have not made the linguistic jump to dialectic gnomes and suggested Mannli/Mandli as alternative to Mond, until Sidler (1939, 1940) mentioned them, Lutz (1956) expanded on them, Bernasconi (1959) acknowledged them, and Fischer (1988 and 1989) advocated them. All these authors relied on medieval uncertain spellings and diverse reconstructed pronunciations. No modern writer has considered that what we hear today in the 20th century has only faint bearing on phonetics and linguistics of the 1350-1650 *early* modern language period. Using a *modern* period word, even one written in the 17th century, one cannot with certainty use it today as having been spoken the same way in the 15th-16th century, particularly not in isolated mountain valleys.

Of concern is that Fischer (1988) and Fischer (1989), when read side-by-side, contain contradictory statements about sources and arguments. In any case, to void or reinstate an obligatory true diminutive is not acceptable (at least not without permission from the Mandli living behind that heavy iron door at the far end of the Mondmilchloch).

Mond

The major argument against Mondmilch has been that it didn't have anything to do with the moon. Bernasconi (1959) and Shaw (1979) showed that it does, and beyond that, silver also has been associated with the moon in early American and European history. As early as the 10th and as late as well into the 17th century, chemists (who still were alchemists) believed that metals came from the planets. Silver came from the moon and thus also its sublimate derivative moonmilk (Latte d'argento—milk of silver). The whiteness of moonmilk was probably the link, because silver is usually found in association with the commonly dull lead.

Belief in the metallic nature of moonmilk was aided by J. D. Major (1667): Citing Guy de la Brosse (1585-1641) he quotes in his Dissertatio Medica de Lacte Lunae: "the rays of the sun caused fire; and the rays of the moon, resembling a translucent sponge, clearly produced a lifeless milky substance."[23]

Paracelsus (1493-1541) had miners suffering from metallic vapors (Blaser, 1960). Alchemy, aside from hoping to provide an elixir for immortality to Chinese Emperors (until too many died prematurely) and making gold (as late as Adolf Hitler), was a search for the philosophers stone with which to make noble metals and find new mineral medications (Agricola, 1546). Gesner must be judged to have been aware of the long prevailing view of metals' origin from the planets—the hallmark of Renaissance scientists/humanists was the esteemed manysidedness of their knowledge.

The silvery moon has been in the milch picture for a long time. It remains with us as a mainstay of romantic poetry.

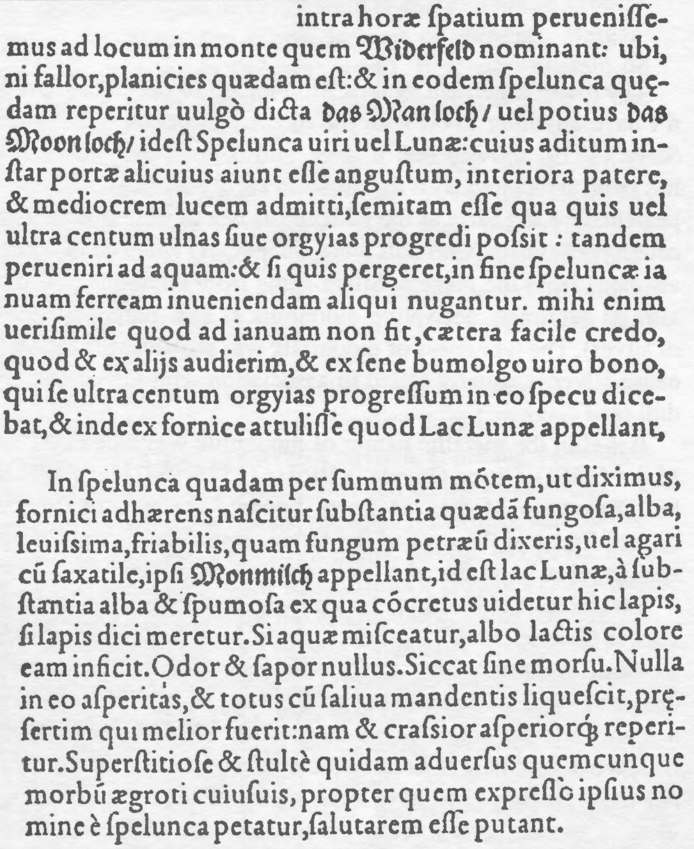
The only etymology which has no gaps is that for "Mond": Me, (from measure, monthly), mêna, mani, môna, the root is ma; 14th century, mône, mon, and mô. There also existed partially the weak declination Mond and the strong declination Mont (Schottel, 1365). "Mon" was used for moon by Martin Luther[24], "mons" in the 17th century (See Table 4). Grimm (1873) cites a Swiss use "Lueg, Müetterli, was isch im mô?" (Look, little mother, what's with the moon? Or figuratively, "what bodes the moon?"), where mô probably was a nasal sound between ô and â.

A firm German grammatical rule requires that words which end in b, d, g, are pronounced as if they were written p, t, k. Montmilch/Mondmilch are mere orthographic variations of the same word. In the middle ages, there was hardly a difference between d, t, dt, and th, except that dt hardened a d, and th softened a t. Learned men listening to local people would try to write what they thought they heard. But there is no reason to go back to old forms since the advent of uniform German spelling at the beginning of the 20th century. Mondmilch (moonmilk) has found its place in international speleologic and geologic (hopefully also: rockart) science. There is currently no attractive or compelling reason to change, unless it were to a modern non-mythological speleologic term.

In defense of Gesner

Besides being a scientist and naturalist, Gesner was a prodigious linguist and writer. He is said to have had a feeling for folklore, he identified 130 languages, published over 1000 botanical woodcuts, wrote a bibliography of all past writings in Greek, Latin, Hebrew, French and German[25]. He was also not only a mountaineer (Boorstin, 1985), but was considered one of the greatest of early mountaineers (Thorington, 1937).

Still, some publications held that Gesner did not know what "little earth men" are, and mistakenly translated gnomes' milk as "lac lunae" (moonmilk). Not only does Gesner's original Latin text clearly dispel that (See Fig. 1), in his earlier letter to his friend Chrysostome Huber (Thorington, 1937) Gesner included his first impressions of the Pilatus mountain he had climbed with, among others, a pharmacist from Lucerne[26]. Gesner had no need to rely on someone speaking to him in a strange dialect; he does not mention gnomes and laughed at a cowherder's joking reference to an iron door at the end of the moonmilk cave. Gesner, in this first description of the Mons Fractus, calls the cave Man-Loch, or Moon-Loch and the substance Moon-Milch (which differs from the Mon-Milch spelling in his later publication).



intra horæ ſpatium perueniſſemus ad locum in monte quem Widerfeld nominant: ubi, ni fallor, planicies quædam eſt: & in eodem ſpelunca quędam reperitur uulgò dicta das Man loch / uel potius das Moon loch / ideſt Spelunca uiri uel Lunæ: cuius aditum inſtar portæ alicuius aiunt eſſè anguſtum, interiora patere, & mediocrem lucem admitti, ſemitam eſſe qua quis uel ultra centum ulnas ſiue orgyias progredi poſsit : tandem perueniri ad aquam: & ſi quis pergeret, in fine ſpeluncæ ianuam ferream inueniendam aliqui nugantur. mihi enim ueriſimile quod ad ianuam non fit, cætera facile credo, quod & ex alijs audierim, & ex ſene bumolgo uiro bono, qui ſe ultra centum orgyias progreſſum in eo ſpecu dicebat, & inde ex fornice attuliſſè quod Lac Lunæ appellant,

In ſpelunca quadam per ſummum mõtem, ut diximus, fornici adhærens naſcitur ſubſtantia quædã fungoſa, alba, leuiſsima, friabilis, quam fungum petræũ dixeris, uel agaricũ ſaxatile, ipſi Monmilch appellant, id eſt lac Lunæ, à ſubſtantia alba & ſpumoſa ex qua cõcretus uidetur hic lapis, ſi lapis dici meretur. Si aquæ miſceatur, albo lactis colore eam inficit. Odor & ſapor nullus. Siccat ſine morſu. Nulla in eo aſperitas, & totus cũ ſaliua mandentis liqueſcit, pręſertim qui melior fuerit: nam & craſsior aſperiorq́; reperitur. Superſtitioſe & ſtultè quidam aduerſus quemcunque morbũ ægroti cuiuſuis, propter quem expreſſò ipſius nomine è ſpelunca petatur, ſalutarem eſſe putant.

to the area of the mountain called **Widerfeld**, where a sort of a cliff is and in it this cave which is commonly called **das Manloch** / or preferably **das Moonloch** / it is the cave of the man or of the moon, to which the approach or portal is somewhat narrow, wide in the interior with low light, then there is a narrow way of about 100 ells into which one can advance; finally one reaches water; and if one continues to the end of the cave, one comes upon an iron door; to me it is just that the door does not exist, but others believe readily what they hear from others and what the old bumbling good fellow says who had gone the 100 ells in this cave, and brought from the ceiling what we call moonmilk,

In this cave almost at the top of the mountain, we are told, a substance grows adhering to the domed ceiling, which is porous, white, light in weight, friable, like a stone fungus, it is said, or rock agaricus, which they call **Monmilch**; it is moonmilk, a white and foamy substance which can solidify to stone, if one can call it stone. When mixed with water, it takes on a white milky color. It has no smell or taste. It dries without grittiness. Nothing of it is rough, and it is liquified by chewing it with saliva, if it is a better kind; it also exists denser and rougher. The superstitious and ignorant, after we pressed for that and the name of the cave, believe it can improve health against any of their grave illnesses.

Figure 1. Photocopy left and translation right of the naming of moonmilk by Conradus Gesnerus, the latinized name of Konrad Gesner (1555). The upper excerpt is from p. 54 and the lower from p. 66.

The people in the mountains said "Mon-Milch" (not Mandlimilch) and he correctly translated it. It is presumptuous to say that Gesner (living close by) had not heard of little earth men and what they were called, nor that two prominent colleagues hadn't either. Gesner is said to have his information about the Mondmilchloch, from an Obwald dialect speaking person, not a local, but Obwald dialect is "Maanmilch" (Lutz, 1956), not Mannmilch. Initially Gesner weighed, in writing, whether the cave was called the Mannloch/Manloch (man hole, Latin: Spelunca viris) but thought it more likely that it was Monloch/Moonloch (moon hole, Latin: Spelunca lunae). The milk he then called "Mon-Milch/Moon-Milch," (not Mond-, Mannli-, or Mandlimilch, see also Heller, 1966). In his Latin writing, Gesner refers to spelunca viris, not spelunca nani (little men's cave). In his first report to Huber, Gesner said that he came within an hour of the Mondmilchloch, but was forced to retreat due to bad weather, yet while doing so, discovered an easy way to reach the cave.

His later Descriptio montis fracti does not specifically say that he visited the Mondmilchloch. Jans (1983) flatly says Gesner never visited the cave and just wrote what he heard from the populace. H. Fischer (1987) says that Gesner did. But Gesner's elaborations imply that he saw cave features without which he could not have made the comparison to a fungus which is not in his letter to Huber. The description of sediment features makes it more likely that he did visit the Mondmilchloch than that he didn't. In any case we do know (Thorington, 1937) that Gesner needed not rely on unfamiliar dialects. He had the pharmacists of Lucerne as local experts.

Gesner's description of the Mons Fractus (companion publication to his "de admirandis et raris herbis," 1555) indicates an addition of facts which could not solely have been based on a valley farmer's ancient dialect.

Gesner has been reported as saying that moonmilk grows on rocks by his other terms "agaricum saxatile" and "fungus petr(a)eus." Despite 16th and 17th century common belief in "spontaneous generation," as physician, botanist, and pharmacologist Gesner can be presumed to have known the "true" agaricum and that it never grows on soil or rocks, that it is only wood-inhabiting. Saxatile means "of, on, or growing on rock," but if growing was what he meant, he would have used the Latin "crescitur" instead of "nascitur." Gesner saw something looking like an agaricum mushroom on the domed ceiling of the Mondmilchloch, and since one can only compare something new to something one knows, he compared it to the spongy shelf fungus he knew. R. Bernasconi (pers. comm.) describes it as "looking like white mold on cheese," Trimmel (1965) describes "Polster und Würstchen" (pillows and little sausages, meaning shapes in the nature of a pad, a raised ridge, a roll)[27] of moonmilk on the walls of caves, remniscent of the mushroom shapes Gesner saw and recognized "so similar are they" (Fig. 1). So, too, Hill and Forti (1986) emphasize the pragmatic approach of classifying secondary mineral deposits based on the *shapes* people see. Figure 1 in Fischer (1989) could be a photograph of the fungus *Fomitopsis officinale*.

What Gesner tasted was dry (air dried?) moonmilk, because he describes how it was chewed with saliva. The chewing told him that it did not have the extremely bitter taste known for the true agaricum (even though he thought some of it tasted immature and raw, rough or tart).

Gesner included Dioscorides' "lithos morochtus" as moonmilk. Heller (1966) puts a question mark to that. In one translation of Dioscorides (Danzium, 1610) morochtus was described as soft, soluble white mass used to bleach linen cloth in Egypt, which comes pretty close to moonmilk but for mention of taste or smell (Gesner stated that moonmilk had no taste or odor, that it was insipid). Bernasconi (1959) suggests that lithos morochtus may have been magnesite; Gèze (1961) speaks of a magnesium carbonate enriched or even a hydromagnesite moonmilk. In any case, this would seem to fall under the definition of moonmilk according to the Glossary of Geology cited earlier.

CONCLUSIONS

1. There is no dispute that gnomes were believed to exist in Swiss-German speaking Switzerland. There is no convincing evidence, however, that the white speleothem was named after them and metamorphosed into Mond in a sense meaning man or men.

2. Bergmilch can be considered an acceptable term based on the meaning of Berg as mining or ore-less rock. It has virtually disappeared from use, possibly because of the difficulty of a unified translation, inasmuch as it does not mean mountain milk, but mined milk. Modern technical dictionaries in Germany use Mondmilch. French and Italian authors do also. Moonmilk is firmly ensconced in English use.

3. Montmilch conclusively is but an older spelling of Mondmilch, itself quite properly pronounced Montmilch, but not written that way anymore. The Berg-Mont or Mont-Berg translation is linguistically unacceptable.

4. Mondmilch is the term of longest use with a legendary explanation more ancient than suddenly man-size gnomes, and it has a solid history based on the belief of 16th century miners that their moonmilk was produced by the rays of the moon. Mondmilch is currently used as such in many languages and is translated as moonmilk into English and into other languages as such.

Scientists do not like to be told what to use, and I offer no sense of prohibition in these conclusions. After all, the scientific community ignored the exhortation by Trimmel (1965), the suggestion by Bernasconi (1981), and the command by Fischer (1988). But it would be extremely helpful to younger students, if authors feeling strangely attached to Bergmilch or Montmilch would at least once in a text give a reference to Mondmilch and moonmilk or both. Then again, maybe it is time to drop antiquity and legend and to start using a strictly geologic and easily translated term. "White plastic mass" (as suggested by

Bernasconi, 1981), though accurate, has not caught on. Possibly "cave milk" might be appropriate; "cave milk" has been used in several Eastern European languages—e.g., Slovene, Serbian, Croatian, and Macedonian. (T. Shaw, pers. comm.; Fischer, 1989). It would easily be translated, e.g., into Höhlenmilch, lait de caverne, leche de caverna.

Prehistoric people knew this whitish substance, probably also that it had medicinal value. At least they found it easy to carve. Possibly, they believed in elves and gnomes and dragons. Certainly they will have admired the pale silvery moon after a day spent in the milk mine.

ENDNOTES

[1] Moonmilk (moon'milk) (a) A soft white plastic calcareous deposit which occurs on the walls of limestone caves. It may consist of calcite, hydromagnesite, nesquehonite, huntite, aragonite, magnesite, or dolomite. Etymol: Swiss dialectic moonmilch, "elf's milk." Syn: *mountain milk; mondmilch; rock milk; rock meal; bergmilch; agaric mineral.* Partial syn: *lublinite.* (Glossary of Geology, 3d. Ed., Bates and Jackson, 1987.)

[2] A Chinese alchemist, Ko-Hung, 300 BC (cited by Shaw, 1992), made a statement about a stone mushroom in China which "in all probability was mondmilch." Bernasconi (1959) doesn't think it was moonmilk which was described; he cites Dioscorides (40 AD-90 AD) describing "lithos morochtus," yet without certainty of what it was: magnesite? Terra lemnia (cimolite)?, Terra samia (fine clay from the island of Samos)? Terra chia (talc from the island of Chio, now Khio)? According to one of seventy translations of Pedacius Dioscorides, it was a soft soluble substance from Egypt, used to bleach linen cloth (Danzium, 1610).

[3] Such as vessels of glass, urinals, decensories, crosslets, sublimatories, cucurbites, alembics, rubifying water.

[4] Orpiment: Auripigmentum, yellow (or King's) arsenic, disulfide of arsenic. Sal armoniac: Sal ammoniac, ammonium chloride, originally prepared from camel dung near the temple of Jupiter Ammon. Bremstone: Brimstone, sulphur.

[5] Gesner has variously been spelled Gessner or Geszner (with the old Gothic German letter for sz, a sharp s). It appears the name was spelled with one s mostly in English and French and the same spelling re-invaded the German language. Gesner himself used Gessner when writing in German, Gesner(us) when writing in Latin. I use the Gesner spelling throughout.

[6] Lärchenschwamm or Lerchenschwamm, oldest term: Agaricum. Later Dannenschwamm (pine bracket fungus), Latin then: *Polyporus officinale or Boletus larici,* now: *Fomitopsis officinalis.* Gesner and later authors called it agaricum saxatile, fossilis, or mineralis (stone fungus). Agaricum derives from Agariae, the Latin form for Sarmantia, a regional Central Asian association of tribal people.

[7] Nier(e)nberg(ius) (1635) places this in the cave which forms the crypt of the monastery at Bethlehem and called it "lac virginis" (milk of the Virgin). Cited by Shaw (1992).

[8] The Gnadenkirche (Church of Mercy) in Mariazell (Styria, Austria) possesses a 60 cm tall statue of the Virgin Mary, carved from limewood (Talia), a wood as pale as moonmilk.

[9] This is not to be confused with the 17th-18th century term of the same name, but meaning "maidens' milk," commonly prescribed by apothecaries, and made from alum (potassium aluminum sulfate) and lead acetate and rose water.

[10] Nix-Berg may also refer to a non-ore mine. To German miners, Berg was an accumulation of rocks not containing ore. A cautionary note: Nil, nihil, may also refer to encrustations or effluents from smelting ovens called nil agrisum, also called Galmei or Pompholyx, either zinc or arsenic oxide.

[11] Sir John Pettus (1617?-1670) refers to "cadmine oar (which some called Callamiae), of which brass is made with a mixture of copper" (cited by Aitchison, 1960).

[12] Agricola's steinomarga, (lithomarga), was found inside rocks, like marrow inside a bone. Dioscorides' morochtus probably was a fine clay (kaolin).

[13] King Mithridates IV, King of Pontus of Anatolia in the second century BC, tried to develop a universal antidote to poisons, but Mithridate or terra sigillata is a fine red clay, as is Armenian bol, a yellow to red clay from Armenia. It was taken as a "theriac," i.e., powder mixed with honey (Howard, 1987).

[14] Just as milk, "cream" is known as a color. People have always associated colors with something they knew well. Note the American usage of "appliance white," a color everyone in America understands and knows precisely what it is.

[15] Heller gives 1706-1708 as the date for Scheuchzer's work. Bernasconi's bibliography says 1752 (1718). Several editions exist.

[16] Nowhere is the double meaning of "Berg" made clearer than in eastern language translations of moonmilk: Russian gornoye moloko = mountain milk, kamennoye moloko = rock milk, Czech nickaminek = rockmilk, Yugoslav grosko mlijeko = mountain milk. Even French (lait de roche = rock milk and lait de montagne = mountain milk) and Italian latte di roccia = rockmilk and latte di montagne = mountain milk. (T. Shaw, pers. comm.)

[17] Similar to English usage of mount as in Mount Rushmore, Sermon on the Mount. There is one exception in French: "Les Monts" (without a name suffix) is a local name for the Alps in general; German uses the word "Gebirge" when a group of mountains or a mountain range is meant: Erzgebirge, the mountains near Saxony with one of the world's richest ore mines.

[18] The Mondmilchloch is at an altitude of about 1,800 m. It is accessible from the south from the Half-Canton of Nidwalden by an alpine route from Widderfelden via Birchboden. The cave entrance is narrow, leading in to a roomy hall followed by 117 m of straight cave passageway. Moonmilk deposits increase as one progresses into the middle part of the cave in a high passage 40 to 60 cm wide, and it consists of several harder and softer layers (Schär, 1895). Schär also describes a fairly heavy outflow of water, which Gesner (1555) did not report. Over almost 500 years, the condition of the cave and the moonmilk in the cave may have changed.

[19] The four major shifts in pronunciation and use of the German language and alemanic dialects occurred after the migrations (Völkerwanderungen) of 400+ AD. They are considered the pre-literary period (to c. AD 750), the middle period (c. 1050-1350), the early modern period (c. 1350-1650), and the modern period (c. 1650 to present).

[20] In the nineteen thirties there was a cosmetic called "Mandel-Milch" (almond milk) (Sidler, 1939/40; Wietschorek, 1937; Schneider, 1968). It was a mixture of almond oil (or any sweet or bitter amygdalaricum), gum arabic, sugar syrup and water, applied externally. Internal medicines for upset stomach were mixtures of almond oil and either morphine or calcitic water (which may have been made from dried moonmilk). Formulations varied all over Europe and the Near East. But as Sidler's young assistant found out, it was not "Mandli- or Mannli-milk."

[21] Actual sightings of "hordes" of spirits on top of the Rigi-Berg and dragons on the Pilatus-Berg were reported in 1566 and 1619 respectively (Bernasconi citing Cysat and Kirchner). The Swiss even had a scientific name for their dragon: *Draconus bipedes helvetiae.*

[22] Philippus Aureolus Theophrastus Bombast von Hohenheim, also called Paracelsus (1493-1541) is said to have taught local men that their miners' illnesses (probably silicosis or tuberculosis) came from breathing metal vapors in the mines; that it was not punishment by cave gnomes. Paracelsus created the word gnome; there is no etymology of the word prior to him, just speculation that it was a blunder of genomus (earth dweller) or an arbitrary invention. Syn: *Pygmaei.* The "metal vapor" theory is part of the alchemists' relation of planets to metals and to sediments created by vapors from the metals.

[23] Agricola (1546) noted the ambiguity of the word "metallum"; it meant a corporeal matter extracted from the sun as well as the mine from which they were extracted and the mineral extracted from the mine.

[24] We still use Monday (German: Montag), month (German: Monat).

[25] Bibliotheca Universalis, 4 volumes, 1545-1555; Mithridates: Observation on the difference of languages, to name just 2 of his 70 publications.

[26] Gesner was well known in pharmacologist circles in Lucerne.

[27] Hill and Forti (1986) show speleothem photographs which could resemble *Fomitopsis* shapes.

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Table 1. Moonmilk (or similar substance) names by date first recorded in literature

Author	Year	Name	Translation and/or meaning
Erasmus	1511	Lac virginis	milk of the Virgin
Agricola	1546	Marck	marrow (sense of "bone marrow")
Agricola	1546	Marga	"
Agricola	1546	Stein(o)marga	stone marrow
Agricola	1546	Medulla saxorum	stone marrow
Agricola	1546	galactite	milk stone
Gesner	1555	Fungus petr(a)eus	stone mushroom (round or shelf fungus)
Gesner	1555	Lac lunae	moonmilk
Gesner	1555	Monmilch	moonmilk
Gesner?	1555	Morochtus (Speckstein?)	lardstone, baconstone? Magnesite?
Gesner	1555	Agaricum saxatile	mushroom or fungus growing on rock
Gesner	1555	Lac lunare	moonmilk
Gesner	1555	Mon-Milch, Moon-Milch	moonmilk
Gesner	1555	Fungus petr(a) eus	rock fungus, stone mushroom
Imperato	1599	Agaricum fossile	fossil(ized) fungus
Imperato	1559	Medulla	pith, plant milk
Calceolarius	1622	Agaricus metallicus	metal mushrooms
Nierenbergius	1635	Lac virginis	Virgin's milk
Recchius	1649	Agaricus fossilis	rock mushroom
Worm	1655	Agaricum minerale	mineral fungus
Worm	1655	Stenomarga	stone marrow
Major	1667	Ammenmilch	wet nurse's milk
Major	1667	latte d'argento	milk of silver
Major	1667	axungia mineralis	mineral axle grease
Charleton	1668	Milk-Marle	milk marl
Hertod	1669	Lapis galactitis	milk stone (or rock)
Hertod	1669	Lapis lunae	moon stone
Hertod	1669	Milchstein	milk rock
Hain	1673	Steinmilch	rock milk
Wagner	1680	Medulla Saxorum	pith of the rock (plant-stem milk)
Wagner	1680	Steinmark	stone marrow
Marx	1687	Nihil, Nihili, Nihilum album	nothing, white nothing
Schroeck	1702	Farina Carolopolitina	flour (or meal), caropolitine (Bohemia?)
Schroeck	1702	Farina mineralis	mineral flour
Schroeck	1702	Lac luna Bethlehemiticum	Bethlehem moon milk
Valentini	1704	Marga saxatilis	marrow (growing) on rocks
Valentini	1704	Marienmilch	Mary's milk
Valentini	1704	Mergel, Mirgel, Mörgel	marl
Valentini	1704	Mondmilch	moonmilk
Valentini	1704	Weisser Mergel	white marl
Lang	1706	Monnmilch	moonmilk
Bruckmann	1728	Lac montis	mountain milk
Bruckmann	1730	Mohnmilch	moonmilk
Boecler	1747	Fungus mineralis	mineral fungus
Woltersdorff	1748	Bergmehl (kalkiges)	mountain (cave) flour, calcitic
Woltersdorff	1748	Lac lunae officinale	apothecary's moon milk
Woltersdorff	1748	Lithomarga	Stone marrow
Woltersdroff	1748	Mondsmilch	moon's milk
Woltersdorff	1748	Nihilum album nativum	white native nothing
Wallerius	1750	Creta fluida	flowing (or fluid) chalk
Wallerius	1750	Guhr album	white guhr (ooze)
Wallerius	1750	Guhr cenereum	ash (gray?) ghur (ooze)
Wallerius	1750	Grau Guhr	gray guhr (ooze)
Wallerius	1750	Himmelsmehl	heavenly flour
Wallerius	1750	Lac lunae solare	Rays of the moon milk?
Wallerius	1750	Lac lunae subterraneum	underground moonmilk
Wallerius	1750	Lerchenschwamm	shelf fungus
Wallerius	1750	Medulla fluida	flowing (or fluid) plant milk
Wallerius	1750	Mondmilch, Bethlehemitische	Bethlehem moonmilk
Keyssler	1751	Latte della Madonna	milk of our madonna
Keyssler	1751	Milk der heiligen Maria	milk of the Holy Mary
Pott	1751	Nihilum Album Fossile	white fossil (mineral) nothing
Schäffer	1757	Erdmehl	earth flour
Schäffer	1757	Gur, weisse	white guhr (ooze)
Schäffer	1757	Mehlkreide	flour chalk
Schäffer	1757	Steinlerchenschwamm	stone fungus
Schäffer	1757	Steinmar(c)k	stone marrow
Schäffer	1757	Steinmarck, kalkiges	calcitic stone marrow (or calcified)
Schäffer	1757	Steinmarga	stone marrow
Schäffer	1757	Nicht, nichts	nothing
?	?	"Galmey"	calamine, cadmia, Hüttenrauch
?	?	"Galmeiflug"	quick (flowing) calamine
Bertrand	1763	Ghur crétacé	guhr of chalk consistency
Hübner	1776	Galmey, weisser	white calamine
Hübner	1776	Mondenmilch	moonmilk (poetic)
Hübner	1776	Nicht, weisser	white nothing
Hübner	1776	Pompholyx	impure zinc oxide
Wartensee	1783	Mondmilch	moonmilk
Wartensee	1783	Mineral Lerchenschwamm	mineral larch fungus
Wartensee	1783	Terra alcalinis	alkaline earth
Blumenbach	1788	Berg-Zieger	mountain cheese (soft cottage cheese)
Flurl	1792	Bergmilch	mountain or mine milk
Flurl	1792	Kalkerde, Weisse	white calcareous earth
Pharm. Univ.	1832	calcareous lactiformis	milkslike calcite
Pharm. Univ.	1832	Breimilch	paste, gruel milk
Pharm. Univ.	1832	Mondmilch	moonmilk
Pharm. Univ.	1832	lait de montagne	mountain milk
Pharm. Univ.	1832	farina fossile	mineral flour
Pharm. Univ.	1832	axungia lunae	moon axle grease
Pharm. Univ.	1845	Breimehl	paste, gruel flour
Pharm. Univ.	1845	lait de lune	moonmilk
Grimm	1854	Bergbutter	mountain butter
Mayer	1857	Bergzuhr	mountain cheese (see Berg-Zieger)
Quenstedt	1863	Montmilch	moonmilk (old spelling)
Schnetzler	1871	Lait de la lune	moonmilk
Fugger	1880	Nix	nothing (dialect for nichts)
Schär	1894	Mondmilch	moonmilk
Kyrle	1923	Montmilch	moonmilk (old spelling)
Sidler	1939	Mandlimilch	gnome's milk
Sidler	1939	Mannlimilch	gnome's milk
Sidler	1939	Mondmilch	moonmilk
Lais	1941	Bergmilch	mountain milk, mine (cave) milk
Gèze	1955	Mondmilch	moonmilk
Lutz	1956	Mondmilch	moonmilk
Minieri	1957	Bergmilch	mountain milk, mine (cave) milk
Schmid	1958	Montmilch	moonmilk (old spelling)
Williams	1959	moonmilk	
Baron	1959	Mondmilch	moonmilk
Bernasconi	1959	Mondmilch	moonmilk
Pobeguin	1960	Mondmilch	moonmilk
Melon	1962	Mondmilch	moonmilk
Thrailkill	1963	moonmilk	
Trimmel	1965	Bergmilch	mountain milk, mine (cave) milk
Heller	1966	Mondmilch/Montmilch	moonmilk
Trimmel	1968	Bergmilch	mountainmilk, mine (cave) milk
Bernasconi	1973	Mondmilch	moonmik
Maleyev	1975	gornoye moloko	mountain milk
Gèze	1976	Mondmilch	moonmilk
Thrailkill	1976	moonmilk	
Urbani	1977	Leche di Luna	moonmilk
Shaw	1979	moonmilk	
Bernasconi	1980	Mondmilch	moonmilk
Bernasconi	1981	moonmilk	
Billy	1981	Mondmilch	moonmilk
Fischer	1987	Mondmilch	moonmilk
Hill/Fonti	1986	Mondmilch	moonmilk
Fischer	1988	Mondmilch	moonmilk
Fischer	1989	Mamilch	moon (man's) milk
Fischer	1989	Maanmilch	moonmilk (man's milk)
Fischer	1989	Mannmilch	moonmilk (man's milk)
Shaw	1992	Cave milk	
Shaw	1992	Moonmilk	

Table 2. Moonmilk terms by meaning, reorganized.

Fungus or mushroom		
Agaricum fossile		Agaricum minerale
Agaricum petr(a)eus		Agaricum saxatile
Steinlerchenschwamm		Lerchenschwamm
Flour or meal		
Bergmehl	Erdmehl	Farina fossilis
Farina mineralis	Himmelsmehl	Mehlkreide
Steinmehl		
Milk (Mond, Stein/Berg, other and milk-product)		
Lac lunae	Lac lunare	Mohnmilch
Mondenmilch	Mondmilch	Monsmilch
Monmilch	Monmilk	Monnmilch
Moonmilk	Lac lunae subterraneum	
Lac lunae officinale	Ammenmilch	Latte del'argento
Bergmilch	Lac montis	Montmilch
Lapis galactitis	Milchstein	Steinmilch
Latte della Madonna	Milch d.hlg Maria	Virgin's milk
Lac lunae Bethlehemitcum	Marienmilch	
Bergbutter	Bergzieger	Bergzuhr
Marrow (sense of bone marrow)		
Lithomarga	Marga, Mar(c)k	Marga fluida
Marga saxatilis	Marga fossilis	Medulla fluida
Medulla saxorum	Steinmark	Steinomarga
Mineral term		
Creta fluida	Guhr album	Guhr cinereum
Grau Guhr	Weisse Guhr	Kalkerde
Lapis lunae	Mehlkreide	Mergel
Weisser Mergel		
Confusion with other minerals(?)		
Galmei = calamine or cadmia, white furnace smoke, Zn or As oxide. Pompholyx = impure zinc oxide from early smelter deposit	Morochtus = varies with author: magnesite, cimolite, terra lemnia, terra samia, terra sigillata	
Valueless, light in weight, nothing		
Nihil, Nihili	Weisser Nicht	Nicht
Nihilum album nativum		Nix
Nihilum album fossile	Weiss(es) Nicht	Nil agrisum

Caution: Nil, nihil may also refer to smelter effluent.

Table 3. Uses of the word "Berg" by category (with English translation)

Unquestionably meaning mountain					
Bergsteiger		Mountaineer	Bergspitze		Mountain top
Bergbahn		Mountain railroad	Bergsohle		Mountain saddle
Berggeist		Mountain gnome	Bergpredigt		Sermon of the mount
Meaning a mining term					
Bergwerk		mine	Bergingenieur		Mining engineer
Bergschule		school of mining	Bergrat		Mine boss
Bergeisen		mining hammer	Bergamt		State mine office
Berghandel		mining trade			
Meaning mined substance					
Bergpech		asphalt	Bergwachs		waxlike subst.
Bergnaphtha		bitumen	Bergöl		oil
Bergbutter		yellow marl	Bergmilch		moonmilk
Bergtalg		tallow, talcum	Bergteer		tar
Bergfleisch		asbestos	Bergbalsam		naphtha
Synonyms for Berg: Stein (stone), Erde (earth)					
Bergöl	=	Erdöl	Bergpech	=	Erdpech
Bergwachs	=	Erdwachs	Bergteer	=	Erdteer
Bergöl	=	Steinöl	Bergkohle	=	Steinkohle
Berghuhn	=	Steinhuhn	Bergbutter	=	Steinbutter
Bergmilch	=	Steinmilch			
Names involving colors					
Berggrün	=	copper green	Berggelb	=	yellow ocher
Bergmilch	=	white	Bergbutter	=	yellow
Names followed by -berg (hill or mountain names)					
Tannenberg		Molkenberg	Friedberg		Röderberg

In German berg is always *after* the proper name.

In French the word mont is always *before* the name, and the name is *separated* from mont or there is a "de, du, d'" between mont and the name: Mont Blanc, Mont St. Denis, Mont d'or, Mont de Piété. Whereas French normally requires "du" (male) or "de la" (female), in adjective use "de" is proper in either case.

Table 4. Etymology of "Mond" and Fischer's etymology of gnomes

Mond (based on Grimm, 1873)	Gnome (Fischer, 1988)	
Me (measure, month, moon)		
Mêna (earliest)	Erdleutemilch	earth men milk +
mâ (root)	Mannlimilch	Diminutive -li
Mani/mona/mône	Mandlimilch	Diminutive -li
Maan/moon	maanmilch	Diminutive dropped
Ma/mô*	mamilch	"
mann/monn*	mannmilch	"
man/mon*	?	Monmilch used by Gesner 1955 and translated as lac lunae
mahn/mohn(?)*	?	
mand/mant, mond/mont*	mondmilch ++	

*All of these have been used between the 14th and the 20th century, pronounciations vary with locality or region, o and a sound similar. aa and oo and ah and oh stretch the vowel, nn shortens it. D and t sound similar, and often were modified as dt (harder than d alone) or th (softer than t alone) or tt (very hard). Medieval local variations are legion. The vowels a and o, even today's dialects in Germany, can sound very close in tonal value. The vowels can be stretched by changing to aa, oo, ah, or oh, they can be shortened by doubling the following consonant.

+The word "Erdleute" (where -leute is the indeterminate plural of Mann [man]) shows up in a German dictionary of superstitions, the expression also shows up as "Erdmännchen" (little earth men). The word "Leute" does exist in the diminutive "Leutchen," but as an endearment only: Liebe Leutchen (My dear friends, or fellows, dear people). It does not make Leute 60 cm tall old men.

++Present unified German spelling: Mond, present unified German pronunciation: mont. (The rule is: b, d, g, at end of word are pronounced as p, t, k.)

M. Degirmenci, C. S. Bayari, C. Denizman, T. Kurttas—Caves in Conglomerate, Köprüçay Basin; Western Taurids-Turkey: *NSS Bulletin* **56**: 14-22.

CAVES IN CONGLOMERATE, KÖPRÜÇAY BASIN; WESTERN TAURIDS-TURKEY

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Speleologic and hydrogeologic properties of the Kuruköprü and Honazdeliği caves developed in Miocene aged karstic Köprüçay Conglomerate were studied in detail. More than 90 percent of both the constituents and the cement of the conglomerate is composed of carbonate. Vertical or sub-vertical fractures and joints, remarkably high amount of precipitation, dense vegetation cover and lateral lithologic changes were found to be responsible for the development of the caves. It also was observed that the mechanical erosion preceded by chemical weathering is the primary control in development of the conglomerate caves. The shape of the cave passages are dominated by both structural features and lithologic differences. Fractures and joints control the direction of the passages while interlayering between conglomerates, sandstones and shales is primarily responsible for ceiling breakdowns and changes in base level. Chemical and isotopic data indicate that the groundwater circulating through the caves is of shallow, local origin.

INTRODUCTION

In a cave research study carried out by the Cave Research Team of the International Research & Application Center for Karst Water Resources (UKAM) 17 caves were explored in Köprüçay Basin and vicinity (Table 1). Among them, the four caves, namely Kuruköprü, Honazdeliği, Yeşilbağ, and Onbaşidüşen are noteworthy as they formed in conglomerate. The former two were studied in detail so that a preliminary evaluation of the cave development in conglomerate was made possible.

The Köprüçay Basin, in which the Kuruköprü and Honazdeliği caves are located, is situated 50km east to the Antalya city, in the central part of the Taurus karst range of Southern Turkey (Fig. 1). The Taurus Mountains, which extends as a 100km wide belt along the southern part of Turkey, is a part of the Alpine-Himalayan orogenic system. The Taurus karst range introduces many geologic, tectonic and hydrologic similarities to those of the other basins situated in Alpine-Dinaric karst areas (Eroskay and Günay, 1980). One of the exceptions of this similarity is the presence of "conglomerate karst" in Taurus range. Although, several caves were found in other basins (i.e. Manavgat, Göksu basins) where carbonate cemented conglomerate is wide-spread; the conglomerate caves in Taurus karst range are encountered mostly in the Köprüçay Basin.

REGIONAL GEOLOGY

In spite of the complex tectonic structure, the geology of the Köprüçay Basin is well understood because of numerous studies carried out during the past 20 years. The geologic units exposed in the basin are autochthonous, allocthonous and post-tectonic in origin. A hydrogeological map of the Köprüçay basin and its vicinity is shown in Figure 1. Of all the geologic units, only the post-tectonic, Tertiary Köprüçay Conglomerate and Beskonak Formation outcrop in the proximity of the Kuruköprü and Honazdeliği caves (Fig. 1, no. 1 and 2). The Köprüçay Conglomerate, in which the caves are formed, consists principally of carbonate clasts and carbonate cement. This formation is extremely karstic, penetrated by deep, vertical fractures that allow the precipitation and rapid infiltration into the aquifer.

Table 1.: Information on the caves located in and around the Köprüçay Basin.

No Name	Depth	Length	Mapping	Lithology	Hydrologic Status
	(m)	(m)	(m)		
1 Kuruköprü	-30	530	5b	Conglomerate	Active
2 Honazdeliği	+24	670	3b	Conglomerate	Active
3 Gürlevik	-5	35	1	Limestone	Active
4 İnkuşaği	+5	10	3	Limestone	Fossil
5 Kayaarasi	+3	15	-	Limestone	Fossil
6 Karain	+20	60	3b	Limestone	Fossil
7 Değirmenözü	+7, -6	60	3b	Limestone	Active
8 Yeşilbağ Düdeni	-62	95	2b	Limestone	Active
9 Yeşilbağ	-10, +5	150	3b	Conglomerate	Active
10 Onbaşidüşen	-16	50	2b	Conglomerate	Active
11 Baridini	0	35	1	Limestone	Fossil
12 Yemişlioğlu	0	75	1	Limestone	Fossil
13 Düdenyayla Düdeni	-70	60	3b	Limestone	Active
14 Zindan	+21	740	3b	Limestone	Active
15 Sorgun	-13	303	3b	Limestone	Active
16 Pinargözü	+300	3000	*	Limestone	Active
17 Pinarbaşi	?	150+	**	Limestone	Active

Notes: *; unmapped, information based on previous explorations
**; unmapped

Inquiries regarding to exact locations of the caves listed above should be made to the second author.

The Beşkonak Formation is made up of interbedded shale and sandstone. In some places, close to the contact with the Köprüçay Conglomerate, large conglomerate lenses are included within the formation. Except in the conglomerate lenses, karstification is not observed in this formation. Detailed information on the autochthonous and allochthonous geologic units exposed in the basin is provided by Değirmenci (1989).

Lithologic Characteristics of Karstic Conglomerate

The Köprüçay Conglomerate, in which the Kuruköprü Cave has developed, is composed principally of clasts of limestone, sandstone, chert, and ophiolite. Chemical analyses of the conglomerate samples show that both the clasts ($CaCO_3$: 65.5%, $MgCO_3$: 31.1%, SiO_2: 1.9%, Al_2O_3: 0.3%) and the cement ($CaCO_3$: 75.9%, $MgCO_3$: 6.3%, SiO_2: 14.7%, Al_2O_3: 0.9%) are rich in carbonate (Değirmenci, 1989). Table 2 gives the percent distribution of the clast lithologies in the Köprüçay Conglomerate. As indicated in the Table, the Köprüçay Conglomerate is made up primarily of limestone clasts.

Table 2.: Percent distribution of the constituents of the Köprüçay Conglomerate

Location	Limestone	Sandstone	Chert	Ophiolite
Dam Site Right Bank	92	4	3	1
Dam Site Left Bank	88	10	1	1
Olukköprü Spring	82	16	1	1
Olukköprü 5km west	63	4	25	9
Dumanli Dağ	45	33	0	22
Böğrümköprü Spring	68	11	14	7
Karacaören Dam	54	3	4	39

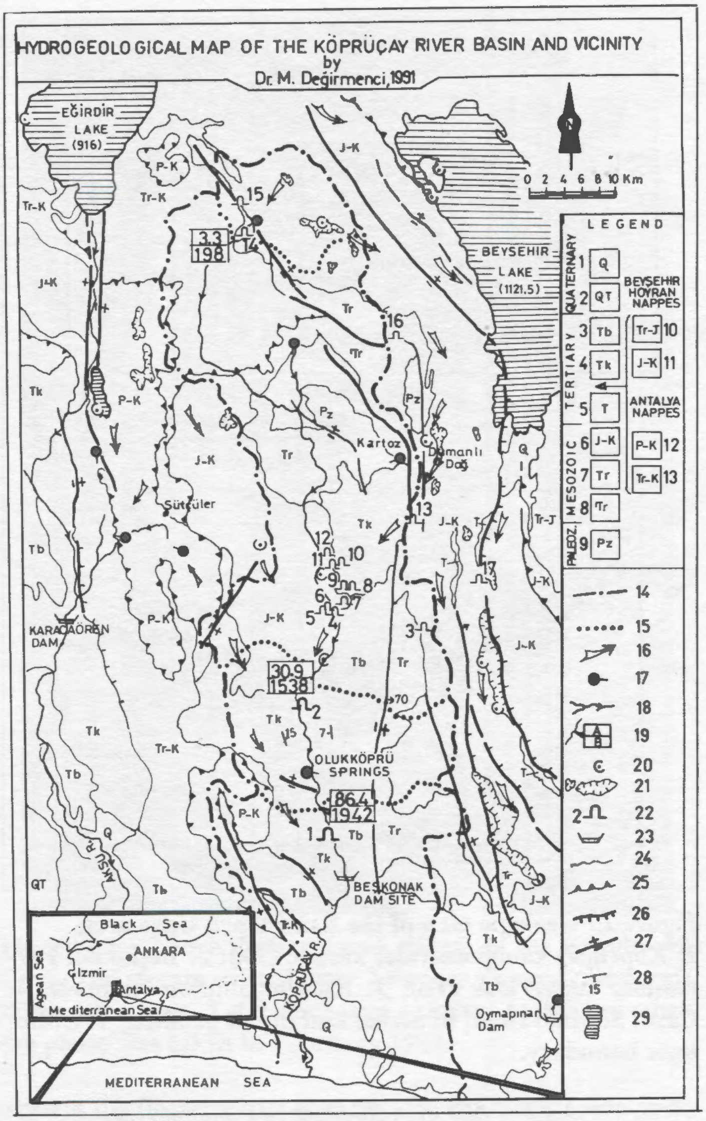


Figure 1.: Hydrogeologic map of the Köprüçay Basin (including Location Map)

1: Alluvium; 2: Travertine; 3: Sandstone-claystone; 4: Conglomerate; 5: Flysch (sandstone, shale, limestone); 6: Limestone; 7: Shale-conglomerate; 8: Limestone-dolomite; 9: Schist-quartzite; 10: Shale; 11: Limestone; 12: Limestone; 13: Shale; 14: Surface water-divide; 15: Second-order surface water-divide; 16: Groundwater flow direction; 17: Karst spring; 18: River; 19: Stream gauging station, A; mean annual discharge (m^3/sec), B; Catchment area (km^2); 20: Sinkhole; 21: Polje; 22: Cave; 23: Planned dam site; 24: Lithologic boundary; 25: Thrust fault (teeth on upper block); 26: Reverse fault (teeth on upper block); 27: Normal fault (+, upthrown; -, downthrown block); 28: Strike and dip of bedding; 29: Fresh-water lake.

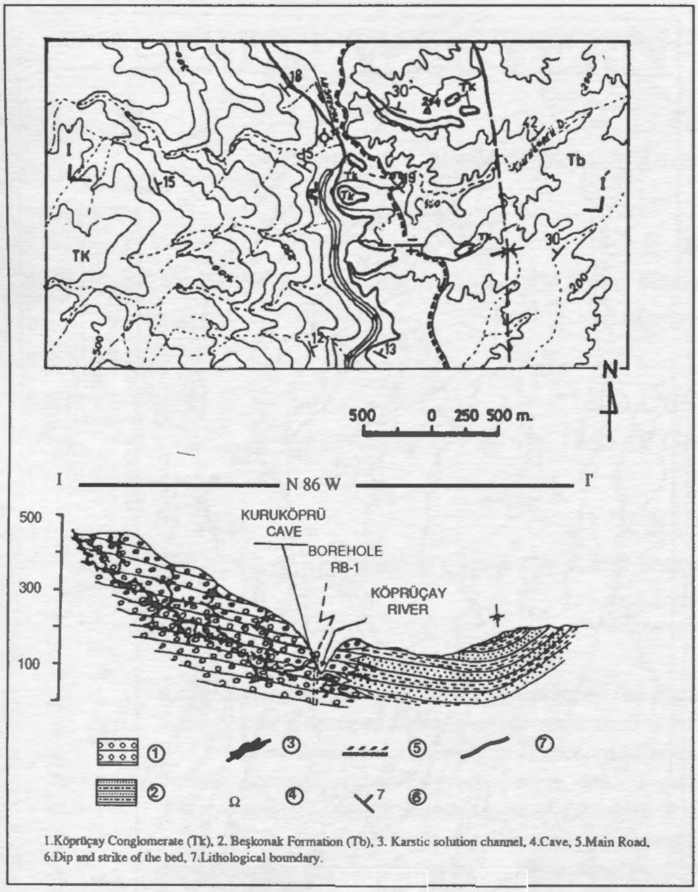


Figure 2.: Geologic map of the Kuruköprü Cave area. 1: Köprüçay Conglomerate, karstic (Tk); 2: Beşkonak Formation, impervious (Tb); 3: Karstic solution channels; 4: Cave; 5: Main road; 6: Strike and dip of bedding; 7: Lithologic boundary.

Tectonics and Karstification in Conglomerate

The Köprüçay Conglomerate has been subject to intensive tectonic activity resulting in a dense network of vertical joints. However, the bedding of the conglomerate is nearly horizontal. The vertical joints and the shale and sandstone lenses with low hydraulic conductivity are the major factors that causes extensive karstification in conglomerate.

Lugeon tests in the Borehole RB-1, located about 200m north from the cave, have shown that most of the karstification has developed in the upper 60m. Similarly, the exploratory drillings have led to the conclusion that karstification depth extends to -200m below sea level at the Beşkonak Dam site, located 6km south of the cave. One of the examples of extensive karstification in the conglomerates is the presence of Olukköprü karst spring. This spring discharges at a minimum rate of 30 m^3/s and is located about 8 km north of and in the same conglomerate as is Kuruköprü Cave.

CLIMATE AND HYDROLOGY

Mediterranean type climate, with warm and rainy winters and dry and hot summers, prevails in the vicinity of caves. Precipitation increases gradually from the coast to inland. Mean annual precipitation ranges between 1100mm at the coastal stations and 1600mm at the Beşkonak station, located 6km north of the Kuruköprü Cave.

The only perennial stream in the region is the Köprüçay River. The other streams/creeks carry water only during the wet period. The drainage network is poorly developed due to the extremely pervious nature of the karstic formations.

KURUKÖPRÜ CAVE

Location and Geologic Structure

Kuruköprü Cave is located on the right bank of the Köprüçay River, 30 km away from the main road to Antalya.

Two geologic units, the Köprüçay Conglomerate and the Beskonak Formation, outcrop in the area where the Kuruköprü Cave is situated (Fig. 2). The Köprüçay Conglomerate extends over the western side of the Köprüçay River, whilst the Beşkonak

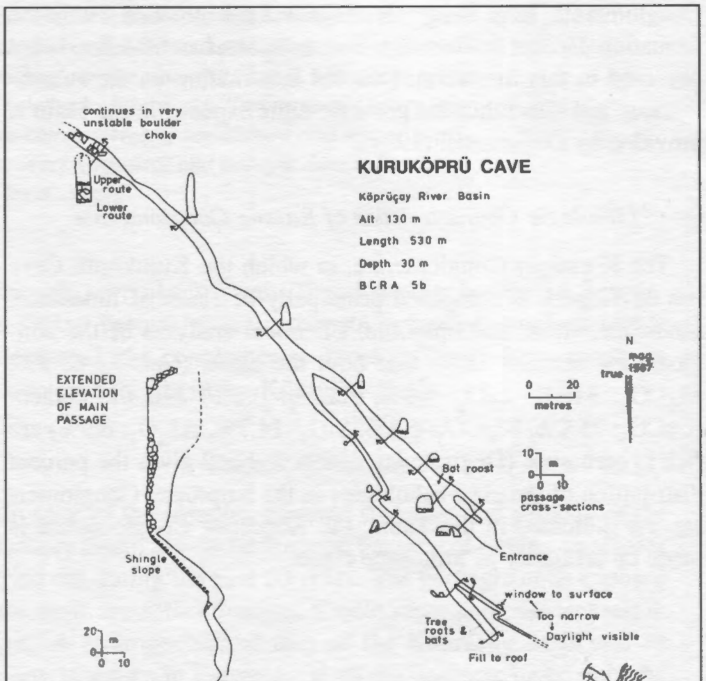


Figure 3.: Plan and extended elevation of the Kuruköprü Cave.

Figure 4.a.: Vadose passage in Kuruköprü Cave. Interlayering of conglomerate and sandstone beds are visible on the right hand side of the photo. Note squeezed block and the sand accumulation at the bottom. Photo taken in July 1988.

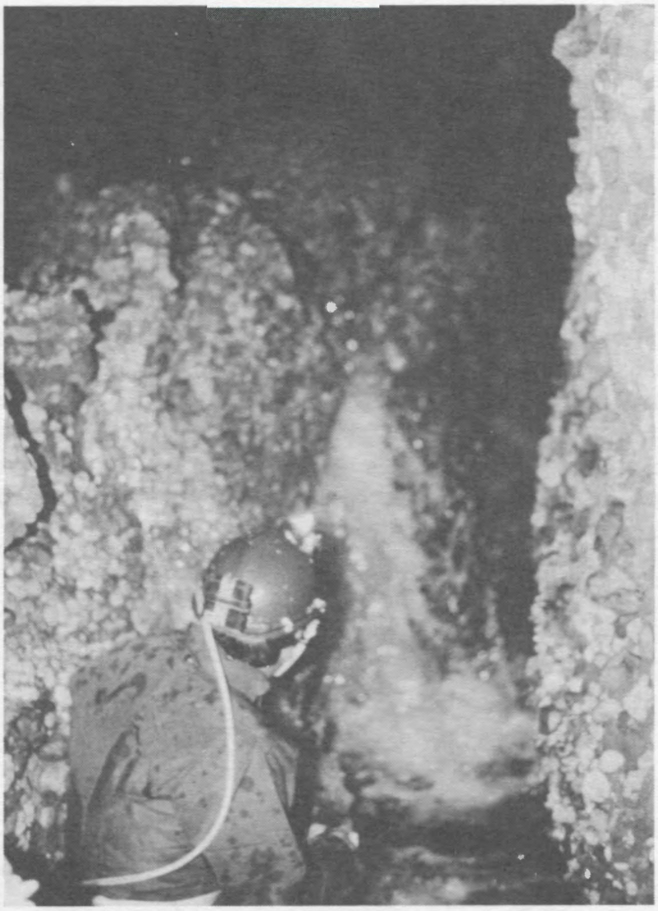


Figure 4.b.: Active underground stream in the Kuruköprü Cave. The stream existed after 2 day long heavy rainstorms around the cave. Total discharge amounts to 3m^3/sec when the photo was taken in February 1989.

Formation lies over the eastern side. These two geologic units are in contact with each other along an inter-fingered boundary. Their borderline extends roughly along the Köprüçay River.

Cave Morphology

The Kuruköprü Cave has been mapped in BCRA 5b detail (Fig. 3). At the time of the topographic surveys, the cave was completely dry allowing for a high quality survey, except for the end of the cave, where fallen blocks were hazardous. As implied by Figure 3, the cave has developed along a fault zone trending in the direction of N45W. Fault breccia can be seen at the entrance of the cave.

The cave begins with a 2m high entrance followed by a 25m long entrance hall with occasional blocks fallen from the ceiling. At the end of the hall, the passage slopes 45°. The slope is paved by sandy-gravel material from the weathering of the conglomerate and sandstone. This detritic material is sorted by particle size so that the coarser material is located at the bottom of the slope whereas the finer material is at the top. The particle size range from 1mm to 5-10cm. The median diameter of the particles at the top was about 1-2mm to which the Hjulstrom (1935) curve gives a groundwater flow velocity range of 8-15cm/sec.

Beyond the slope, on the southwestern side of the cave there appears the only secondary branch. This branch extends towards the Köprüçay stream and terminates at a narrow window through which daylight infiltrates into the cave. The main branch, like the entrance hall and the sandy slope, strikes N45W for 250m. In the main branch, side walls are nearly vertical and the ceiling heights range from 2m to 15m (Fig. 4a). Although the dominant lithology in the cave is conglomerate, from the middle of the main branch to the cave terminus, interbeds of sandstone and shale appear. Most of the fallen blocks at the terminus are composed of the shale collapsed due to the erosion of supporting sandstone and conglomerate beds.

Both the fallen blocks and pebbles can be easily removed from the conglomerate indicating that mechanical erosion also is important in the development of cave passages. Once the chemical erosion removes the carbonate cement of the conglomerate and sandstone, then the particles are rapidly dispersed by the weak friction forces applied by the flowing groundwater in the wet season (Fig. 4b). It is obvious that the chemical weathering not only erodes a minor part (cement) of the rock but also causes the rock (pebbles) to be weakened and, consequently eroded by mechanical forces. When the conglomerates and sandstones are removed by chemical and mechanical erosion, then the shale beds cannot resist against the vertical axial forces of the overlying layers.

None of the depositional cave features (such as stalagtites, stalagmites and dripstones) are observed in Kuruköprü Cave. The chemical and mechanical erosion of the underground stream does not allow any deposition. However, occasional scallops as evidence of vadose flow are seen at some places of the cave. These features have developed only on the sandstone walls of the cave.

Groundwater Level Fluctuations

The Kuruköprü Cave is still active and plays an influential role in the karst groundwater flow system. The entrance of the cave is about 25m above the Köprüçay River. The 3 years of groundwater level observations carried out in the Boreholes RB-1 (located at 200m north of the cave) and RB-2 (located at 4 km north of the cave), indicates that the groundwater levels around the cave vary between 35m below the river level in the summer time and 8m to 10m above the stream level in winters (Fig. 5).

The following groundwater level and discharge rate observations demonstrate how the karst system around the Kuruköprü Cave behaves:

28th July 1988: the groundwater level in the RB-1 is 32m below the stream level,

1st February 1989: the groundwater level in RB-1 is only 4m above the stream level whereas the water level in the cave is 18m above the stream level. The highest point of discharge from

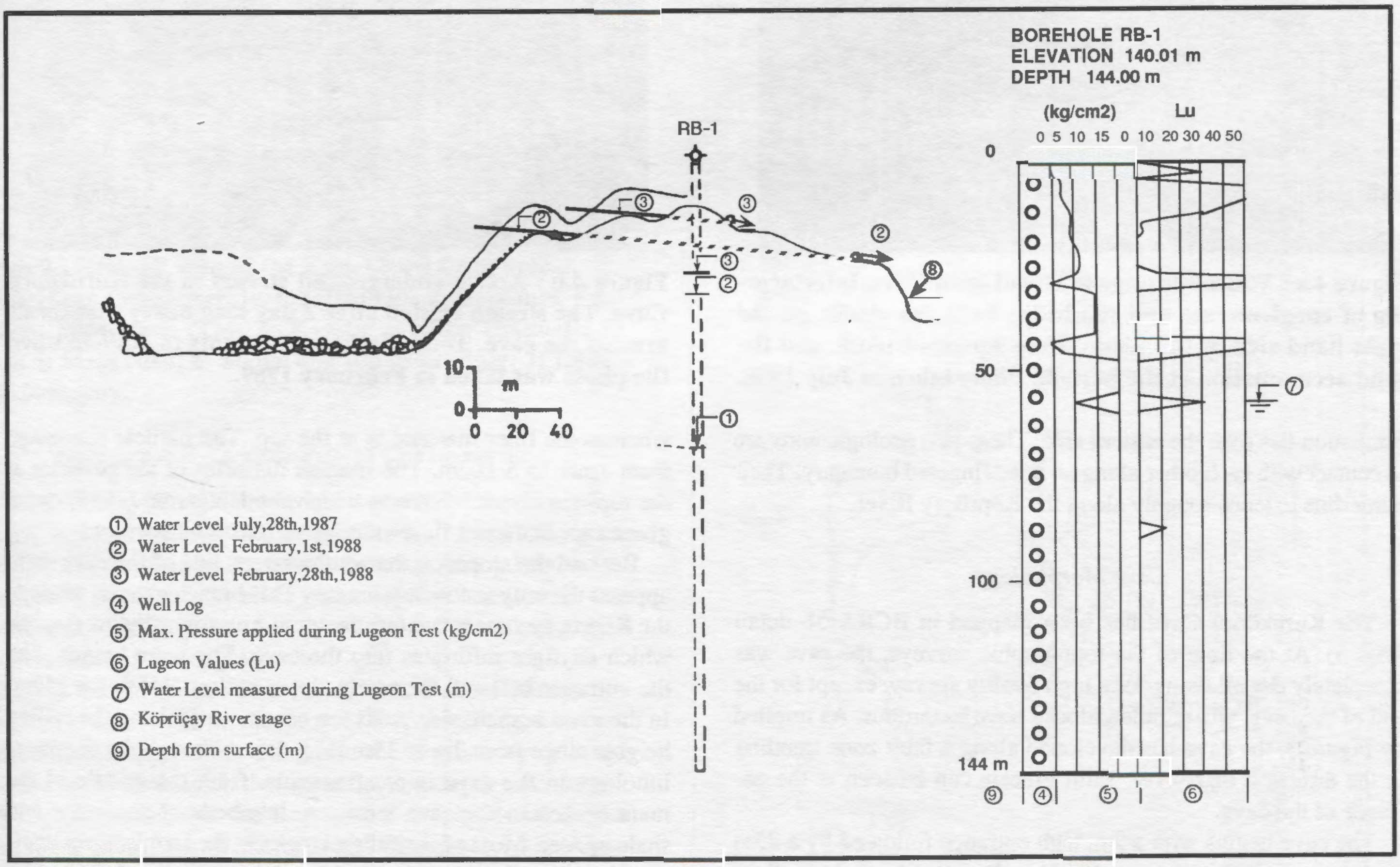


Figure 5.: Comparison of the karstification zones in Borehole RB-1 and in the entrance part of the Kuruköprü Cave. 1: Water level, July 28th, 1987; 2: Water level, February 1st , 1988; 3: Water level, February 1st, 1988; 4: Lithologic well log (all conglomerate); 5: Max. pressure applied in Lugeon Tests; 6: Lugeon values; 7: Groundwater level in the borehole during the test; 8: Mean level of Köprüçay River; 9: Depth of borehole from the surface.

Table 3.: Results of the in-situ hydrochemical measurements.

Measurement Point	EC	Temp.	CO_2	Date
	(µS)	(°C)	(mg/1)	
Köprüçay, upstream of Olukköprü springs	238	11.2	1.5	February 1st, 88
Olukköprü springs	335	14.0	4.5	February 1st, 88
Borehole RB-2	490	17.0	9.0	February 1st, 88
Kuruköprü Cave discharge	380	13.4	3.0	February 1st, 88
Köprüçay, downstream of cave	283	12.0	2.0	February 1st, 88
Olukköprü springs	335	14.0	4.5	February 1st, 88
Kuruköprü Cave discharge	230	13.2	3.0	February 2nd, 88
Köprüçay, downstream of cave	285	12.0	2.0	February 2nd, 88
Olukköprü springs	335	14.0	4.5	February 3rd, 88
Kuruköprü Cave discharge	239	13.3	3.0	February 3rd, 88
Köprüçay, downstream of Kuruköprü Cave	293	12.2	2.0	February 3rd, 88

the cave is about 11m above the stream level. Total discharge from the cave is estimated to be 4-5 m^3/s,

28th February 1989: groundwater level in borehole RB-1 is 8m above stream level whilst the water level in the cave is 21m above the stream level. The highest point of discharge from the cave occurs 20m above the stream level. Total discharge from the cave is estimated to be 7-8 m^3/s.

Based on the groundwater level observations and associated changes in the discharge from the cave, it was deduced that the Kuruköprü karst system is under the influence of shallow, rapid groundwater flow. This system becomes active only if a sudden and heavy storm occurs locally (within 50km of the cave).

Hydrochemical Observations

The above mentioned conclusion has been examined by hydrochemical measurements made at the observation points scattered around the cave (Table 3). As can be inferred from the available data, the Electrical Conductivity (EC) of the water in cave decreases from 380 micro Siemens to 230 micro Siemens within 48 hours. The decrease in EC shows that the Kuruköprü system has been discharging waters both from static and dynamic karst reservoirs. Initially when the infiltrating storm water reaches the static reservoir, the groundwater discharging from the cave would have higher electrical conductivity, because it first forces the old groundwater to be flushed out from the system. After the flushing out of the static (old) groundwater, the young (recent) groundwater will tend to flow within the system. This will reduce the EC of the cave water. The EC of the stream water was measured to be 238 micro Siemens on February 1, 1988 at the upstream of Olukköprü spring. At this point, the stream water is composed of the surface runoff of the recent storm. Therefore, it can be deduced that the contribution of the storm water to the cave is substantial.

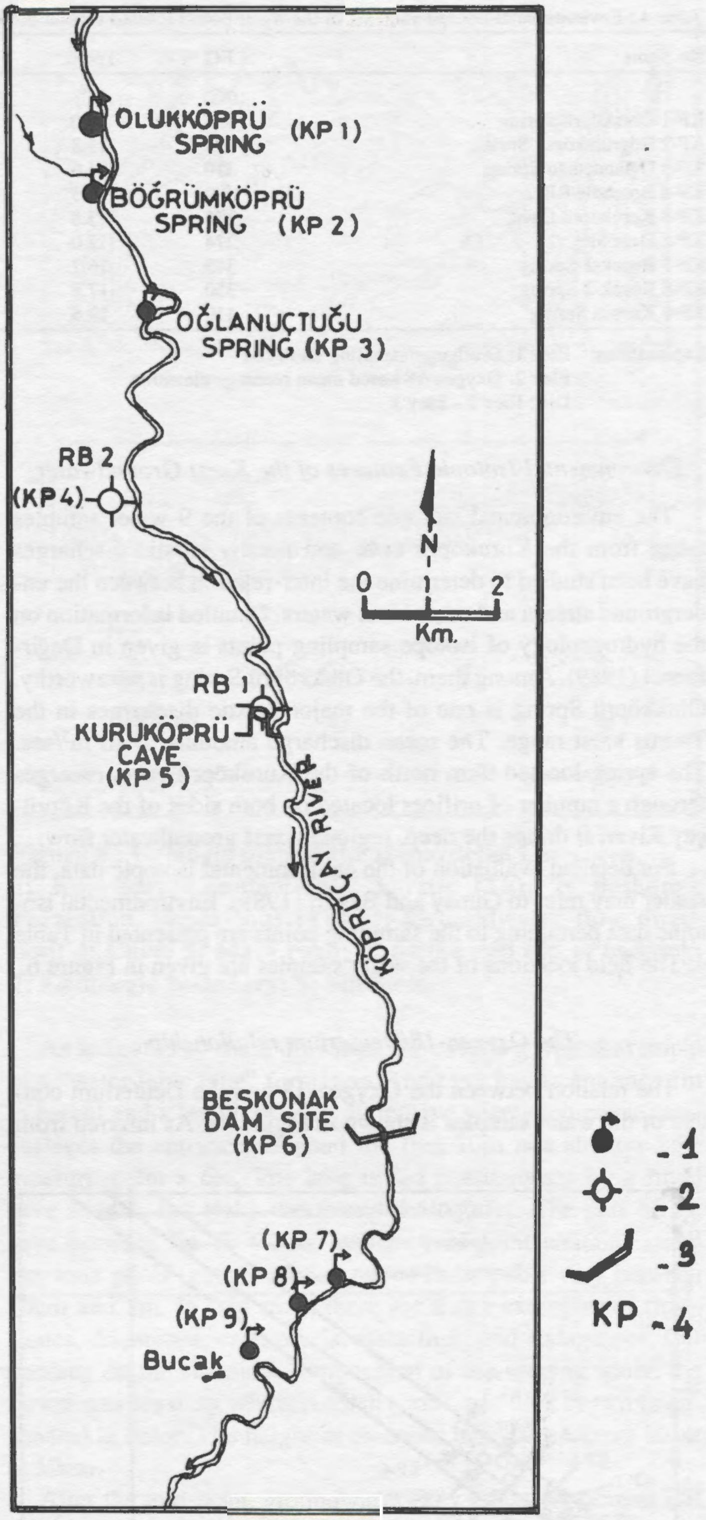


Figure 6.: Field locations of the environmental isotopic sampling points.
1: Karst spring, 2: Bore-hole, 3: Planned dam site; 4: Sampling point (KP)

Table 4.: Environmental isotope contents of the water points located around the Kuruköprü Cave.

No Name	EC	Temp.	^{18}O	^{2}H	^{3}H	Elev 1	Elev 2	Diff.
	(µS)	°C)	(δSMOW)	(δSMOW)	(TU)	(m)	(m)	(m)
KP-1 Olukköprü Spring	335	14.0	-7.55	-44.1	11.2	172	1367	1195
KP-2 Bögrümköprü Spring	325	13.8	-7.57	-44.1	12.2	160	1380	1220
KP-3 Oğlanuçtuğu Spring	310	14.6	-6.96	-37.4	12.2	150	973	823
KP-4 Borehole RB-2	490	17.3	-6.16	-31.0	22.9	134	440	306
KP-5 Kuruköprü Cave	275	13.8	-7.06	-36.0	23.4	120	1040	920
KP-6 Dam Site	274	12.0	-7.47	-42.9	16.7	40	1313	1273
KP-7 Bucak-1 Spring	345	16.2	-6.46	-33.4	20.1	35.6	640	604
KP-8 Bucak-2 Spring	350	17.8	-6.79	-33.9	10.5	35.3	860	824
KP-9 Kuruca Spring	410	19.5	-6.04	-26.8	11.6	35.5	360	324

Explanations: Elev 1: Discharge/sampling elevation
Elev 2: Oxygen-18 based mean recharge elevation
Diff: Elev 2 - Elev 1

Environmental Isotopic Features of the Karst Groundwater

The environmental isotopic contents of the 9 water samples taken from the Kuruköprü cave and nearby karstic discharges have been studied to determine the inter-relation between the underground stream and other karst waters. Detailed information on the hydrogeology of isotope sampling points is given in Değirmenci (1989). Among them, the Olukköprü Spring is noteworthy. Olukköprü Spring is one of the major karstic discharges in the Taurus karst range. The mean discharge amounts to 40 m³/sec. The spring located 9km north of the Kuruköprü cave, emerges through a number of orifices located on both sides of the Köprüçay River. It drains the deep, regional karst groundwater flow.

For detailed evaluation of the environmental isotopic data, the reader may refer to Günay and Bayari (1989). Environmental isotopic data pertaining to the sampling points are presented in Table 4. The field locations of the water samples are given in Figure 6.

The Oxygen-18/Deuterium relationship

The relation between the Oxygen-18 and the Deuterium content of the water samples is shown in Figure 7a. As inferred from the figure, the water samples are located between the Eastern Mediterranean and Antalya Meteoric lines. Yurtsever (1980) proved that the Antalya line, with a Deuterium excess value of +16, represents the precipitation falling on the Western Taurids range. Therefore, the samples (Olukköprü and Böğrümköprü springs) located on this line are fed from the deep regional karst groundwater flow. The other samples which correspond to Eastern Mediterranean line (Deuterium excess value of +22) are fed from coastal precipitation affected by high evaporation rates. The water of Kuruköprü Cave closely resembles the Oğlanuçtuğu Spring.

The Oxygen-18/Tritium relationship

The plot of Oxygen-18 and Tritium content of the samples are given in Figure 7b. The graph clearly indicates waters with different turn-over times and recharge altitudes. Water samples numbered KP-1, KP-2, KP-3, KP-8 and KP9 have longer turn-over times compared to those of samples KP-4, KP-5 and KP-7 with shorter turn-over times. For the water sample taken from the Köprüçay River (KP-6), the turn-over time is between these

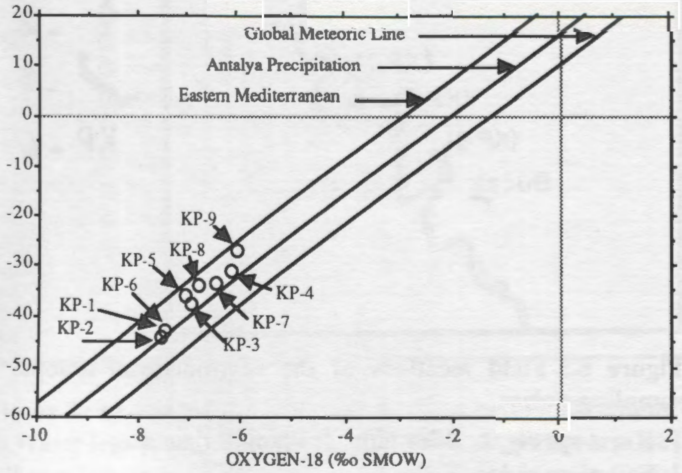


Figure 7.a.: Oxygen-18 vs deuterium plot of water samples.

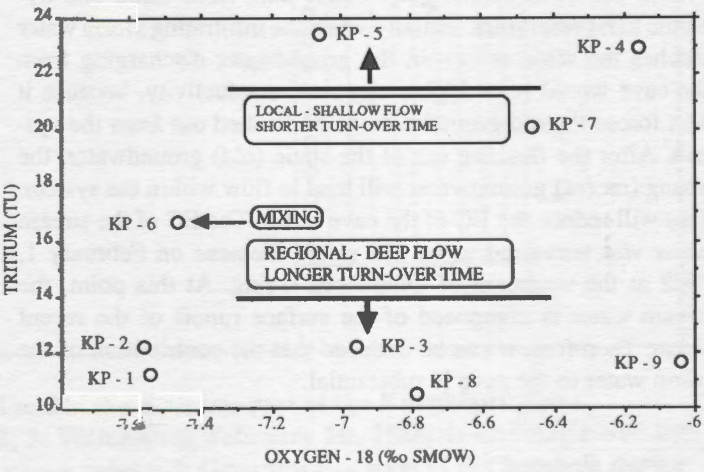


Figure 7.b.: Oxygen-18 vs tritium plot of water samples.

two groups. This suggests that the stream water comprises of a good mixture of deep and shallow circulation.

Forecasted Recharge Elevations

The forecasted recharge elevations of the waters were computed by the Oxygen-18/Altitude relationship of the samples (see Table 4). Forecasted mean recharge elevation for the Kuruköprü Cave (1040m) is between those of deep (KP-1 and KP-2) and shallow (KP-4, KP-7, KP-8, KP-9) circulation waters. The forcasted recharge area elevation denotes that the recharge area of the water discharging from the cave should be the Bozburun Mountain, located 35km northwest of the cave, and comprised of Köprüçay Conglomerate. The conglomerate observed in this region is connected to that of cropping out in the area where the cave is located. Therefore, the groundwater recharge indicated by isotope content seems quite reasonable.

Speleogenetics

Kuruköprü Cave is a good example of "secondary vadose cave formation." The zone where the cave developed can be called both "inactive" or "high-water vadose" zone. In low-water season (when the cave was explored), it is completely dry and there is no groundwater flow. In the high-water season, the cave contains a stream, implying that the zone becomes active and is a high-water vadose zone.

Considering the passage shapes and the ceiling breakdown in the cave, it is concluded that the geomorphologic evolution is between the "maturity" and "old-age" stages.

The following excerpt from Bögli (1980) should be kept in mind in evaluating the conclusions pertaining to the speleogenetics of the cave; "...In conclusion it should be pointed out that each cave presents an individuality to which speleogenetic theories cannot always do justice."

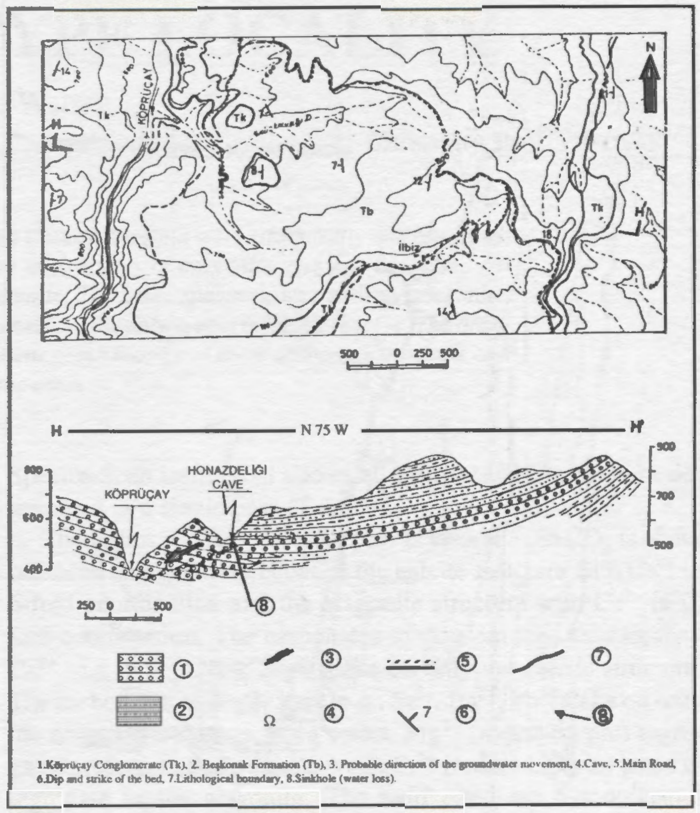
HONAZDELIĞI CAVE

Location and the Geologic Structure

The Honazdeliği Cave is located at the Gelinkavaği site, 15km north to the Olukköprü Spring. Although the cave has formed within the Köprüçay Conglomerate, the area in which the cave is developed is very close to the contact between the karstic Köprüçay Conglomerate and the impervious Beşkonak Formation. These two formations are inter-fingered along the zone where the cave formed (Fig. 8).

Cave Morphology

The Honazdeliği Cave was mapped in BCRA 3b detail and the length and depth were found to be 670m and +24m respectively (Fig. 9).



1.Köprüçay Conglomerate (Tk), 2. Beşkonak Formation (Tb), 3. Probable direction of the groundwater movement, 4.Cave, 5.Main Road, 6.Dip and strike of the bed, 7.Lithological boundary, 8.Sinkhole (water loss).

Figure 8.: Geologic map of the Honazdeliği Cave area. 1: Köprüçay Conglomerate, karstic (Tk); 2: Beşkonak Formation, impervious (Tb); 3: Groundwater flow direction; 4: Cave; 5: Main road; 6: Strike and dip of bedding; 7: Lithologic boundary; 8: Sinkhole.

As indicated by these drawings, the cave is a typical example of a "water-table type" formation. The cave has an entrance 1m in height and a length of 10m. Extensive vegetation cover camouflages the entrance. Beyond the first 10m is a shallow lake measuring 2m x 6m. The lake is fed continuously by a small cave stream, but leaks water into the aquifer. The part of the cave between the first 10m and the mid-point contains many rimstone pools (gours). The depth of these pools vary between 10cm and 2m. In this zone, there are many examples of flowstones, dripstones, cave pearls, stalactites, and stalagmites. Depending on the chemical composition of the seeping water, the flowstones are dirty white, reddish (iron), and dark brown (manganese) in color. The height of rimstone bars ranges from 10cm to 50cm.

After the mid-point, groundwater flow gradually ceases. The cave is a network cavern indicating strong phreatic conditions. The dense network of impassable passages is characteristic of this part. All the passages are "bedding-plane type" and formed along the conglomerate-sandstone contact.

The last 180m of the cave is developed in interbedded conglomerate, sandstone and shale. The shales appearing at this point

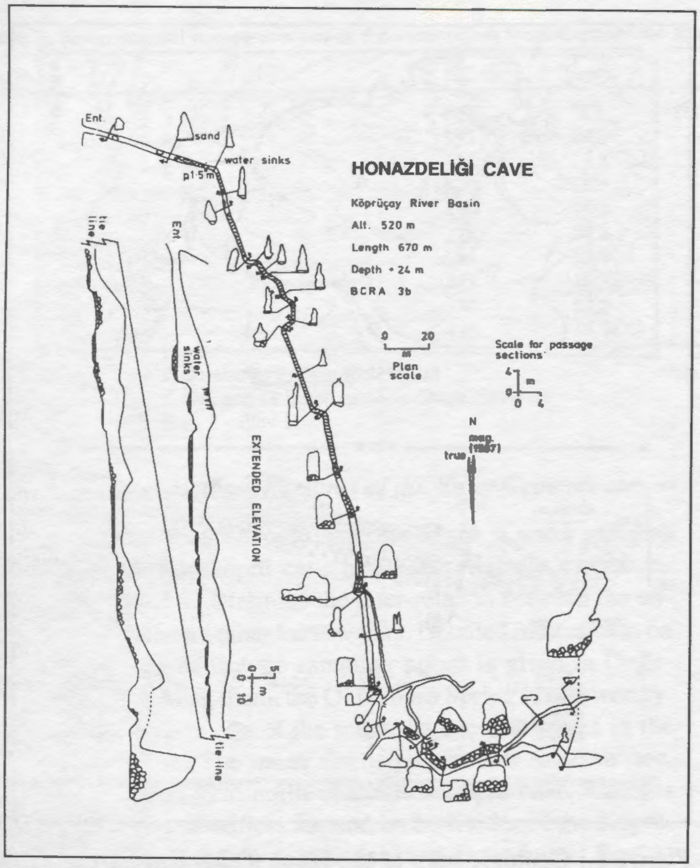


Figure 9.: Plan and extended elevation of the Honazdeliğii Cave.

belong to the impervious Beşkonak Formation. As in Kuruköprü Cave, the Honazdeliği cave ends in collapsed shale blocks. This part of the cave is extremely unstable and dangerous.

Hydrochemical Observations

Hydrochemical measurements made in the entrance pool yields the following results;

Electrical Conductivity: 435 microSiemens
Temperature: 13.9° C
pH: 7.9.

The relatively high value of pH indicates carbonate precipitating conditions. These values, when compared to those of the Olukköprü Spring (EC: 335 microSiemens, Temperature: 14.0° C, pH: 7.4) reveal that the water in Honazdeligi Cave has not reached an equilibrium condition.

Speleogenetics

The Honazdeliği Cave contains many features of deep-phreatic origin. Most of the "key forms" of this origin (step-like change of base level, passage shapes and the labyrinth forming passage network) are encountered throughout the cave. Developmentally, the "maturity," "old age" and "selinity" stages prevail in the cave. The "water-sink" at the entrance implies that the "phase of cessation of sinking of the karst water level" has already started. This means that the deepening of local karstification base level has just initiated. The deepening process can be considered as the beginning of the vadose stage of cave development. An examplė of this is a slowly flowing underground stream.

CONCLUSIONS

An overall evaluation of the speleologic and hydrogeologic data gathered throughout this research reveals that cave development in conglomerate is possible if the prerequisites such as, soluble lithologic composition, fractures-joints and carbon-dioxide source are provided. However, some of the factors that govern the development of typical limestone-dolomite caves have much more importance in the development of conglomerate caves. Among these, the most remarkable ones are the mechanical erosion coupled with chemical weathering and the frequently repeated interlayering of the lithologies with different permeabilities. Moreover, the ceiling breakdowns and passage shapes indicating shallow phreatic and/or high-water vadose zone are among the important properties of conglomerate caves.

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THE ANTHODITES FROM SKYLINE CAVERNS, VIRGINIA: THE TYPE LOCALITY

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Two specimens of anthodite from Skyline Caverns, Warren County, Virginia were structurally and chemically analyzed. Although both had the characteristic acicular morphology of aragonite, one was composed entirely of calcite which had apparently inverted from aragonite. The other specimen was entirely aragonite. The aragonite specimen was high in strontium, low in magnesium, the calcite specimen the reverse. The aragonite to calcite inversion is consistent with the trace element geochemistry of these carbonate minerals and also consistent with an early to mid-Pleistocene age for the cave.

The speleothem known as the anthodite was originally described in Skyline Caverns, a commercial cave in Warren County, Virginia (Henderson, 1949). They occupy a position in the cave (see Douglas, 1964; Holsinger, 1975 for description) that was apparently sealed until clay plugs were removed during commercialization (Fig. 1). Anthodites are radiating, spiky, clusters of crystals usually composed of aragonite. They have been described in many caves (Hill and Forti, 1986). The Skyline Caverns anthodites occupy an intermediate position in the size scale. Anthodites range in size from tufts of crystals a few centimeters across to aragonite "trees" that can approach a meter in height.

Although Skyline Caverns is the type locality for anthodites, there appears to be no mineralogical investigation of these particular speleothems beyond Henderson's purely descriptive paper. In the process of commercialization of the cave, it was necessary to remove several chunks of anthodite. These specimens have been long displayed in a case in the visitor center. Through the courtesy of the cavern management, it was possible to borrow these specimens for mineralogical and chemical analysis.

The specimens were irregular blocks of about 0.34 and 3.2 kg weight. The radiating crystals were somewhat chipped and broken. Two small samples were removed from each specimen, one from the radiating crystals and one of the more massive material making up the base of the specimen.

Both samples of the smaller specimen were composed entirely of calcite as determined by x-ray powder diffraction. Both samples of the larger specimen were composed of aragonite. Under the binocular microscope the calcite sample, although it had the same external morphology as the aragonite specimen, was seen to be made up of white granular crystals (Fig. 2). Judging from the external form, this specimen apparently crystallized as aragonite and then recrystallized to calcite at some later time. The recrystallization gave calcite grains on the scale of 0.1 to 1 mm. The aragonite samples were composed of white fibrous crystals with individual fibers 5-10 mm long and tenths of a mm in diameter.

The chemical compositions of all four samples were determined by dissolving the crystals in dilute hydrochloric acid and analyzing the solutions by atomic emission spectroscopy. The Spectra-Span instrument allows all elements of interest to be determined in a single pass (Table 1).

The radius of Ca^{2+} ion (114 pm) is such that $CaCO_3$ is about balanced energetically between the calcite structure with Ca^{2+} in 6-fold coordination and the aragonite structure with Ca^{2+} in 9-fold coordination. The carbonates of divalent ions smaller than Ca^{2+} (e.g., Cd^{2+}, Ni^{2+}, Mg^{2+}) take on only the calcite structure. The carbonates of larger ions (e.g., Sr^{2+}, Ba^{2+}, Pb^{2+}) take on only the aragonite structure. As a result, Mg^{2+} (radius 86 pm) segregates preferentially in calcite while Sr^{2+} (radius 132 pm) tends to segregate in the aragonite. The radii cited are 6-coordinated "crystal radii" from Shannon's (1976) table.

In Figure 3 are plotted the concentrations of Mg^{2+} and Sr^{2+} found in a selection of calcite and aragonite samples from caves. These delinate two distinct fields with little or no overlap. A boundary line can be drawn between the two fields with a 45° slope on the log-log plot which implies a linear relationship between the mole fraction of $MgCO_3$ and the mole fraction of $SrCO_3$. A simple fitting of the boundary curve in Fig. 3 gives

$$N_f(MgCO_3) = 12.5\ N_f(SrCO_3)$$

The Skyline Caverns samples conform to this general pattern. Calcite sample 92MM002 is plotted on Figure 3. The other calcite sample lies in the calcite field but with a strontium content below the detection limit. Both aragonite samples have the same chemical composition. This point lies in the aragonite field with respect to strontium but with a magnesium content below detection limit.

Table 1. Chemical analyses of Anthodites.

Component (Weight Percent)	Calcite Sample 92MM002	92MM003	Aragonite Sample 92MM004	92MM005
Al_2O_3	<0.005	<0.005	0.01	0.01
BaO	<0.005	<0.005	0.02	0.03
MgO	0.52	1.53	<0.005	<0.005
Na_2O	<0.005	0.01	<0.005	0.01
SiO_2	<0.005	<0.005	<0.005	<0.005
SrO	0.06	<0.005	0.14	0.14

Analyses are given for trace elements only. The matrix is nearly pure calcium carbonate.

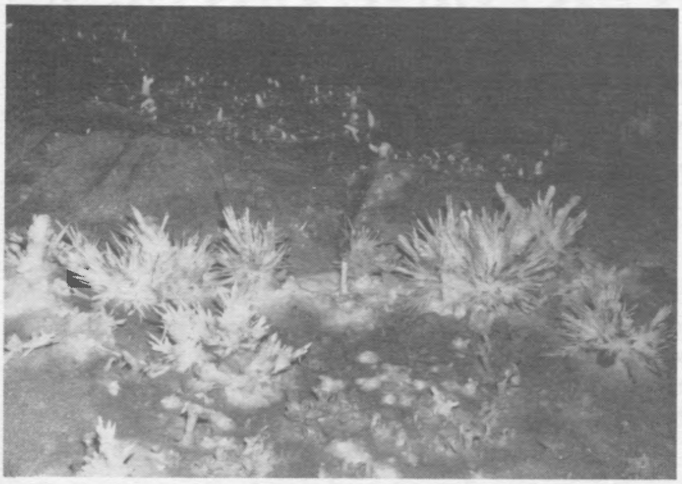

Figure 1a. A selection of the anthodites that occur in Skyline Caverns showing types of radiating clusters (a. and b.) and more massive speleothems (c.). The typical cluster is about 10 cm across.

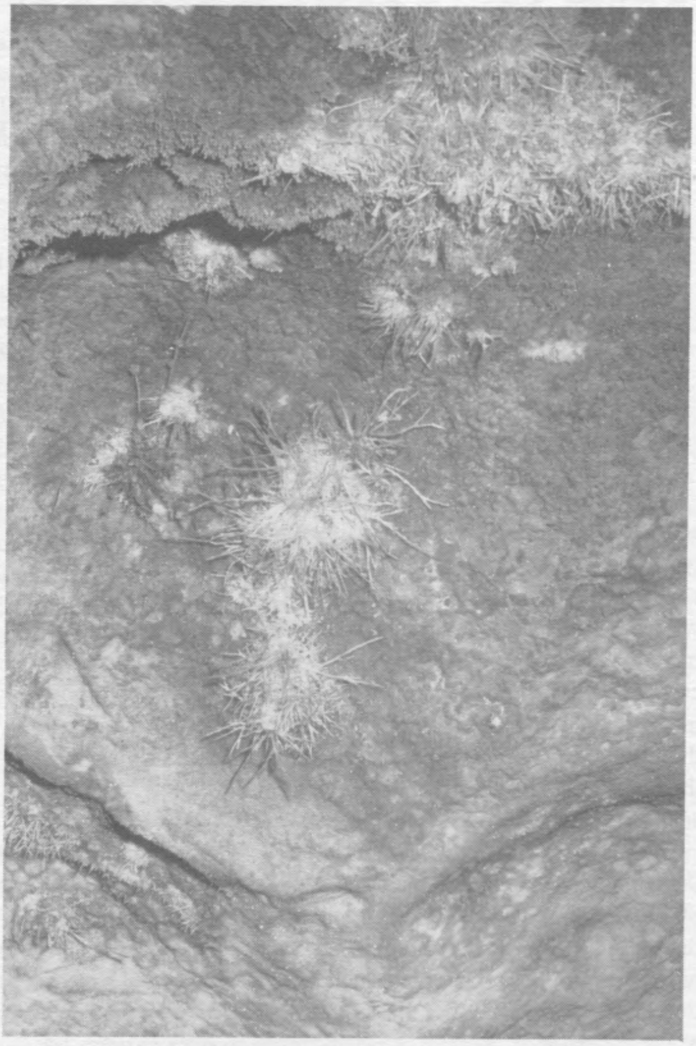

Figure 1b.

The distribution of trace elements in Figure 3 poses a problem. Although the plot is as expected from crystal chemistry—magnesium enriched in the calcite; strontium enriched in the aragonite—from morphological evidence the Skyline Caverns samples all originated as aragonite. The low-strontium, high-magnesium speleothem inverted to calcite, while the high-strontium, low-magnesium speleothem remained aragonite. The composition data used to map out the calcite and aragonite fields were collected on specimens which retained the crystal structure in which they precipitated.

The available data for the kinetics of aragonite/calcite inversion comes from Pleistocene corals taken from the Florida Keys (Siegel, 1960). The Florida corals grew as aragonite. The fraction that inverted to calcite in the roughly 2 million years since their deposition depended on the strontium content (Fig. 4). Siegel's data can be fitted with a linear segment as shown although the overall function must be assymtotic to both 0% conversion at short times and to 100% conversion at long time. However, the plot gives only a single isochron, not very well defined since the corals were described only as "Pleistocene." Other data such as Siegel's (1965) investigation of the aragonite in Great Onyx Cave, Kentucky do not provide evidence that the calcite now present in the specimens was inverted from aragonite and not a primary precipitate.

The mole fractions of strontium carbonate in the Skyline Caverns specimens would plot on Figure 4 near the left edge of the diagram, well to the left of the Pleistocene isochron, thus implying a younger age. How much younger cannot be determined with precision from the available data. The data do suggest an early to middle Pleistocene age, which is consistent with the location of the cave in the valley uplands of the Shenandoah River drainage (White and White, 1991).

Age dating by determination of calcite/aragonite ratios in speleothems that originally precipitated as aragonite seems to have some promise, although the results presented here are too fragmentary to be more than suggestive.

In summary: the anthodites from Skyline Caverns have the morphology expected for primary precipitation as aragonite. However, the deposits are sufficiently old that some of them have inverted to calcite. The inversion is related to both strontium and magnesium trace element contents.

ACKNOWLEDGEMENTS

The management of Skyline Caverns is thanked for the loan of the anthodite specimens. Acknowledgement is made to the Donors of the Petroleum Research Fund, administered by the American Chemical Society, for the support of this research.

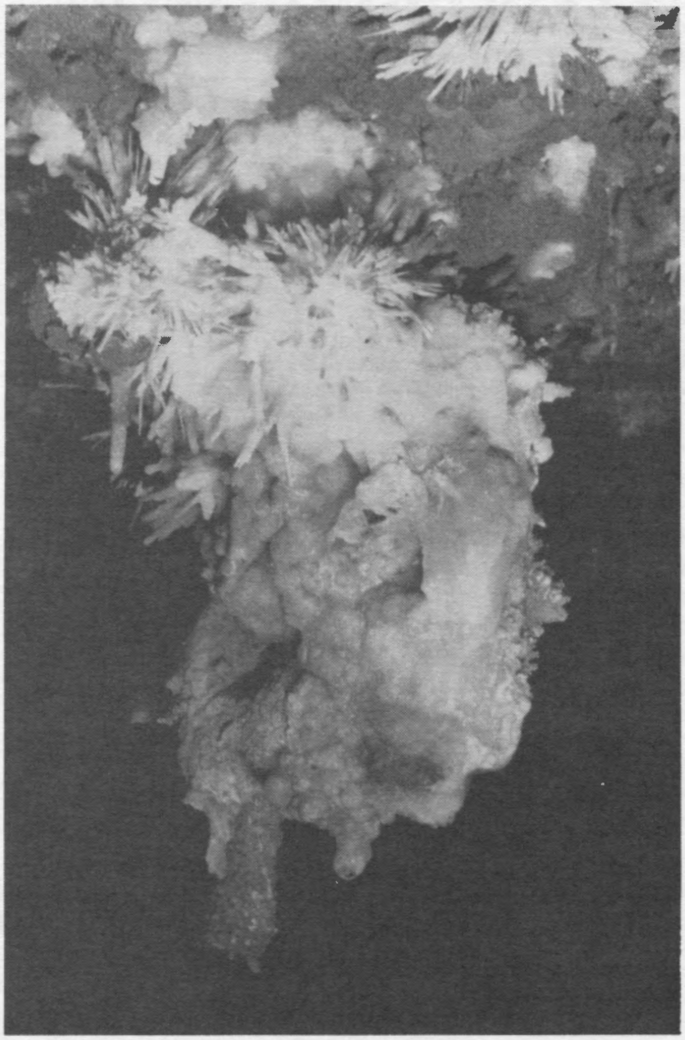

Figure 1c. A selection of the anthodites that occur in Skyline Caverns showing types of radiating clusters (a. and b.) and more massive speleothems (c.). The typical cluster is about 10 cm across.

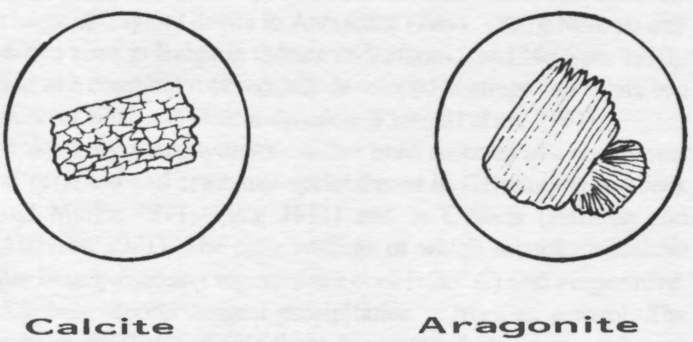

Figure 2. Microscope sketches showing contrasting textures of calcite and aragonite specimens. Circle diameter about 1.5 cm.

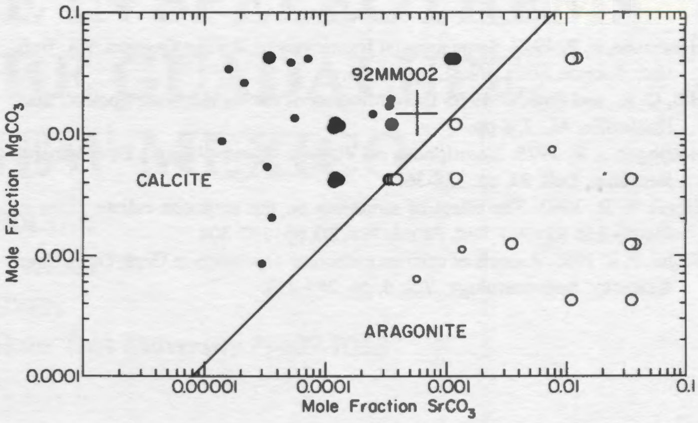

Figure 3. Partitioning of strontium and magnesium into calcite and aragonite based on chemical analyses. Open circles are analyses of aragonite; closed circles are analyses of calcite. Large circles are a set of previously unpublished analyses of speleothems from Pennsylvania done with a rapid semi-quantitative emission spectroscopic method (White and Ellisher, 1958). The accuracy is only to half an order of magnitude. Small circles are analyses from various literature sources for which both Sr and Mg concentrations are given.

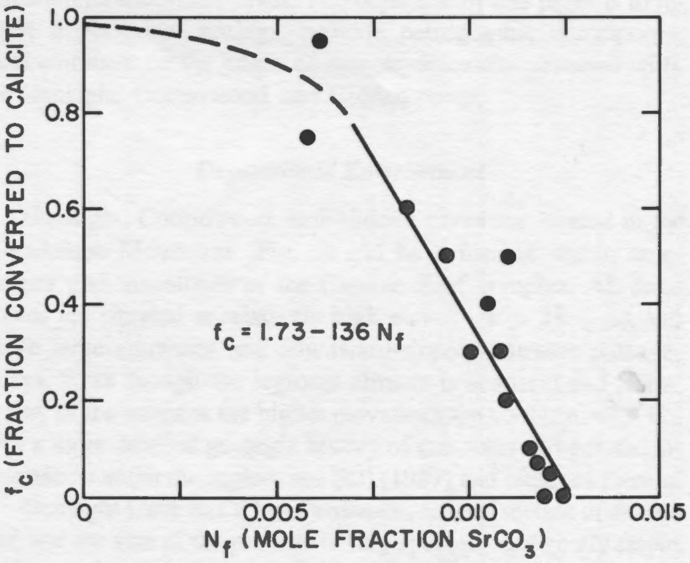

Figure 4. Fractional conversion to aragonite to calcite in Pleistocene corals from the Florida Keys as a function of strontium content. Data from Siegel (1960). Equation gives linear least squares fit to data.

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MONOHYDROCALCITE IN SPELEOTHEMS FROM CAVES IN THE GUADALUPE MOUNTAINS, NEW MEXICO

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Monohydrocalcite, a hydrated carbonate mineral which has been rarely documented in caves, has been found in crusts in three caves of the Guadalupe Mountains. The settings in which monohydrocalcite crusts were observed are near or adjacent to the zone of indirect light (twilight zone) of caves having large entrances with downward sloping passages. These areas are cool (<12° C) and organic materials are associated with the crusts. In two caves, Gunsight and Cottonwood, monohydrocalcite, hydromagnesite, aragonite, and dolomite are constituents in crusts which have formed on inactive stalagmites in the zone of indirect light; precipitation of these minerals seems to have been from aerosols generated by collision of dripping water with the cave floor. In Hidden Cave monohydrocalcite with minor amounts of aragonite are constituents of crusts that have formed on broken stalactites lying on a silty mud floor which was moistened by small intermittent streams in a zone of complete darkness at the fringe of the twilight zone.

INTRODUCTION

Monohydrocalcite ($CaC0_3 . \bullet H_20$) is a rare mineral having been documented in nature in only a few localities in the world. The first documentation of monohydrocalcite in a natural setting was by Sapozhnikov and Tsvetkov (1959) as precipitates in a lake bottom in the former Soviet Union. It has been reported in lake sediments of Australia (Last and De Deckker, 1990), East Africa (Stoffers et al., 1974), and southwestern U.S.A. (Benson et al., 1991). It also is included in beachrock and tufaceous-like material surrounding small lakes in southeastern Australia (Taylor, 1975). Monohydrocalcite has been found as precipitates in animals by Carlstrom (1963) in otoliths of tiger sharks, and by Skinner and Osbaldiston (1977) in the bladder stone of a guinea pig. The mineral has been reported in minor amounts from saline discharge of Taylor Glacier in Antarctica (Keys, 1982); from an oxidation zone in Bulgaria (Minceva-Stefanova and Neykov, 1990); and as a constituent of recently developed coatings and crusts in a mine in what was Czechoslovakia (Ridkosil et al., 1991).

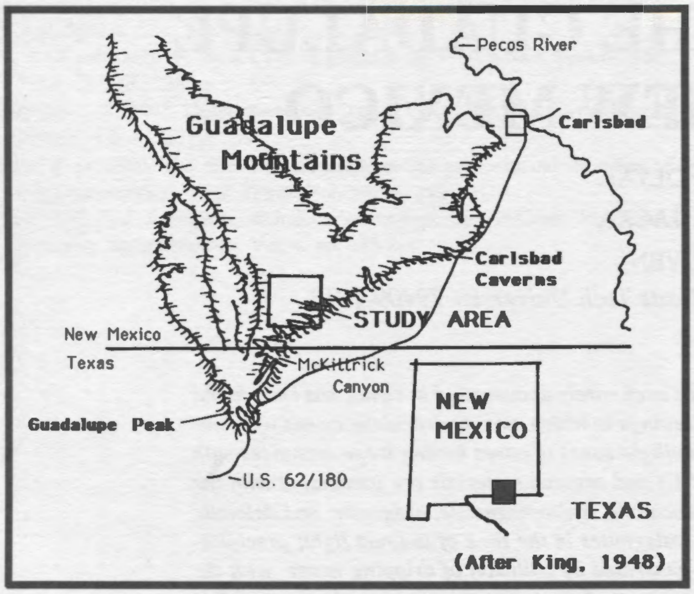
In caves, monohydrocalcite has been reported as a constituent of coralloid and crust-like speleothems in Germany (Fischbeck and Müller 1971; Tietz 1981) and in Canada (Harmon and Atkinson 1981). The cave settings in which monohydrocalcite has been previously reported are cool (<20° C) and evaporative. All three reports suggest precipitation is from an aerosol. The authors are aware of only these documented cave occurrences of monohydrocalcite. Little is known about the extent of deposition of the hydrated carbonate in caves, and petrographic descriptions of the mineral are lacking.

This study addresses the presence of monohydrocalcite in Guadalupe Mountain caves. The objective of this paper is to report depositional settings, provide petrographic descriptions, and comment on the origin of monohydrocalcite observed within Gunsight, Cottonwood, and Hidden caves.

Depositional Environment

Gunsight, Cottonwood, and Hidden caves are located in the Guadalupe Mountains (Fig. 1) and have formed within dolostones and limestones of the Capitan Reef complex. All three caves are situated at relatively high elevations (> 1800 m), and have large entrances and downward-sloping entrance passageways. Even though the regional climate is semiarid and warm, many of the caves at the higher elevations are cool (i.e. <15° C). For a more detailed geologic history of the caves and general information about the region, see Hill (1987) and citations therein.

Gunsight Cave has a large entrance, tens of meters in diameter, and the size of the passage is very spacious and gently slopes downward several hundred meters to the back of the cave, which in the late winter of 1992 had a measured temperature of 8°C and a relative humidity of 77%. Faint indirect light penetrates to the farthest reaches of Gunsight Cave. The cave floor consists mostly of breakdown boulders covered with a thin layer of dry dust; bird and bat guano, bone, and plant debris sparsely litter the floor. The few actively dripping areas have speleothems such as stalagmites, flowstone, and coatings and crusts. Two small stalagmites and a stalactite mid-section were collected adjacent to dripping areas and were covered with thin crusts. Deposition



(After King, 1948)

Figure 1. Location map showing the Guadalupe Mountains, New Mexico and Texas, and study area.

of crusts were not observed on speleothems receiving active drip water, but were observed covering inactive dripstones immediately surrounding these active areas, and seemed to be restricted to these areas.

Thin crusts in Cottonwood Cave are similar to those of Gunsight Cave. Cottonwood Cave has a large entrance and a voluminous front chamber which slopes gradually downward and extends over 300 meters. Air temperature and relative humidity were measured in the summer of 1991 as 10°C and 95%. Massive speleothems decorate the front chamber, and the cave floor consists mostly of breakdown blocks and flowstones. A fragment of stalagmite enveloped by a thin crust was collected in an area of large speleothems approximately 100 meters from the cave entrance. A fragment of rimstone dam also was collected at the base of large stalagmites 260 meters into the front chamber. Dripping water was more active in these two areas of the front chamber, and organic debris such as bird and bat guano, and invertebrate parts also were observed.

Hidden Cave has a large entrance and an entrance passage which steeply descends 25 meters to the cave floor. Air temperature and relative humidity in the cave were measured in the summer of 1991 as 11°C and 94%, and in the winter of 1992 as 9°C and 85%. The floor in much of the cave is flat and consists of a silty organic-rich mud. Many areas show evidence of small intermittent streams which probably are active only during periods of heavy rainfall or rapid snow melt. While the streams were not observed running, much of the water seems to enter from inlets other than the main entrance. A small mid-section of broken stalactite, lying in-place (undisturbed) in the silty mud, was observed having brown tufaceous-like crust which formed on the exposed surface, whereas the buried surface had no crust. In-situ stalagmites have similar crusts around their bases; these stalagmites were inactive when observations were made. Brown tufaceous-like crusts also formed on small breakdown rubble on the mud floor where runoff water enters the room. A stalactite mid-section covered with this crust was collected from the same room. Sediment comprising the mud floor is rich in detrital quartz and organic debris. Small bits of bones, wood, leaves, and pine needles are incorporated into the silty mud.

METHODS

Approximately 100 samples were collected from 10 caves as part of a study of the mineralogy, petrography, and diagenesis of carbonate speleothems. During the study, six samples were found to contain monohydrocalcite, and these were selected for analyses. The samples collected were inactive and water chemistry was not available. Cave temperature and humidity measurements were performed with a sling psychrometer. Thin sections of the samples were prepared and stained with Feigl's solution and alizarin red-S. Random powder X-ray diffraction (XRD) was performed using a Philips Norelco diffractometer operated at 40 kV and 20 mA with nickel filtered Cu-Kα radiation. A Gandolfi camera (114.6 mm diameter) was used to perform XRD of small multicrystalline grains removed from the Hidden Cave crust. X-ray microanalysis of monohydrocalcite was carried out using a Kevex 8000 analyzer attached to a JEM 100 CX electron microscope column. Unit cell parameters were determined using the Appleman and Evans (1973) indexing and least-squares powder diffraction program revised for the PC by Benoit (1987). The Geological Society of America (GSA) rock-color chart was used to determine speleothem color.

RESULTS

The speleothems found to contain monohydrocalcite all were crusts, and were deposited on six of the collected samples; these consisted of two stalactite mid-sections, three stalagmites, and rimstone dam. All six were located in or adjacent to the twilight zones of the three caves. Crust containing monohydrocalcite had only trace amounts of calcite directly associated. Gunsight Cave crust contained monohydrocalcite, hydromagnesite, and aragonite; calcite and dolomite, if present, were trace constituents. Cottonwood Cave crust was comprised of monohydrocalcite, hydromagnesite, aragonite, and dolomite. Hidden Cave crust contained monohydrocalcite and aragonite with minor amounts of calcite. Table 1 lists the relationship between cave occurrences, mineralogy and depositional settings.

SEM microanalysis provided the chemical composition of Hidden Cave monohydrocalcite. The analysis showed the presence of magnesium in some areas of the sample, but in other areas of the sample only calcium was present. Hexagonal unit cell parameters and principal X-ray diffraction interplanar spacings for monohydrocalcite from Hidden Cave were: a = 1.0564(4) nm, c =

Table 1. Characteristics of the cave settings in which monohydrocalcite has formed and the associated carbonate mineralogy. Temperatures and relative humidities are 1992 measurements and may not reflect those at the time of crust deposition.

CAVE	Gunsight	Cottonwood	Hidden
ASSOCIATED CARBONATE MINERALOGY	monohydrocalcite hydromagnesite aragonite	monohydrocalcite hydromagnesite aragonite dolomite	monohydrocalcite aragonite minor calcite
PRECIPITATING SOLUTION	aerosol	aerosol	water from small intermittent streams
SPELEOTHEM TYPE	crust on inactive stalagmites and stalactite mid-section	crust on rimstone dam and stalagmite	crust on stalactite mid-section
TEMPERATURE AND RELATIVE HUMIDITY	8° C (winter) 77% RH	10° C (summer) 95% RH	9° C (winter) 86% RH 11° C (summer) 94% RH
LOCATION OF CAVE SETTING	twilight zone	twilight zone	twilight zone and dark zone at fringe of twilight zone

0.7536(4) nm, V = 0.7328(6) nm^3; and d_{111} = 0.431 nm, d_{112} = 0.307 nm, d_{202} = 0.2902 nm, d_{301} = 0.2823 nm, d_{302} = 0.2378 nm.

Petrographic description of monohydrocalcite

In all three caves, monohydrocalcite precipitated as submicron to micron-sized (micron refers to micrometer) anhedral crystals, as wavy bands of subequant crystals less than 50 µm thick, and as spherules 20-50 µm in diameter. The predominant fabric in all samples is a mosaic of randomly oriented micron-sized anhedral crystals. SEM images of monohydrocalcite from Hidden Cave crust reveal very irregular and structureless tightly packed crystals (Fig. 2). Individual crystal boundaries are difficult to discern.

While X-ray diffraction is the best method for identifying monohydrocalcite, a tentative identification can be obtained using a polarizing microscope. Monohydrocalcite has moderate birefringence exhibiting second order to third order interference colors. The range of interference colors may be lower than expected owing to small crystal size. Extinction pattern is difficult to determine because of the small size and undulosity of the crystals. Alizarin red-S stains monohydrocalcite a slightly darker red than calcite and aragonite, and Feigl's solution does not stain monohydrocalcite or calcite.

Hidden Cave crusts are brownish-gray (5 YR 4/1) in reflected light and range up to 1 cm thick. The crust which formed on a stalactite mid-section lying on the mud floor contains an abundance of silt-sized detrital quartz grains, and where it is thickest it can be described as tufaceous-like. Figure 3 shows the Hidden Cave crust in thin section. Crusts containing monohydrocalcite from Gunsight Cave samples are less than 1 mm thick and yellowish-gray (5 Y 8/1) to light gray (N 8) in reflected light. The Gunsight Cave crust, in thin section, is shown in Figure 4. Crusts from Cottonwood Cave samples are dark yellowish brown (10 YR 4/2) to light olive gray (5 Y 5/2), and less than 0.5 mm thick.

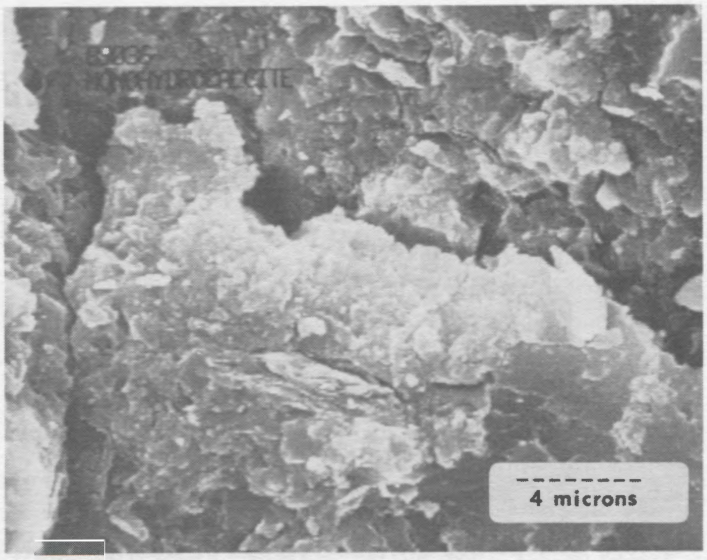


Figure 2. SEM micrograph showing tightly packed anhedral crystals of monohydrocalcite in the Hidden Cave crust.

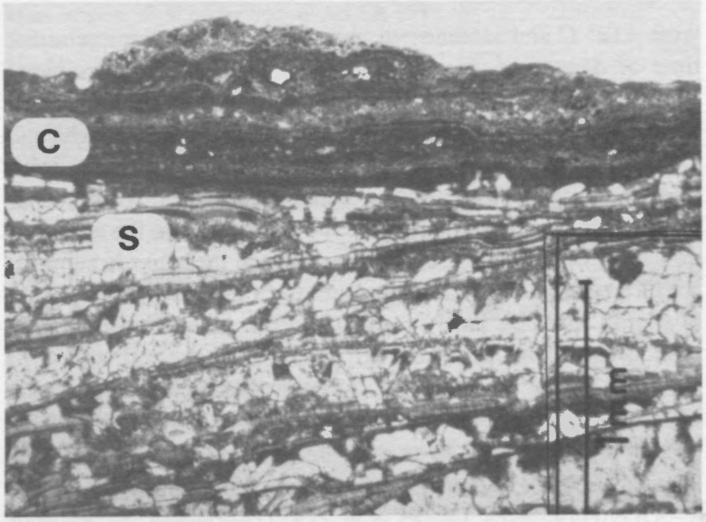


Figure 3. Thin section photomicrograph of Hidden Cave crust (C) which consists of monohydrocalcite, minor amounts of aragonite, and detrital quartz silt. The crust formed on a stalactite mid-section (S) which consists of alternating layers of calcite and aragonite.

DISCUSSION

Fischbeck (1976) suggested that monohydrocalcite can precipitate from solutions with a Mg/Ca ratio >1 at temperatures below 20°C. Temperatures measured in the caves of this study

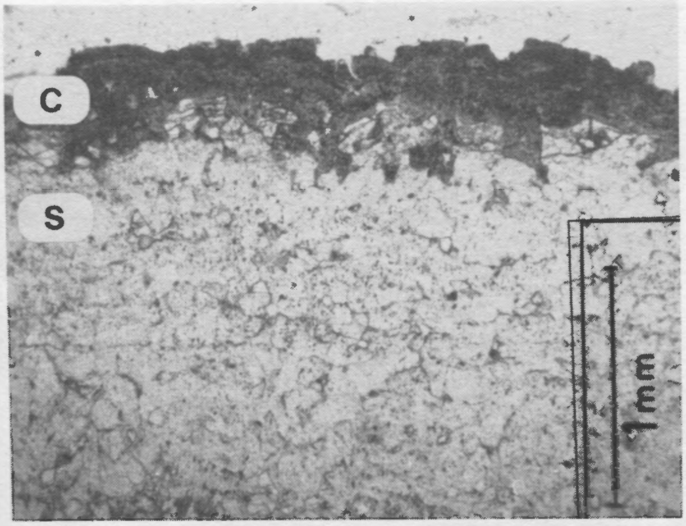


Figure 4. Thin section photomicrograph of Gunsight Cave crust (c) which consists of monohydrocalcite, hydromagnesite, and aragonite. The crust formed on a small stalagmite (s) which consists of calcite.

were <12° C and assumed to represent the temperatures at the time of deposition. No water chemistry data, however, were available regarding the concentrations in the cave solutions. The presence of hydromagnesite and dolomite in the Gunsight and Cottonwood crusts definitely indicate that the precipitating solutions were rich in magnesium. Some magnesium, while not as convincing, also was found to be incorporated into the monohydrocalcite of Hidden Cave. Some evidence therefore is supportive of the availability of magnesium from the precipitating solutions and could be partly responsible for the mineralization of monohydrocalcite as Fischbeck (1976) has suggested.

An additional variable that may be involved in the precipitation of monohydrocalcite in Guadalupe Mountains caves is the presence of organic matter. In an experiment simulating carbonate diagenetic processes occurring in evaporative shallow-water, organic-rich environments, Davies et al. (1977) attributed the origin of monohydrocalcite to soluble organic material and high Mg concentrations. They postulated that magnesium inhibited calcite nucleation and organic substances such as humic acids inhibited aragonite nucleation, therefore nucleation of monohydrocalcite was possible. Carlstrom (1963), Taylor (1975), and Skinner et al. (1977) also relate the origin of monohydrocalcite to organic matter or biological activity. Organic matter observed in thin sections of the crusts such as arthropod parts and plant debris provide evidence of an organic component which may have possibly played a similar role in the origin of cave monohydrocalcite.

In Gunsight and Cottonwood caves, monohydrocalcite with hydromagnesite and aragonite precipitate as crusts probably from an aerosol that is produced by the impact of drip water. Fischbeck and Müller (1971) proposed this origin for monohydrocalcite in crusts from a small cave in Germany. They indicate that the aerosol is produced by the ejection of small droplets from dripping water, and is transported by air currents generated by convection owing to an upper and lower entrance to the cave. In Gunsight and Cottonwood caves, the aerosol is carried only a short distance, and as a result, precipitation has occurred in areas immediately adjacent to areas of dripping water.

In the case of monohydrocalcite crusts from Hidden Cave, the abundance of detrital quartz, organic debris, and the setting in which the crust formed suggest that the precipitating solution was running water within the cave. Origin of monohydrocalcite in Hidden Cave appears to be related to cool temperatures, water from rain or snow runoff, and a silty mud floor containing much organic matter. The origin of Hidden Cave monohydrocalcite (runoff water along the mud floor) seems to be different than the other two caves (aerosol), but all three settings have at least two variables in common, cool temperatures and the presence of organic matter.

CONCLUSION

Precipitation of monohydrocalcite seems to be favored in cave settings with magnesium rich solutions at lower temperatures in the presence of organic matter. Monohydrocalcite has been observed in crusts in three caves with these characteristics. In the Guadalupe Mountains, such a cave setting generally will be in or near the zone of indirect light within caves having large entrances and downward-sloping passages.

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TWO NEW TYPES OF GYPSUM SPELEOTHEMS FROM NEW MEXICO: GYPSUM TRAYS AND GYPSUM DUST

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In this paper two new types of speleothems are described, and their genesis is discussed on the basis of the available climatic and hydrodynamic data. The speleothems are located in the Permian-age gypsum karst area of New Mexico, in several caves close to Carlsbad and Roswell (Rocking Chair Cave and Park's Ranch Cave). Inside of these caves gypsum speleothems are widespread and more developed than in the other gypsum karst areas of the world. In two cases the gypsum speleothems were identified which now or have never been described before in the literature. Gypsum trays are a type of stalactite with sub-horizontal development and a maximum axis of elongation outwards from the wall (Rocking Chair Cave). They are the product of evaporation and air flow direction and velocity, which factors control deposition and the expansion level of the speleothem. Gypsum dust is a powdery deposit (crystal size range between 15-30μ) located on the walls and ceiling of the first 300-500 m of Park's Ranch Cave, close to the entrance. Scanning electron microscope observations show that the dust is composed of small aggregate grains of gypsum crystals partially cemented by very small calcite grains (3-5% $CaCO_3$ total dust composition). Its genesis is related to seasonal variations of deposition (dry conditions) and dissolution (flood conditions).

INTRODUCTION

For a long time gypsum karst has been thought of as a second class phenomenon, far less interesting than limestone karst.

Only since the 1980's cavers and scientists have realized that gypsum karst may develop peculiar epigean and hypogean morphologies which often are of as great an interest as those in limestone (AA.VV. 1986; AA.VV. 1989). Speleothems are normally not widespread in the gypsum caves of the world and therefore papers on the genesis of chemical deposits in these caves are rare. Recently, a general study has been started on gypsum-karst speleogenesis in the different climatic zones of the world. Such research (still in progress) has so far shown that gypsum karst may differ significantly from limestone karst with respect to speleothems, several peculiar chemical deposits being developed in it (Forti & Rabbi, 1981; Calaforra et al., 1992).

As a part of this systematic study of the gypsum karst of the world, members of the *Gypcap Project* of the NSS invited us to visit the most interesting gypsum caves of New Mexico previously studied by Gypcap Project (1987) and Peeman & Belski (1991). Among the most interesting things we had the chance to see during this trip were some strange stalactites in Rocking Chair Cave (Fig. 1) and a deposit of gypsum powder in Park's Ranch Cave (Fig. 6). Both are new speleothem types (Hill and Foti, 1986) and are the subject of this paper.

GYPSUM TRAYS, ROCKING CHAIR CAVE

Rocking Chair Cave is a middle-sized length cave developed in the Permian gypsum outcrop northeast of Carlsbad in the midst of the oil field lay Burton Flat. This cave has been mapped (over 1500 feet of passage) by Pecos Valley Grotto members in the late 1980's (Peerman S. and Belski D., 1991). From the ceiling of one of the rooms in Rocking Chair Cave are several stalactites with a very strange shape: in fact, their vertical development stops at a certain level, and then the speleothem expands subhorizontally thus looking like an elephant foot or a turned tray (Fig. 2). The stalactites are growing in a large room connected to the entrance by a squeeze while some different small galleries lead to the deeper part of the cave and some short pits allow access to a lower level. The room is about 15 m in length, 7 m wide, while its maximun height is 3-4 meters.

The stalacites are gypsum trays. The name "trays" was derived from very similar carbonate formations of the Cango III and Thabazimbi caves in South Africa described by Martini (1986, p. 46), but in the Rocking Chair Cave the trays are composed of pure gypsum while in the caves of South Africa aragonite needles predominate over pseudomorphic calcite.

The gypsum trays have their sub-horizontal development at different heights in the gallery, therefore their shape cannot be related to a water or mud level: it is evident that they start to displace themselves just when reaching the middle of the gallery.

Fig. 1. (photo) The "Christmas Tree" of the Rocking Chair Cave: the speleothem consists of a gypsum tray under which a stalagmite is growing.

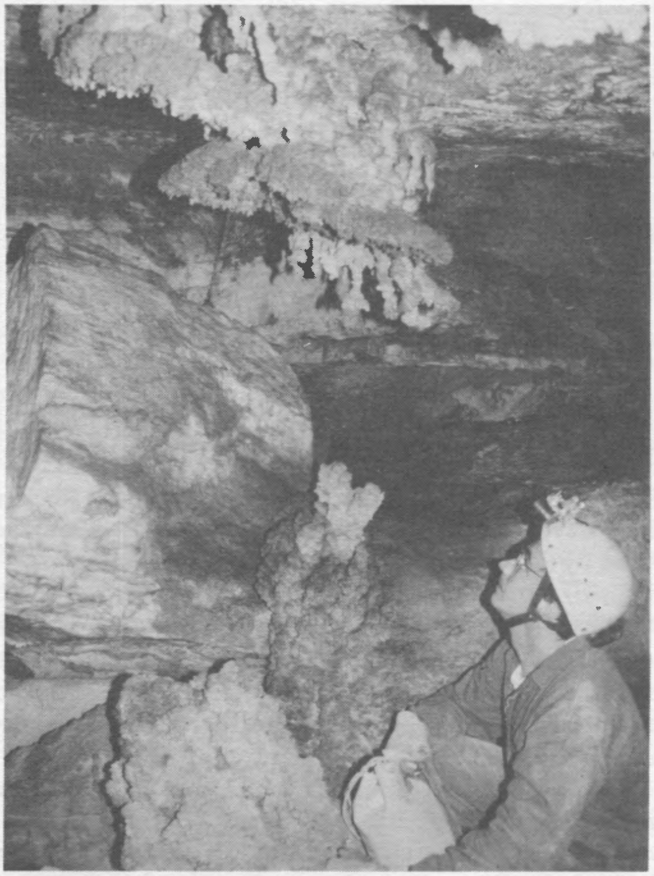

Fig 2. (photo) General view of the gypsum trays of the Rocking Chair Cave, New Mexico.

The diameter of the sub-horizontal part of tray may reach up to 0.5 m. Rarely they have a perfectly circular shape, but normally they are asymmetrically elongated. All the gypsum trays in Rocking Chair Cave grow close to walls and have their maximun elongation toward the center of the room. The observed asymmetry for all the stalactites are similar in size and direction (Fig. 3), thus suggesting their relationship to the direction of dominant air circulation in the gallery.

Morphologically the upper part of a gypsum tray corresponds to a normal stalactite which is fed by the flowing water over its external surface. The inner hole is closed as normal: in fact, only the gypsum soda straws may sometimes have their holes open, while the depositional process rapidly fills the feeding tube of the stalactites (Hill & Forti, 1986). At a given height the gypsum stalactite starts expanding horizontally forming like an asymmetrical shield. The lower part of the stalactite is characterized by the presence of several gypsum coralloids and some small gypsum stalactites, the last developing where the water supply is sufficient for dripping.

It is well known that the gypsum speleothems are the product of evaporation (Hill & Forti, 1986). The development of the gypsum trays in Rocking Chair Cave confirms this mechanism, evaporation fundamentaly controlling the peculiar shape of these formations. The genetic mechanism for the origin of gypsum trays can be divided in to two steps. The first step consists in the growing of a normal gypsum stalactite which increases in length and thickness as usual. When the stalactite reaches a given height then its elongation stops and the second step of subhorizontal growth begins. This second stage is controlled, in our opinion, by the maximum evaporation-rate zone existing in the gallery. The shape and the height of this zone is not regular, being controlled by the local direction and speed of the air, thus causing different heights and bends in the trays. The fact that all the gypsum trays develop in the middle-high of the room as their asymmetric growth increases from the center to walls is consistent with the hypothesis of an air control upon them: in fact, air flow must be higher in the center of the room and must decrease radially up to the walls (Fig. 3).

Lastly, the development of the subhorizontal part of the trays suggests that in Rocking Chair Cave the air flow and water supply must have been very steady in order for suitable conditions to allow deposition of gypsum just on the edges of the trays. If the water supply had been increased the dripping should have

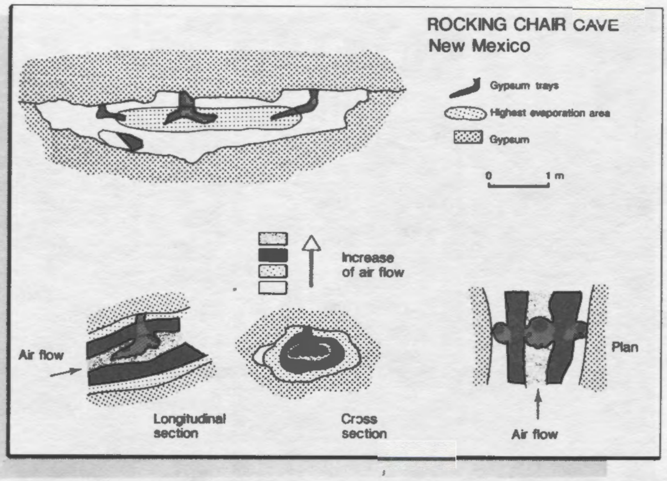

Fig. 3. Schematic plan and section of the area of the Rocking Chair Cave: the elongations of the gypsum trays are controlled by the direction and intensity of the air currents.

prevailed over the evaporation and consequently a new stalactite would have developed along the lower part of the trays. On the other hand, if the air flow had been increased, supersaturation conditions would have been reached sooner or later and therefore an upper or a lower tray would have developed.

The process of development of the gypsum trays is schematized in Figure 4. In the first step (Fig. 4.1) a normal stalactite is developed until the maximum evaporation level is reached, then a horizontal expansion of the top (Fig. 4.2 - 4.3) is caused by enhanced deposition at that level. If all the boundary physicochemical conditions are steadily maintained, then a gypsum tray will originate (Fig. 4.4).

In Rocking Chair Cave it is also possible to observe stalagmitic deposits related to the dripping from the gypsum trays pendants. The most spectacular example is given by a strange speleothem, called by local cavers "The Christmas Tree" (Fig. 1). This deposit is composed of a gypsum tray under which a stalactite seems to be (but in reality it is not) linked to the center of the horizontal part of the tray. The genesis and the development of the stalagmite in the lower part of the "Christmas Tree" is strictly controlled by the evolution of the upper part, the gypsum tray, which in turn is modified by the presence of the stalagmite. In fact, the space between the tray and the stalagmite is due to the setting up of opposite processes, evaporation and condensation, which two processes control the shape of both speleothems. The lower part of the trays has a deep bell-shaped surface, in which there is clear evidence of enhanced dissolution due to condensation, while the top of the stalagmite consists of vertically-elongated gypsum monocrystals, whose genesis seems to be related to capillary feeding and evaporation.

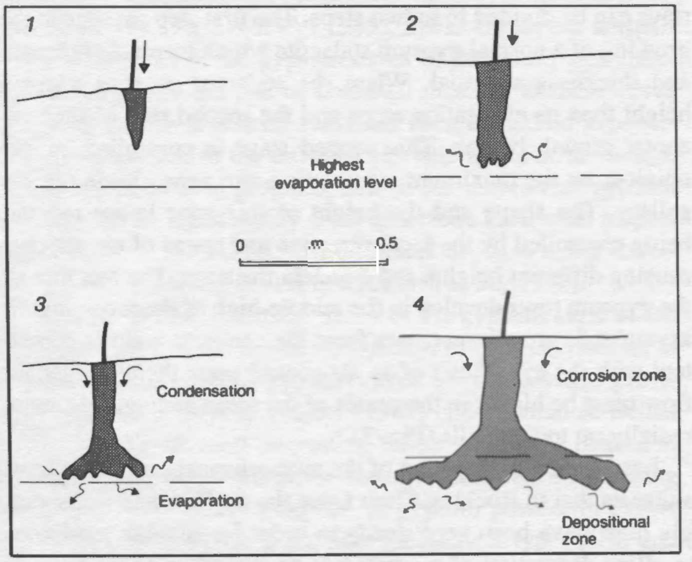

Fig. 4. Evolutionary steps for a gypsum tray.

Starting from these direct observations it is possible to schematize the developmental stages for the trays-stalagmites as follows (Fig. 5): during an initial step a normal stalactite and stalagmite are deposited. When the top of the stalactite reaches the maximum evaporation line, it starts to transform into a tray and then a peculiar microenvironment is created between the tray and the stalagmite. Moisture coming from the evaporation on the top of the stalagmite is forced by convection to reach the lower part of the tray where it condenses. As condensation is maximum just on the apex of the stalagmite in that place of the tray the condensation-corrosion will be more active on the tray, thus causing the development of a corrosion dome corresponding to the apex of the stalagmite (Fig. 5). Condensation water flowing along the dome surface rapidly becomes saturated with respect to gypsum and when it arrives sufficiently apart from the center of the bell shaped cavity, the presence of the strong air current causes evaporation to prevail over condensation, thus creating

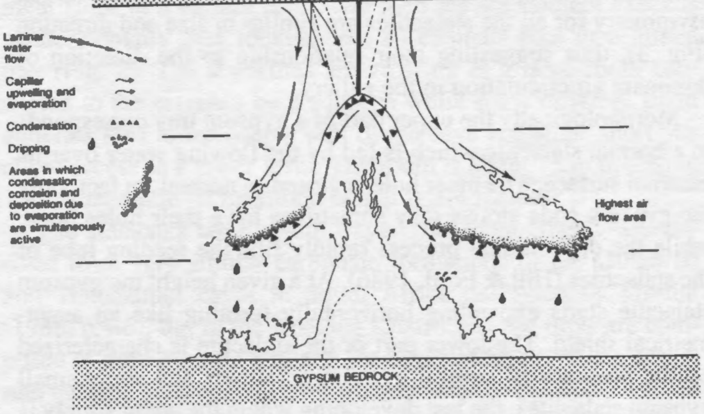

Fig. 5. Cross section of the "Christmas Tree" to put in evidence the evaporation-condensation processes active in the space between the tray and the stalagmite.

gypsum popcorn on the lower part of the tray. Condensation water, in excess with respect to water removed by evaporation, feeds the dripping, which in turn reaches the crystal at the top of the stalagmite by capillarity from which the cycle restarts. The permanent condition of undersaturation at the top of the dome avoids the possibility of linking between the stalagmite top and the trays.

GYPSUM DUST, PARK'S RANCH CAVE

The Park's Ranch Cave is the karst drainage of a wide area, not far from the Rocking Chair Cave entrance, developed in Castile anhydrite/gypsum Formation. Park's Ranch, southwest of Carlsbad, is only a few miles from the nearest highway on land managed by the Bureau of Land Management. This cave has been mapped in the late 1960's (over 9000 feet) but recent surveys have discovered more passage and entrances (19 to date) with a total map over 19,000 feet (Peerman, S. and Belski, D., 1991). The cave, in its first part, consists of a large subcircular or elliptical tube with a diameter ranging from 1.5 to 2.5 m. Inside the cave, even in dry conditions, a small active stream flow and a strong air current are present. In the first 300-500 meters of the cave, the walls and the ceiling of the main passages are completely covered by scallops which testify to the complete flooding of this portion of the cave during rainstorms. The first part of the cave is lacking in normal speleothems, due to its active drainage condition. The only chemical deposit present is some macrocrystaline gypsum boxwork made evident by the rapid dissolution of the microcrystaline walls of the gypsum tube.

At the time of our research several tens of meters of the gallery of the main entrance were covered by a white impalpable dust deposit, which became thicker getting closer to the vertical fractures (Fig. 6). Normally the thickness of the dust was less than 1 mm but in some cases, as in presence of small jutting points, it was 1 cm thick or more.

Chemical analyses show that this dust in Park's Ranch Cave consists of about 95-97% gypsum and 3-5% calcite. Scanning electron microscope observations showed that the dust is formed by small aggregates of gypsum crystals, with mean size ranges from between 15 and 30 μ, which are partially cemented togeth-

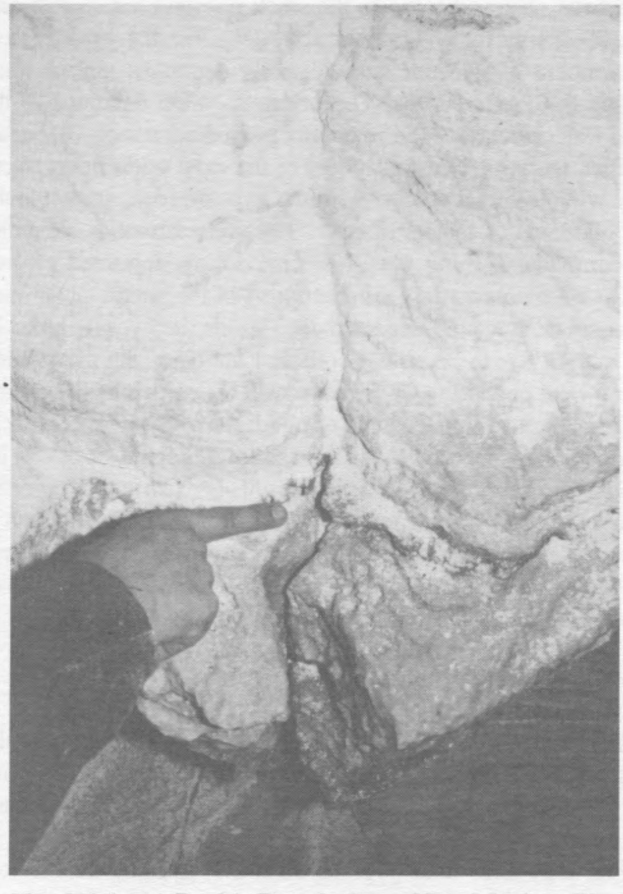

Fig. 6. (photo) Park's Ranch Cave, New Mexico: The wall of the main gallery is completely covered by gypsum dust. The vertical fractures which allowed the infiltration in the bedrock are evident.

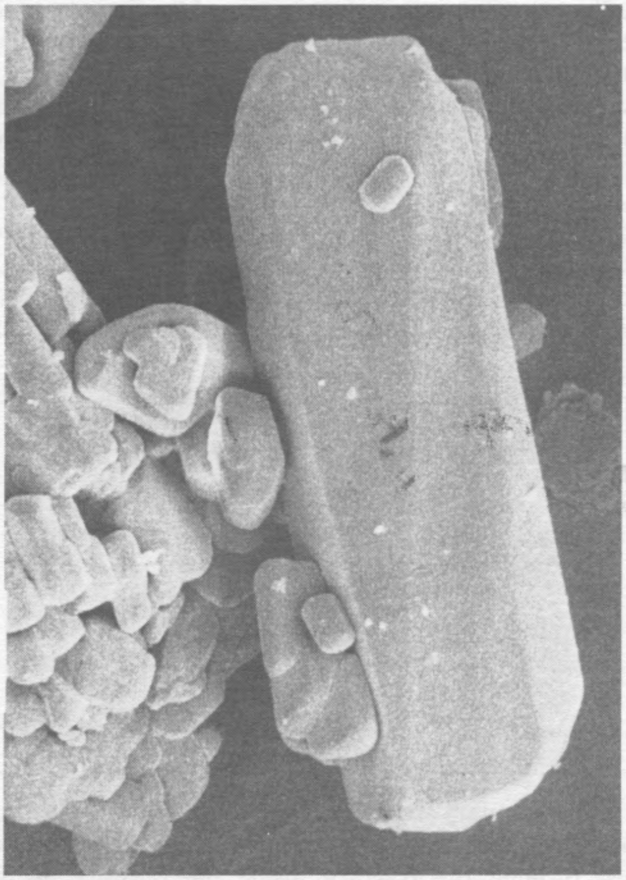

Fig. 7. (photo) Electron Scanning Microscope view of the gypsum crystals (10-50 microns) of the dust: several very small calcite grains are visible over them.

er by very small calcite grains (Fig. 7). The chemical composition and the structure of the dust suggest that such a deposit was produced by the total evaporation of a meteoric water saturated with respect to gypsum.

Until now only two gypsum powder deposits were known from caves: the first is the mineralization product of thick guano deposits in the St. Ninfa Cave in Sicily (Forti, 1989), and the second is the segregation deposit over large ice flowstones of the Kungur Cave in Siberia (Forti, 1990). Neither of these deposits is related to gypsum dust in the Park's Ranch Cave. In order to understand the origin of gypsum dust deposits in Park's Ranch Cave, it is necessary to look at the climatic and hydrodynamic conditions peculiar to this cave, and to consider the medium to high porosity of the microcrystalline gypsum bedrock.

For most of the year a very small river flows inside Park's Ranch Cave, while strong air currents together with a low relative humidity and a sufficiently high temperature cause fast evaporation rates. During short flood periods, however, the flow inside the Park's Ranch Cave is so high that the main gallery is insufficient to drain all of the incoming water and therefore becomes completely flooded. Thus, saturated conditions are temporarily established inside the cave, as testified by the evolution of scallops over the walls and the ceiling of the first part of the gallery. As the flood conditions pass, saturated conditions are terminated as quickly as they were established, and the cave is again subject to strong air flow evaporation. The presence of such short periods of flood, followed by long intervals of high air flow are the factors controlling the development of the gypsum dust deposits.

During the time of flooding, water is 'injected' deep inside fractures and pores of the microcrystalline gypsum rock (Fig. 8 left). The water in contact with this bedrock becomes rapidly saturated with respect to gypsum; when the flood subsides, capillary forces make the water migrate along the intergranular voids up to the cave walls and this process is sufficiently slow to spread small volumes of water over a relative wide area. The air currents and the relative low cave humidity cause a fast and complete evaporation of the appearing water, so causing the deposition of the gypsum dust (Fig. 8 right). The high supersaturation degree reached as a consequence of the strong evaporation rate justifies the presence in the dust of very small crystalline elements, while the fact that the process goes on until all the water is completely dried causes the deposition of the few calcium carbonate present in the solution over the gypsum crystals. During the long unflooded periods the cave air is sufficiently hot and dry to prevent condensation and consequently no redissolution phenomena may occur: therefore in all the dry periods the gypsum dust is mantained unaltered. On the contrary, during the short floods, the high flow rate, which is testified by the widespread scallops, and the consequent undersaturation of the cave waters lead to the complete redissolution and/or washing out of the gypsum dust deposits.

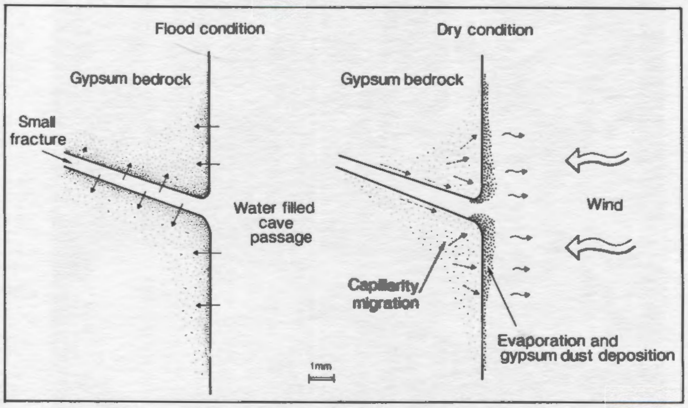

Fig. 8. Evolutionary steps for the gypsum dust of the Park's Ranch Cave. Left: during flooded conditions the waters are forced through the fracture inside the porosity of the bedrock; Right: when the vadose conditions are restored capillarity uplifting and evaporation cause the deposition of the gypsum dust.

The genetic mechanism, as outlined above, is in good agreement with direct observation: in fact, thicker gypsum dust deposits have been observed close to the small fractures which represent the easiest way for water 'injection' deep into the gypsum rock. The amount of gypsum dust normally decreases rapidly while leaving the fracture rims. The undersaturation condition of the flood waters was not experimentally proved but it seems to be reasonable. During a rainstorm most of the cave water flows practically without direct contact with the gypsum rock, at least in the first hundreds of meters of cave. The undersaturation simplifies the complete washing out of the previously deposited gypsum dust and also avoids the chemical filling of the intergranular voids through which water is injected deep inside the gypsum bedrock.

Lastly it has to be pointed out that the complete evaporation of the water appearing on the cave wall is testified by the calcitic grains, which aggregates tens or hundreds of gypsum crystals in the dust. The observed value for the total amount of calcite inside the gypsum dust (3-5 % in weight) is exactly that expected from a meteoric water saturated with gypsum (Forti, 1992). It is still to be explained why no large gypsum dust deposits exist and why diagenetic processes have not transformed at least some of the dust into a cemented speleothem.

SUMMARY

Inside the gypsum caves of New Mexico, and in particular those in the Carlsbad area, some genetic mechanisms are active for the development of gypsum speleothems namely gypsum trays and gypsum dust.

The growth of both gypsum trays and gypsum dust is controlled by low humidity, strong air currents, sudden floods such as characterize these two caves and which are a direct consequence of the New Mexico climate. Therefore the existence of such speleothems confirms the general rule of very strict climatic control over the chemical deposits in gypsum caves (Calaforra et al., 1992). Such a relationship, which is certainly far stronger than in limestone karst, may be utilized in the future as a powerful tool to study the paleoclimatic evolution of the gypsum environment in different parts of the world.

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A STUDY OF FUNGI OF REMOTE SEDIMENTS IN WEST VIRGINIA CAVES AND A COMPARISON WITH REPORTED SPECIES IN THE LITERATURE

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This project was an attempt to determine whether populations of microflora could be used to identify uniquely remote (ancient) cave sediments via their microfloral "fingerprints." If so, then cross-correlations could perhaps be made with other sediments in the same or other regional caves, ultimately leading to the establishment of stratigraphic sequences in the karst region. Culture studies of samples obtained from large caves of the Greenbrier Karst of West Virginia revealed a variety of bacteria, actinomycetes, and fungi. Actinomycetes were dominated by members of Nocardia *and* Streptomyces, *followed by* Actinomadura, Pseudonocardia, *and* Thermoactinomyces. *A total of 35 fungal taxa was isolated, varying from four to eleven per sediment, including eight that could not be identified to the species level and may include undescribed forms. Present in these isolates were 20 genera, represented by 31 deuteromycetes, two members of the Mastigomycotina, and one ascomycete. Mycelia Sterilia were the most prominent forms, followed in decreasing order by* Aspergillus aureolatus, Byssochlamys fulva, Penicillium steckii, Gliocladium roseum, Paecilomyces varioti, Mortierella alpina, Aspergillus caespitoses, *and* Fusarium oxysporum. *The similarity between these microfloral fungi and those of desert or tropical soils is discussed. Reproducibility problems due to sample heterogeneity prevented establishment of the desired microfloral fingerprints of the sediments studied. Many fungi not previously reported from caves were found, and a preliminary comparison of these taxa with those reported in the scattered literature suggests the latter do not provide a representative picture of indigenous cave fungi remote from the entrances. Attempts to isolate the pathogen* Histoplasma capsulatum *were unsuccessful.*

INTRODUCTION

The examination of cave sediments to shed light on the ages or sequences of cavern development is not a new idea. Early speleologists looked for correlations between geologic processes evident in the surrounding base level streams with the periods of cavern development or cave sedimentation. Bretz, for example, suggested that the pervasive fine clay deposits in Missouri caves were laid down under the quiet phreatic conditions associated with arrested or stable water-table conditions at the close of a peneplanation cycle (Bretz, 1942). It has been suggested that caves in this West Virginia study area correspond to the Harrisburg Peneplain (Davies, 1958) and may be as old as 30 million years. This age is supported by a study of caves in Pocahontas County, West Virginia (Wolfe, 1964). The clastic fills in these caves may contain very complex clues to erosional sequences evident in the local base level streams, as reported for the Central Kentucky Karst region (Miotke and Palmer, 1972), but such studies must be approached with caution because of their complex nature (Howard, 1968).

More direct dating by utilizing $^{230}Th/^{234}U$ ratios in speleothems in Minnesota (Milske et al., 1983), and similar work from West Virginia caves in this area, have given speleothem dates as old as 200,000 years BP (Harmon et al., 1975). More elegant has been the use of magnetostratigraphic analysis of cave sediments. After preliminary studies in Bone-Norman Cave, West Virginia, had indicated ages of at least 750,000 years BP for undisturbed sediments (Schmidt, 1969), sediments in Mammoth Cave, Kentucky, were found giving ages of at least 1-2 million years BP (Schmidt, 1982).

Attempts at cave dating by close examination of materials found within clastic cave sediments have not been very successful. Pleistocene bones have been found in area caves (Guilday and McCrady, 1966; Guilday, 1971), but these have been mainly surficial deposits more recent than the sediments they overlie. *In situ* paleontological material of substantial antiquity does not appear to be known from remote cave sediments. The closest in approach to this projected investigation are cave-associated palynological studies. Unfortunately, these pollen studies have not been generally successful for correlation purposes in Pennsylvania (Guilday et al., 1964), nor in the Central Kentucky Karst (Wright et al., 1966) where systematic sampling of older cave sediments (Peterson, 1976) was not successful in detecting pollen.

With the foregoing in mind, an effort was made to see if remote West Virginia cave sediments (i.e., clastic fills at least 610 m (2,000 ft.) from known entrances and preferably in older abandoned upper levels) might be found that contain unique microfloral "fingerprint patterns." Remote ancient sediments were preferred to those near cave entrances to minimize possible contamination associated with heavy traffic patterns of transient fauna (human and otherwise) and to eliminate possible deleterious effects from exposure to light or from seasonal or diurnal temperature fluctuations outside the cave (Cropley, 1965). It was hoped that such ancient sediments would optimize the possibility that relict or perhaps even fossil forms might be resident therein. If such sediments could be sampled and studied, then the possibility of establishing inter- or intracave contemporaneity of these sediments could be explored and stratigraphic sequences outlined. This approach involves the following assumptions:

1) that such long term storage conditions in a substantially radiation-free environment at constant temperature and humidity, and with the absence of either physical disturbances or aqueous challenges to germination, would enhance the viability of at least some of the spores deposited within or on top of these sediments;

2) that dry, remote sediments could be found containing a variety of viable microflora, whether originally resident within or subsequently deposited thereon by air currents or transient fauna; and

3) that culturing these sediments would reveal unique microfloral distribution patterns that might serve as "fingerprints" of the deposits.

In the first regard, the long-term viability of spores stored under deep cave conditions is not known, no experiments having been conducted over the long time frames contemplated. Reports of 10,000 year old viable seeds of *Lupinus arcticus* appear to be unreliable (Milberg, 1990). The best that can be said is that microflora exhibit a long history in the fossil record, which attests to their diversity and ability to survive the rigors of preservation without substantial morphological deterioration. Cyanobacteria are known from cherts of the Belcher Supergroup, Canada, from about 2000 million BP, and the colonial fossil *Eosaccharomyces ramosus*, which resembles aggregations of slime molds, is found in the 900-1000 million BP mudstones of the Lakhanda Group of eastern Siberia (Knoll, 1992). Sheathed fungi and fungal spores have recently been observed in Triassic ambers (Poinar et al., 1993). Fossil fungal spores are abundant in some Cenozoic sediments (Elsik, 1970), and members of the genera *Meliola* and *Asterina* have been reported from Eocene deposits in western Tennessee (Dilcher, 1963). Caumartin may be right that there are no truly cavernicolous fungi (Caumartin, 1963), but fossil fungal sclerotia have been reported from Belgian cave sediments having ages estimated at 2750-7500 BP (Malloch et al., 1987). Whether they are properly termed fossil cave fungi is moot. What is germane is that "fossil" botanical remains of currently extant species *can* carry clues of the past, be it in the stomatal frequencies of *Quercus petraea* (Van Der Burgh et al., 1993) or the taxonomic distribution patterns of cave soil fungi.

In the second regard, one may question why no pollen was observed in the remote sediments sampled in Kentucky (Peterson, 1976), since it certainly would have been present outside the cave. Unless it somehow eluded the isolation procedure, pollen had either been ground down to unrecognizable morphologies by hydraulic transport processes, or its sedimentation rate from the subterranean airstream was sufficient to preclude its aerial transport over the long distances involved to the particular sampling sites. For the present study, however, even if the original sediments were devoid of viable fungal spores, given the long residence time, surficial accumulations from assorted transient cave fauna could become quite significant. Many organisms are known to harbor or transport fungi, including the cave rat *Neotoma magister* (Call, 1897), the troglobitic carabid cave beetles (Rossi, 1978), other arthropods (Mercado Sierra et al., 1988), man (Northup et al., 1992), and of course bats.

In the third regard, fingerprint patterns have been found to provide remarkable insights to a variety of studies, especially via the elemental isotope distribution patterns obtained by neutron activation analysis. The origins of some flint and copper stocks used by moundbuilding Amerindians for artifact preparation have been shown by this technique to be quite distant, demonstrating the existence of extensive trade patterns not previously recognized. Perhaps most outstanding is the isotopic iridium anomaly identified by neutron activation analysis in the thin, shaley layer marking the Cretaceous-Tertiary geological boundary, which was persuasively identified (Alvarez et al., 1990) as a marker for a massive extraterrestial impact upon the earth. This impact has recently been traced to the Chicxulub crater in the Yucatan (Kerr, 1992) with present debate on its presumed major role in the extensive biological extinctions associated with the end of the Cretaceous turning toward possible additional impacts, either asteroidal or cometary (Swisher et al., 1992; Kerr, 1993), and possibly volcanism (McLean, 1993).

Subsequent to the discovery of antibiotic properties associated with certain microflora, diverse scientific groups have eagerly sought exotic substrates for screening in various commercial applications (Holden, 1991), such as drugs from the sea (Ruggieri, 1976), industrial fermentation processes (Demain, 1981; Borman, 1992), anti-cancer agents in remote tropical rain forests (Anon, 1986), lignin-degrading fungi for the pulping step in papermaking (Anon, 1987), and thermophilic bacteria from geothermal sites (Borman, 1991), to name a few.

In order to pursue this study, organisms isolated from remote cave sediment samples were fermented and analyzed for biological activities by various screening procedures, with the fungi being classified down to the species level.

MATERIALS AND METHODS

Over the period June 1985 to February 1988, a series of eight sediment samples was collected from remote locations in various large caves in Greenbrier County, West Virginia, within about a 15 mile radius of Lewisburg. Because of their remoteness, the sample sites had not been heavily traversed by cavers. Caves sampled included The Greenbrier Caverns (the Organ Cave System) (Rutherford and Handley, 1976), The Hole (Rutherford, 1971), McClung Cave, Buckeye Creek Cave, and Dry Cave (Fig. 1). A sample size of approximately 200-350 cc of the cave sediment was scooped out from the surface downward to a depth of about 9-12 cm into freshly washed and dried, tin-lined metal containers with snug fitting plastic lids. Upon arrival at a central repository, samples were transferred into wide mouth, screw cap jars for protection from desiccation during in house storage at ambient temperature. The sample from Dry Cave was inadvertently frozen during transport (overnight in the trunk of a car during wintertime). At the same time, portions of these samples were forwarded to Pfizer, Inc. for culture studies.

The isolation procedures were on 2% tap water agar and M-3 medium (Rowbotham and Cross, 1977) for bacteria and actinomycetes, on glucose ammonium nitrate agar for fungi (Gochenaur, 1964), and *Histoplasma capsulatum* assays were made following the procedure of Emmons et al., (1977) using minced pieces of liver, spleen, and lung of mice injected with a suspension of the cave sample. With the exception of the *H. capsulatum* assays, half a gram of a sample was suspended in 50 ml sterile distilled water. The suspension was blended in a sterile blender twice each for 20 seconds and then poured into a sterile flask. The flask was shaken for 30 minutes on a rotary shaker at 200 rpm. Three ml of the suspension was pipetted into 7 ml sterile distilled water. From this the 1:1,000, 1:3,000, 1:10,000, and 1:100,000 dilutions were made. From each dilution an aliquot of 0.2 ml was evenly spread onto each of five agar medium plates with a glass rod. The plates were incubated at 24°C for two to four weeks for fungi, and 28°C for four days and for two weeks for bacteria and actinomycetes, respectively.

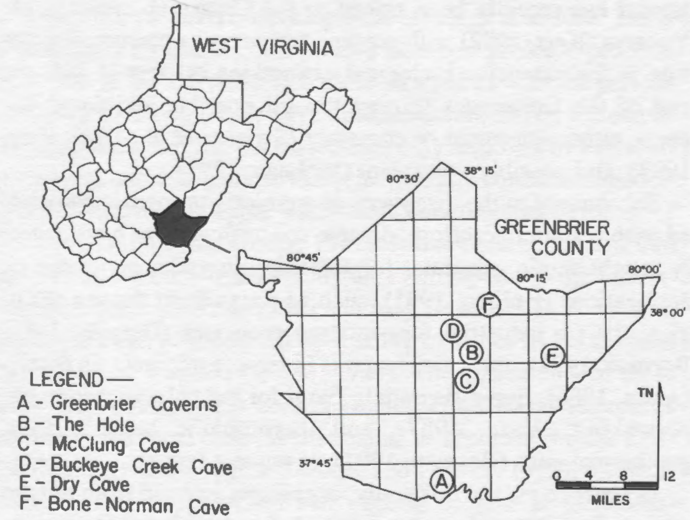

Figure 1.

For *H. capsulatum*, one gram of each of the cave samples was added to 10 ml of sterile distilled water in a 1 x 6 inch sterile test tube. The tube was placed on a wrist action shaker and shaken vigorously for 5 min. The suspension was allowed to settle for 5 min., and a 5 ml sample was withdrawn from the interface; 0.1 mg of chloramphenicol was added to the 5 ml interface; 1 ml of the interface suspension was IP injected into a 20 gram mouse with an 18-gauge needle. After one month the mouse was sacrificed and the crushed pieces of liver, lung, and spleen were plated on Sabouraud's dextrose agar. The plates were incubated at 28°C for two to three weeks and examined for the presence of *H. capsulatum.*

RESULTS

Bacteria and actinomycetes were the most common microbes found, with nocardioforms having by far the greatest abundance. No attempt was made to classify any of these to the species level, but after *Nocardia* in abundance came the *Streptomyces* and then *Actinomadura, Pseudonocardia,* and *Thermoactinomyces* in smaller numbers.

Fungi were classified down to the species level in most cases, although eight isolates could not be identified to the known species. The Greenbrier Caverns was sampled at four separate locations, making a total of eight different cave sediments. Table I shows all identified taxa from these initial studies, separated by sample of origin. It is noteworthy that only 10 of these 30 taxa (*Acremonium cerealis, Aspergillus aureolatus, Cladosporium cladosporioides, Humicola grisea, Mycelia Sterilia* (any member of the order Agonomycetales, which does not produce fruiting bodies upon culture for taxonomic identification), *Paecilomyces varioti, Penicillium notatum, P. steckii, Pythium* sp., and *Rhodotorula* sp.) were found in more than one sediment, and only *P. steckii* was found in more than one sediment from the same cave, despite the fact that half of the eight sediments were from Greenbrier Caverns.

In this study a total of 35 taxa from 20 genera was isolated from these remote cave sediments, with a single sediment yielding from four to eleven taxa. Of these taxa, 31 belong to the Deuteromycetes, two are Mastigomycotina, and one Ascomycetes. No Basidiomycetes were isolated, probably because the isolation medium favors various fungal groups such as zygomycetes, ascomycetes, hyphomycetes, and coelomycetes. The comparatively high number of Mycelia Sterilia isolates from the single sediment from The Hole is interesting, since it is commonly found in deserts and the tropics. Regarding the total number of isolates, these were followed in decreasing order by *Aspergillus*

Table 1. Number of Initial Fungal Isolates from Remote Cave Sediments

	Remote Cave Sediment Source [a]							
					Greenbrier Caverns			
TAXON	DRY	BCC	HOL	MCL	"A"	"B"	"C"	"D"
Acremonium cerealis (Karst.) W. Gams				1			2	
Acremonium sp.						1		
A. strictum W. Gams								9
Aspergillus aureolatus Munt.-Cvet.			1		328			
A. sclerotiorum Huber						1		
A. caespitosus Raper & Thom								53
A. versicolor (Vuill.) Tiraboschi	4							
Aureobasidium pullulans (deBary) Arnaud	1							
Byssochlamys fulva Olliver & Smith							273	
Chrysosporium pannorum (Link) Hughes (=*Geomyces pannorum*) (Link) Singler & Carmichael								1
Cladosporium cladosporioides (Fres.) deVries	4					1		
Fusarium oxysporum Schlect. emend. Sny. & Hans.						28		
Gliocladium roseum Bain.		91						
Gliomastix murorum (Corda) Hughes					3			
Hormiactis candida Hohn.			2					
Humicola grisea Traaen			1	2		4		
Monocillium sp.			9					
Mortierella alpina Peyronel			54					
Mycelia Sterilia			492			1		
Paecilomyces varioti Bainier				36			26	
Penicillium chrysogenum Thom					5			
P. frequentans Westling		3						
P. notatum Westling				12				
P. roqueforti Thom		1			1			
Penicillium sp. I								1
Penicillium sp. II	1							
P. steckii Zaleski		1			1	233		
Pythium sp.			1				1	
Rhodotorula sp.	2				1			
Ulocladium botrytis Preuss								17

[a] DRY = Dry Cave; BCC = Buckeye Creek Cave; HOL = The Hole; MCL = McClung Cave; "A" = varved layer near Organ-Hedricks Junction; "B" = near Revak Room; "C" = Jones Canyon; "D" = Sand Room.

aureolatus, Byssochlamys fulva, Penicillium steckii, Gliocladium roseum, Paecilomyces varioti, Mortierella alpina, Aspergillus caespitosis, and *Fusarium oxysporum*.

DISCUSSION

Results from the first set of eight samples are summarized in Table 1. These data suggest that, indeed, each sample presents a different assemblage of fungal isolates, consistent with the hypothesis that microfloral distribution patterns might be used as unique "markers" for cave sediments of different antiquity. Reproducibility studies were then carried out to confirm this possibility and perhaps to define further the uniqueness of these sediment microfloral patterns.

Approximately two years later, one of the cave sediments was resampled, and replicate samples from three of the original sediments were sent to Pfizer Inc. for examination using the same culture protocols.

These results all gave different pictures, as shown in Table 2, where the data are given as percentages of total isolates in a given sample for better comparative purposes. It is clear from Table II that the results from the initial sampling of a sediment are not sufficiently reproducible to define a microfloral "fingerprint" of that sediment.

Inasmuch as the three replicate assays from the original samples all showed clearly different results, the difficulty does not appear due to possible contamination by the initial sampling process. Rather, it is postulated as due to use of a small portion (0.5 g) having been removed for culture studies from a large (>100 g) sediment sample which had not been homogenized by first being mixed thoroughly and blended. A vertical distribution of spores in originally uniform, ancient cave sediments could easily arise from several sources, such as:

1) a sparse but continuous accretion over millenia from air currents, overflying or roosting bats, or foraging cave fauna (including human explorers);

2) intrusive additions near the surface from ovipositing cave crickets; and,

3) vertical gradations in soil chemistry or resident microorganisms, possibly resulting from very slow processes controlled by oxygen diffusion or desiccation, which alter spore viability.

Table 2. Comparison of First Fungal Isolates with Replicate and Resampled Isolates

The Hole

TAXON	First	Replc[a]
Acremonium cerealis	—	>98%[c]
Acremonium sp.	0.2%	<1
Aspergillus aureolatus	0.2	—
Gliomastix murorum	—	<1
Hormiactis candida	0.4	—
Humicola grisea	0.2	<1
Monocillium sp.	1.6	—
Mortierella alpina	9.5	—
Mycelia Sterilia	87.0	—
Penicillium chrysogenum	0.9	—
Pythium sp.	0.2	—
(total)	100%	100%

Buckeye Creek Cave

TAXON	First	Replc[a]
Aspergillus versicolor	—	3.1%
Gliocladium roseum	94.9%	—
Monocillium humicola Barron	—	95.7
Paecilomyces sp.	—	0.6
Penicillium frequentans	3.1	—
P. notatum	—	0.6
P. roqueforti	1.0	—
P. steckii	1.0	—
(total)	100%	100%

Greenbrier Caverns (Revak Room)

TAXON	First	Resam[b]
Acremonium sp.	0.4%	—
Aspergillus sclerotiorum	0.4	—
Chrysosporium sp. I	0.4	93.2%
Chrysosporium sp. II	—	5.9
Cladosporium cladosporioides	0.4	—
Fusarium oxysporum	10.0	—
Humicola grisea	1.5	—
Mycelia Sterilia	0.4	0.3
Paecilomyces varioti	—	0.3
Penicillium brevi-compactum Dierckx	—	0.3
P. steckii	86.9	—
(total)	100%	100%

Greenbrier Caverns (Jones Canyon)

TAXON	First	Replc[a]
Acremonium cerealis	0.7%	—
Byssochlamys fulva	90.4	—
Gliomastix murorum	—	60.0%
Paecilomyces varioti	8.6	33.3
Pythium sp.	0.3	—
Scolecobasidium constrictum Abbott	—	6.7
(total)	100%	100%

[a] Re-assay using another portion of original sediment sample.
[b] Re-assay using a different sediment sample taken 2 meters away from initial sediment.
[c] All numbers as percentage of all colonies isolated in the single assay.

Such vertical distribution has been reported for *H. capsulatum* in Puerto Rican cave sediments, where positive culture results were shown to increase with sediment depth (Carvajal Zamora, 1977). To the extent that the inhomogeneity in the remote sediments of this study results from substantial surface accretions, it could be alleviated by carefully removing the top portion of the sediment prior to sampling. Unfortunately, such a procedure would also obliterate any "fingerprints" lying thereupon, and given the substantial age(s) of the sediments, their surfaces were assumed to be very likely places for them. However, the additional work to develop this hypothesis or obviate the reproducibility problem would have been far beyond the scope of the contemplated study.

Most of the fungi isolated in this study are soil fungi (Domsch et al., 1980; Huang and Schmitt, 1975), which when compared with fungal floras of different habitats resemble those of deserts and the tropics. Dermatiaceous microfungi including dark "Mycelia Sterilia," Sphaeropsidales, and Ascomycetes appear to be characteristic groups in tropical and desert soils, contributing both a diversity of species and high proportions of isolates (Abdel-Hafez, 1982; Durrell and Shields, 1960; Gochenaur, 1970; Huang, 1971; Moubasher and Moustafa, 1970; Ogbonna, 1983; and Ranzoni, 1968). The fungi often isolated from these habitats include *Alternaria spp., Aspergillus fumigatus, A. niger, A. ustus, Chaetomium spp., Cladosporium cladosporioides, Fusarium semitectum, Penicillium chrysogenum, Stachyboturys spp.*, and *Ulocladium spp. Cladosporium cladosporioides* and *Ulocladium botrytis* isolated in this study also have been listed as common microfungi in Arizona and Utah desert soils (States, 1978).

The low number of taxa obtained per sample is more characteristic of desert soil than tropical soil. In this regard, the high, abandoned upper levels of the caves sampled in this study are essentially free of liquid water, and at 11°C and 90+% RH (about 12 mbar vapor pressure) probably fall between desert and tropical habitats in annual mean humidity. Compare, for example, 6 mbar at Reno and Albuquerque or 8 mbar at Phoenix and El Paso, versus 24 mbar at Merida in the Yucatan of Mexico (Landsberg, 1974). Fungi that survive this dry environment must be equipped with structures that will withstand desiccation. The dark Dematiaceae, the dark Mycelia Sterilia, the ascomycetes, and the Sphaeropsidales mentioned above either possess melanin or fruiting structures which are resistant to desiccation.

CONCLUSIONS

While this project did not support the objective of determining microfloral fingerprints unique to particular cave sediments, quite a few of the species identified in this work do not appear to have been reported previously in the literature on cave soil fungi. While certainly not conclusive, this would be expected if, in fact, ancient remote cave sediments harbor a characteristic

Table 3. Cave Fungal Species Reported in This Work or in the Literature

Sampling This Work	Lit.	Species Reported	Geographic Location	Ref.
	CS	*Absidia blakesleeanus* Lendner	Bah	(1)
	CS	*A. cylindrospora* Hagem	Bah	(1)
	CS	*Acremonium bacillisporum* (Onions & Bar.) W. Gams	Kor	(2)
	CS	*A. butyri* (van Beyma) W. Gams	Kor	(2)
CS		*A. cerealis* (Karts.) W. Gams		
CS		*A. strictum* W. Gams		
	CS	*A. vitis* Cataneo	Bah	(1)
	CS	*Actinomucor elegans* (Eidam) Benj. & Hesseltine	Bah	(1)
	A	*Alternaria alternata* (Fr.) Kreissier	TX	(15)
	CS	*A. tenuis* Nees	Bah	(1)
	CS	*Arthroderma tuberculatum* Kuehn	Isr	(3)
CS		*Aspergillis aureolatus* Munt.-Cvet.		
CS		*A. caespitosus* Raper & Thom		
	CS	*A. candidus* Link	Bah	(1)
	CS	*A. carbonarius* (Bain) Thom	Bah	(1)
	CS	*A. flavipes* (Bain. & Sart.) Thom & Church	Bah	(1)
	CS	*A. flavus* Link	Bah, Kor	(1, 2)
	CS	*A. fumigatus* Fresenius	Bah	(1)
	CS	*A. heterothallicus* Kwon, Fennell & Raper	Kor	(2)
	CS	*A. luchuensis* Inui	Bah	(1)
	CS	*A. niger* Van Tiegh	Kor, MI	(2, 4)
	CS	*A. ochraceous* Wilhelm	Bah	(1)
	CS	*A. rugulosus* Thom & Raper	Bah	(1)
CS		*A. sclerotiorum* Huber		
	CS	*A. sulphureus* (Fres.) Thom	Bah	(1)
	CS	*A. unguis* (Emile-Weil & Gaudin) Thom & Raper	Bah	(1)
	CS	*A. ustus* (Bain.) Thom & Church	Bah	(1)
CS	CS	*A. versicolor* (Vuill.) Tiraboschi	Bah, Kor	(1, 2)
	CS	*A. wentii* Wehmer	Bah	(1)
CS	CS	*Aureobasidium pullulans* (de Bary) Berkhout	Bah	(1)
CS		*Byssochlamys fulva* Olliver & Smith		
	F	*Cephalosporium lamellaecola* Smith	NV	(16)
	A	*Chaetomium distortum* Ames	TX	(15)
	CS	*Chrysosporium keratinophilum* (Frey) Carmichael	Isr	(3)
CS	CS	*C. (Geomyces) pannorum* (Lind) Hughes	MI	(4)
	CS	*C. tropicum* Carmichael	Isr	(3)
	D	*Circinella muscae* (Sorokine) Berlese & de Toni	Bah	(1)
CS		*Cladosporium cladosporioides* (Fres.) deVries		
	CS	*C. herbarum* (Pers.) Link	Bah	(1)
	W	*Coprinus micaceus* (Bull. *ex* Fr.) Fr.	KY	(17)
	CS	*Ctenomyces serratus* Eidam	Isr	(3)
	CS	*Cunninghamella elegans* Lender	Bah, Kor	(1, 2)
	A	*Curvularia senegalensis* (Speg.) Subram	TX	(15)
	CS	*Dictostelium aureo-stipes* Cavender, Raper, & Nor.	WV	(5)
	CS	*D. caveatum* Wadell, Raper, & Rahn	AK	(6)
	CS	*D. discoideum* Raper	WV	(5)
	CS	*D. giganteum* Singh	WV	(5)
	CS	*D. minutum* Raper	WV	(5)
	CS	*D. mucoroides* Brefeld	Bah, WV	(1, 5)
	CS	*D. purpureum* Olive	WV	(5)
	CS	*D. rosarium* Raper & Cavender	WV	(5)
	CS	*D. sphaerocephalum* (Oud.) Sacch. & March.	WV	(5)
	CS	*Doratomyces stemonitis* (Persoon) Morton & Smith	Kor	(2)
	A	*Drechslera australiensis* (Bugnicourt) *ex* Ellis	TX	(15)
	A	*D. halodes* (Dreschslera) Subram. & Jain	TX	(15)
	A	*D. teres* (Sacc.) Shoemaker	TX	(15)
	CS	*Epicoccum nigrum* Link	MI	(4)
	CS	*Fayodia agloea* Singer & Passauer	Ast	(7)
	W	*Fomes (Polyporus) applantus* Pers.	KY	(17)
	CS	*Fusarium avenaceum* (Corda: Fr.) Sacc.	Kor	(2)
	CS	*F. conglutinans* Wollenweber	Bah	(1)
	CS	*F. culmorum* (W. G. Smith) Saccardo	Bah	(1)
	F	*F. moniliforme* Sheld	IN	(18)
CS	CS	*F. oxysporum* Schlect. emend. Sny. & Hans.	MI	(4)
	F	*Gibberella fujikuroi* (Sawada) Wollenweber	IN	(18)
CS		*Gliocladium roseum* Bain.		
CS		*Gliomastix murorum* (Corda) Hughes		
	W	*Gymnoascus setosus* Eidam	KY	(17)
	W	*G. uncinatus* Eidam	KY	(17)
	D	*Helicostylum pyriforme* Bainer	Bah	(1)
	CS	*Histoplasma capsulatum* Darling	Col	(8)
CS		*Hormiactis candida* Hohn.		
	CS	*Humicola fuscoatra* Traaen	MI	(4)
CS	CS	*H. grisea* Traaen	Blg	(9)
	O	*Isaria (Spototrichum) densa* Link	KY	(17)
	D	*I. felina* (Dc.) Fries	Bah	(1)
	W	*I. (S.) flavissimum* Link	KY	(17)
	CS	*Microascus caviariformis* Malloch & Hubart	Blg	(10)
	W	*M. longirostris* Zukal	KY	(17)
	CS	*Microsporum amazonicum* Moraes, Dorelli & Feo	Bzl	(11)
	CS	*M. gypseum* (Bodin) Guiart & Grigorakis	Tvl	(12)
CS		*Monocillium humicola* Barron		
CS	CS	*Mortierella alpina* Peyronel	Kor	(2)
	A	*Mucor globosus* Fischer	TX	(15)
	D	*M. pyriformis* Fischer	Bah	(1)
	CS	*M. racemosus* Fresenius	MI	(4)
	CS	*M. subtilissima* Oudemans	Bah	(1)
	CS	*Nigrospora sphaerica* (Sacc.) Mason	Bah	(1)
	CS	*Oospora variabilis* (Lindner) Lindau	Bah	(1)
CS		*Paecilomyces varioti* Bainer		
CS		*Penicillium brevi-compactum* Dierckx		
	A	*P. charlesii* Smith	TX	(15)
CS	CS	*P. chrysogenum* Thom	Kor	(2)
	CS	*P. cyclopium* Westling	Kor	(2)
	CS	*P. duclauxi* Delacroix	Bah	(1)
CS	CS	*P. frequentans* Westling	Kor	(2)
	CS	*P. granulatum* Bainer	Kor	(2)
	CS	*P. implicatum* Biourge	Bah	(1)
	CS	*P. janthinellum* Biourge	Kor	(2)
	CS	*P. lanosum* Westling	Bah	(1)
CS		*P. notatum* Westling		
	CS	*P. oxalicum* Currie & Thom	Bah, Kor	(1, 2)
CS		*P. roqueforti* Thom		
	CS	*P. solitum* Westling	Bah	(1)
	CS	*P. stoloniferum*	Kor	(2)
CS		*P. steckii* Zaleski		
	CS	*Pestalotia palmarum* Cooke	Bah	(1)
	CS	*Phaeomarasmius granulosis* (Lange) Singer	Ast	(7)
	CS	*Pithomyces chartarum* (Berk. & Curt.) M. B. Ellis	Kor	(2)
	CS	*Polysphondylium pallidum* Olive	Bah, WV	(1, 5)
	CS	*P. violaceum* Raper	WV	(5)
	CS	*Pseudeurotium ovale* Stolk	Blg	(9)
	O	*Rhachomyces beronii* Rossi	Ngu	(19)
	A	*Rhizopus oryzae* Went & Prisen Geerlings	TX	(15)
CS		*Scolecobasidium constrictum* Abott		
	CS	*Scopulariopsis bervicaulis* (Sacc.) Bainer	Mex	(13)
	CS	*S. brumptii* Salvanet-Duval	MI	(4)
	CS	*Spicaria violacea* Abbott	Bah	(1)
	A	*Syncephalastrum racemosum* Cohn ex Schroter	TX	(15)
	O	*Tolypocladium extinguens* Samon & Soares	Nzl	(20)
	CS	*Trichoderma viride* Persoon: Fr.	Kor	(2)
	CS	*T. harzianum* Rifai	Kor, MI	(2, 4)
	CS	*Trichophyton mentagrophytes* (Robin) Blanchard	Tvl	(14)
	CS	*T. terrestre* Durie & Frey	MI	(4)
CS	CS	*Ulocladium botrytis* Preuss	Blg	(9)
	A	*Verticillium cinnabarinus* Nees Fide Hughes	TX	(15)
	A	*V. tenuissimum* Corda	TX	(15)
	W	*Zasmidium cellare* Fr.	KY	(17)

Site: CS = cave soil (all spp. reported from "cave soil" are included here); A = limestone aquifer; D = on dung in cave; F = on active cave formations; O = on living organisms in caves; W = growing on wood or plant debris.

Location: AK = Arkansas; IN = Indiana; KY = Kentucky; MI = Michigan; NV = Nevada; TX = Texas; WV = West Virginia (not this work); Ast = Austria; Bah = Bahamas; Blg = Belgium; Bzl = Brazil; Col = Columbia; Isr = Israel; Kor = Korea; Mex = Mexico; Ngu = New Guinea; Nzl = New Zeland; Tvl = Transvaal.

Ref: (1) Orpurt, 1964; (2) Min, 1988; (3) Ajello et al., 1977; (4) Volz and Yao, 1991; (5) Landolt et al., 1992; (6) Wadell, 1982; (7) Singer and Passauer, 1980; (8) Hamrick et al., 1986; (9) Malloch and Kahn, 1988; (10) Malloch and Hubart, 1987; (11) Casirillon et al., 1976; (12) Lurie and Way, 1957; (13) Gonzales-Ochoa, 1960; (14) Lurie and Borok, 1955; (15) Kuehn and Koehn, 1988; (16) Went, 1969; (17) Call, 1897; (18) Hasselbring et al., 1975; (19) Rossi, 1978; (20) Samson and Soares, 1984.

fungal population that differs significantly from those populations found in other niches of the cave environment. Table 3 provides a list of the 26 species identified in this study, along with 102 additional species encountered in a limited survey of the literature on cave fungi, where 17 of the species found in this work are missing from the list of 111 species reported for other caves. This table also includes records of species of cave fungi reported from other niches, such as water from a carbonate aquifer (Kuehn and Koehn, 1988), active speleothem formation (Hasselbring et al., 1975; Went, 1969), wood (Call, 1897), dung (Orpurt, 1964) or associated with various cave fauna (Rossi, 1978; Mercado Sierra et al., 1988).

It should be pointed out, however, that the cited references are surely incomplete, due to the diverse journals where they may be found, the absence of some classification records at the species level, and the lack of a comprehensive compendium. In addition, the best overall literature survey on the subject is not up to date (Dickson and Kirk, 1976). The situation may be further distorted by a disproportionate sampling of cave entrances to document adverse effects of human traffic in caves open to the public or especially in tropical settings, to document histoplasmosis episodes. In any event, the published data give a substantially incomplete picture, and probably a misleading one with regard to the fungal populations characteristic of the "true" cave environment uncontaminated by epigean biota.

Furthermore, if this is the case it is quite likely that much of the early sampling of caves for industrial microbial prospecting failed to obtain a representative collection of indigeneous cave microflora. With the continuing industrial search for unusual sources of biological activity, and with the lingering possibility that the isolates not classified to the species level in this study may represent undescribed forms, a more extensive and detailed study of the cave fungi of remote cave sediments appears warranted.

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A PLEISTOCENE HERPETOFAUNA FROM WORM HOLE CAVE, PENDLETON COUNTY, WEST VIRGINIA

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*The late Wisconsinan Worm Hole Cave Site, Pendleton County, West Virginia, has yielded the remains of at least three salamanders (*Ambystoma *cf.* A. jeffersonianum, A. maculatum *and* A. opacum*) two anurans (*Bufo *sp. and* Rana sylvatica*) and six snakes (*Carphophis amoenus, Lampropeltis triangulum, Opheodrys vernalis, Nerodia sipedon, Storeria *sp. and* Thamnophis *sp.). All of the fossil amphibians and reptiles of the Worm Hole Cave fauna may be found in the area today. This is in sharp contrast to the mammalian fauna of the cave which contains several extinct and extralimital species. This situation is consistent with the pattern that exists in other late Wisconsinan Appalachian faunas.*

INTRODUCTION

Worm Hole Cave is a small passage about 50 meters in length that developed in limestone of Devonian age, and is located along Thorn Creek, a tributary of the South Branch of the Potomoc River in Pendleton County, West Virginia. The cave lies at 38° 34' 10" N. Latitude and 79° 21' 51" W. Longitude at an altitude of about 560 meters.

The cave was discovered by speleologists Tom and Joan Reinbold who recovered some teeth from the site. Among these elements was the tooth of an extinct Pleistocene tapir that was identified by the junior author. Subsequently, several collecting trips were made into the cave and about 110 kg of bone-bearing matrix was collected from four fossiliferous units, all within 10 meters of one another. It is believed that all of these units represented a single depositional event, based on their proximity to each other and the similar texture of their sediments.

The fossiliferous matrix was washed through mosquito net bags and the dried concentrate was sorted for bones, teeth and other organic remains under a binocular microscope. An attempt by Beta Inc. to extract enough collagen from a composite bone sample for a radiocarbon date was unsuccessful.

It seems likely that the fauna was largely derived as the result of feeding activities of large mammalian carnivores, the scavenging activities of the wood rat *Neotoma floridana*, and the predatory activities of avian raptors. This is suggested because (1) most of the larger fossils consisted of fragmentary bones, (2) mammalian taxa of deer size or larger were represented by teeth that had their roots gnawed by rodents, and (3) small vertebrates were represented mainly by complete or nearly complete bones. There were also some coprolites from mammalian carnivores, some with a diameter of 2 cm., as well as some small "worm-like" fossil invertebrates that may represent fly larvae.

Aside from fossil amphibians and reptiles, the Worm Hole Cave fauna also includes several fishes, at least five birds, and 46 mammalian taxa. This fauna has more taxa in it than in any of the other three cave faunas in the area of similar late Pleistocene age (Guilday and Hamilton, 1978) probably because the other faunas were largely derived from owl predation, whereas the Worm Hole fauna was derived from the several sources mentioned above.

Five species of mammals in the Worm Hole fauna are extinct. These include cf. *Brachyprotoma obtusata* (Short-faced Skunk), *Tapirus* cf. *T. veroensis* (Vero Tapir), *Mylohyus* sp. (Long-nosed Peccary), cf. *Sangamona fugitiva* (Fugitive Deer), and *Bootherium bombifrons* (Woodland Musk Ox). Moreover, several rodents, small carnivores, and an artiodactyl (e.g., Northern Bog Lemming, Heather Vole, Yellow-nosed Vole, Pine Martin, and Caribou) represent extralimital taxa, with both northern and western extralimital affinities. A preliminary analysis of the mammalian fauna, especially the extralimital voles, indicates that the fauna accumulated some time after the maximum Wisconsinan glaciation and before the major extinction event at the end of the Pleistocene.

SYSTEMATIC PALEONTOLOGY

The specimens reported on herein were collected by Frederick Grady and his associates and are deposited in the National Museum of Natural History (USNM).

Class Amphibia

Order Caudata

Family Ambystomatidae

Ambystoma cf. *Ambystoma jeffersonianum* (Green)

Jefferson Salamander

Material.—Three vertebra, USNM 474621. Holman and Grady (1987) gave criteria for the identification of individual vertebrae of salamanders of the *Ambystoma jeffersonianum* complex of species. *Ambystoma jeffersonianum* is the only salamander of this complex that occurs in West Virginia today (Green and Pauley, 1987), thus we tentatively refer these vertebrae to this species on zoogeographic grounds. *Ambystoma jeffersonianum* normally lives underground or under piles of wet leaves or fallen logs, but it has been found in caves in Greenbrier and Pendleton Counties, West Virginia (Green and Pauley, 1987).

Ambystoma maculatum Shaw

Spotted Salamander

Material.—Two vertebrae, USNM 474622. Holman and Grady (1987) have discussed the identification of individual vertebrae of *Ambystoma maculatum*. This species occurs in Pendleton County today (Green and Pauley, 1987). This salamander is a woodland species that spends much of its time underground.

Ambystoma opacum (Gravenhorst)

Marbled Salamander

Material.—Two vertebrae, USNM 474623. Vertebrae of this species may be identified on the basis of characters given in Holman and Grady (1987). This species has not been reported in the modern fauna of Pendleton County, but it has been collected in adjacent Pocahontas and Hardy Counties (Green and Pauley, 1987). *Ambystoma opacum* is typically found beneath leaves, logs, or rubbish in flood plains, deciduous forests, swamplands and stream banks in West Virginia today (Green and Pauley, 1987).

Ambystoma sp.

Undetermined Mole Salamander

Material.—Sixteen vertebrae, USNM 474624. These vertebrae are too fragmentary for specific identification.

Order Anura

Family Bufonidae

Bufo sp.

Undetermined True Toad

Material.—Two sacral vertebrae, USNM 474625. These large procoelous sacral vertebrae are easily assigned to the genus *Bufo*, but we were unable to identify them to the specific level. *Bufo americanus* and *Bufo woodhousii fowleri* both occur in the modern fauna of Pendleton County (Green and Pauley, 1987). Both of these species are rather ubiquitous terrestrial forms in West Virginia today, but the latter species tends to prefer sandy habitats.

Family Ranidae

Rana sylvatica Le Conte

Wood Frog

Material.—Two left and three right ilia, USNM 474626. Holman (1984) has given characters for the recognition of individual ilia of *Rana sylvatica*. This species occurs in the modern fauna of Pendleton County (Green and Pauley, 1987). Aside from the breeding season, this is a terrestrial species that lives in moist woodlands in West Virginia today.

Rana sp.

Undetermined True Frog

Material.—Five sacral vertebrae and two ilia, USNM 474627. The diplasiocoelous sacral vertebrae and crested ilia are easily assigned to the genus *Rana*, but they are too fragmentary for specific identification.

Class Reptilia

Order Squamata

Suborder Serpentes

Family Colubridae

Subfamily Xenodontinae

Carphophis amoenus (Say)

Eastern Worm Snake

Material.—Two trunk vertebrae, USNM 474628. Holman and Grady (1987) have discussed how to distinguish the individual trunk vertebrae of *Carphophis amoenus* from the similar Ringneck Snake, *Diadophis punctatus*. *Carphophis amoenus* occurs in the modern fauna of Pendleton County (Green and Pauley, 1987). In West Virginia today this species occurs in forested situations where it is usually found under litter on rocky hillsides.

Subfamily Colubrinae

Lampropeltis triangulum Lacepede

Milk Snake

Material—Twelve trunk vertebrae, USNM 474629. Distinctive characters of trunk vertebrae of *Lampropeltis triangulum* were detailed by Holman and Grady (1987). This species occurs in the modern fauna of Pendleton County (Green and Pauley, 1987). It occurs in a wide variety of modern habitats in West Virginia.

Opheodrys vernalis (Harlan)

Smooth Green Snake

Material.—Twenty four trunk vertebrae, USNM 474630. Holman and Richards (1981) discussed characters for distinguishing the vertebrae of *Opheodrys vernalis* from the Rough Green Snake, *Opheodrys aestivus*, both of which occur in West Virginia today. *Opheodrys vernalis* occurs in the modern fauna of Pendleton County; but *O. aestivus* mainly occurs in Western West Virginia today, and has not been found in Pendleton County (Green and Pauley, 1987). The Smooth Green Snake is partial to terrestrial grassy habitats, whereas the Rough Green Snake is an arboreal vine snake.

Subfamily Natricinae

Nerodia sipedon (Linnaeus)

Northern Water Snake

Material.—Thirteen trunk vertebrae, USNM 474631. Holman (1967) gave characters for distinguishing the trunk vertebrae of the various species of *Nerodia*, including *N. sipedon*. This snake occurs in the modern fauna of Pendleton County and occurs in a wide variety of aquatic habitats in West Virginia today (Green and Pauley, 1987).

Storeia sp.

Brown Snake or Redbelly Snake

Material.—Two trunk vertebrae, USNM 474632. Vertebral characters of the genus *Storeria* were given by Holman and Grady (1987). Two species of this genus, the Brown Snake, *Storeria dekayi*, and the Redbelly Snake, *Storeria occipitomaculata* occur in West Virginia today (Green and Pauley, 1987), but we were unable to determine which species was represented in Worm Hole Cave based on the two vertebrae. The Redbelly Snake occurs in the modern fauna of Pendleton County (Green and Pauley, 1987). The Brown Snake has not been recorded in the modern fauna of the county, but it does occur in adjacent Randolph and Hardy counties in West Virginia (Green and Pauley, 1987). Both species are secretive snakes.

Thamnophis sp.

Garter Snake and Ribbon Snake

Material.—Thirty eight vertebrae, USNM 474633. Brattstrom (1967) has discussed the identification of individual vertebrae of the genus *Thamnophis*. Two species of *Thamnophis* occur in West Virginia today: the Ribbon Snake, *Thamnophis sauritus*, and the Garter Snake, *Thamnophis sirtalis* (Green and Pauley, 1987). We are unable to determine which species occurs in Worm Hole Cave based on the above vertebrae. The Ribbon Snake has not been recorded in the modern fauna of Pendleton County, but it occurs in adjacent Randolph and Hardy Counties in Virginia (Green and Pauley, 1987). The Garter Snake has been recorded in the modern fauna of Pendleton County. The Ribbon Snake is usually found near aquatic habitats where small anurans occur, whereas the Garter Snake is more ubiquitous.

DISCUSSION AND SUMMARY

The Worm Hole Cave late Wisconsinan herpetofauna consists of at least five species of anurans and six species of snakes. None of these are extinct and all can be found in or very near the area today. On the other hand, the mammalian fauna from this locality shows evidence of extinction at the familial, generic, and specific level, as well as extralimital northern and western species. The same pattern is seen in the several other late Wisconsinan herpetofaunas from the Appalachian Region (Holman and Grady, 1987; Fay, 1988).

The lack of extinction of amphibian and reptile taxa at the end of the Pleistocene compared with the avian and mammalian faunas which suffered familial, generic, and much specific extinction has led to the question, "What attributes have allowed the herpetofauna to survive the stresses that have caused dramatic extinctions in other classes during the Pleistocene?" (Holman, 1991).

Possible explanations for this may emerge from new and continuing comparative studies on herpetological metabolic rates, hibernation and aestivation potentials, size relationships, food web relationships in megaherbivore-dominated communities, reproductive potentials, and desirability as a human food resource.

Unfortunately, explanations for the lack of extralimital herpetological species in late Wisconsinan Appalachian faunas compared to those in avian and mammalian faunas have been convoluted and contradictory (e.g., Holman and Grady, 1987; Fay, 1988). One overriding operational constraint in constructing such explanations is that there are practically no strictly "boreal" herpetological species in the eastern United States. Moreover, those few species that are strictly "boreal" (e.g., *Rana septentrionalis*) may not be osteologically separable from other closely related species. Thus, intrusive herpetological populations or osteologically cryptic "boreal" species displaced southward by advancing glaciers are probably not detected in Appalachian late Wisconsinan faunas.

Fay (1988: 217) suggested that "Herptiles have a marked capacity for acclimatization to seasonal climatic change that may also provide the ability to adapt to progressive, long term change by alterations in physiology or behavior rather than distribution." This will be an important consideration if it becomes widely substantiated by experimental ecological and physiological studies on modern amphibian and reptile species.

ACKNOWLEDGEMENTS

Mr. Homer Glover kindly gave permission for the removal of fossil material from Worm Hole Cave on his property. Tom and Joan Reinbold brought the locality to the junior author's attention, and they assisted in the collection and processing of the material. Tony Ryan donated specimens he collected in the cave previous to the current investigation. Bob Hoke and Art Laterner assisted in collecting and processing the bone-bearing matrix. The Cave Conservancy of the Virginias provided funds for the attempted Carbon 14 date.

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SOME COMMENTS ON SECRETIVE CAVE EXPLORATION

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INTRODUCTION

At one time or another, secrecy is used at least briefly by every modern American speleologist. Many of the "suggested guidelines and considerations" of Hose's provocative article in the June 1992 NSS Bulletin (Hose, 1992) are broadly accepted. But much of her text and rhetoric are at odds with these "guidelines" and with the speleological literature. Furthermore, speleological opinion in the western United States does not monolithically support such assertions as "Secrecy as a style of cave exploration and management is exceedingly attractive"; note, for example, Veni, 1986.

In the short space allotted to responses to NSS Bulletin articles it is not possible to deal with all the assertions in Hose's paper. This communication will document only the following points:

1) the Stanford Grotto was not the secretive organization portrayed by Hose, and the emergence of the "secrecy movement" in 1952 may have destroyed it;

2) contrary to Hose's assertion, the first major "secrecy" battle arguably was not about publication of *Caves of California*, but about seizure of N.S.S. property by the initiators of the "secrecy movement."

3) a strong body of western speleological opinion rejects the "secrecy movement" while protecting cave resources and values by approaches more compatible with peer-review science.

Low-profile western speleological organizations other than those mentioned by Hose (1992), within or closely cooperating with the National Speleological Society, have made contributions to cave science, management, and conservation arguably equal to those she cites within the "secrecy movement." Such publications as the *Technical Note* series of the Salt Lake Grotto, *Speleograph* (Oregon Grotto), and the serial and special publications of the Western Speleological Survey are readily available in (or from) the National Speleological Society Library. The conclusions in this communication are largely based on data in these publications, plus those of the *Stanford Grotto Monthly Report* (here abbreviated SGMR), the Colorado Grotto's *News and Notes*, and publications by state agencies cited in the attached bibliography.

The Stanford Grotto of the National Speleological Society

California speleology came of age in the late 1940's and early 1950's. In late 1948, Robert Hackman and John Funkhowser organized the Stanford Grotto (Moore, 1950). It quickly brought together an exceptional group of Stanford University students who began intensive field and bibliographic research. Soon it began to publish notable scientific contributions to speleology in SGMR and elsewhere. Some probably are unexcelled even today. SGMR was distributed to the N.S.S. and to various grotto and other libraries. Apparently all the early grotto members except Arthur Lange were or became members of the N.S.S. Erwin Bischoff who conducted and published the first systematic surveys of western cave regions (Bischoff, 1942, 1949) was elected an honorary member of this grotto (Moore, 1951). Although not enrolled at Stanford University, Raymond deSaussure became a member of the grotto and of the N.S.S. Except for Lange and deSaussure, who asserted that they spoke for the grotto, nothing was heard from this grotto *per se* after the September 1952 issue of SGMR.

In 1949 the Southern California Grotto began publication of *The California Caver* for regional liaison (Hildinger, editor, 1949). Review of its first few years reveals numerous inter-grotto field trips plus articles and field trip reports by members of the Stanford Grotto.

Clearly, the Stanford Grotto was no tight group that caved only with like-minded "insiders" as asserted by Hose (1992). This is especially obvious in the case of George W. Moore, grotto chairman from 1950 to 1951. In 1951, Moore joined the U.S. Geological Survey in Denver (A. Lange, editor, 1951c). Here he was co-founder and later a chairman of the Colorado Grotto. He was active in the grotto for several years, and participated in its pioneer visits to Lechuguilla and Manhole caves in 1953 (Wrucke, 1953; Thrailkill, 1953). Later he became president of the N.S.S. His many published contributions are beyond the length of this communication; one of the best-known is Moore and Nicholas, 1964.

Chester Wrucke, formerly a secretary of the Stanford Grotto, also participated in activities of the Colorado Grotto and published the first report on Lechuguilla Cave in its newsletter (Wrucke, 1953).

The Stanford Grotto developed an extensive cave file. Its intent was clearly contrary to that of the "secrecy movement." Its stated intent was that "information from these files is available for any NSS or private research" (A. Lange, editor, 1951b).

The Constitution of the Stanford Grotto required transfer of these files and other grotto assets to the N.S.S. in case of dissolution of the grotto. Because of the excellence of the grotto, its files were designated a N.S.S. "Regional Duplicate Data Repository," with copies of data in the national cave file to be forwarded to it. Western speleologists were encouraged to send cave data to it, and, in fact, did so.

Caves of California and "the battle"

The California grottos hailed the belated appearance of N.S.S. Bulletin 10—THE CAVES OF TEXAS—(Mohr, editor, 1948) as something that could and should be replicated in California (Herd, editor, 1950). The N.S.S. scheduled Bulletin 13 as *Caves of California*, and *Caves of California* is referred to as Bulletin 13 throughout SGMR. Contrary to Hose's assertion, perusal of SGMR shows that the Stanford Grotto supported its publication and contributed considerable data (A. Lange, editor, 1950a, 1950b, 1951a).

In early 1952, SGMR changed significantly. New grotto officers were elected (not including Lange nor deSaussure), but these new officers contributed only two short articles published in SGMR and SGMR soon ceased publication.

At least in 1950 and 1951, however, representatives of the Stanford Grotto and Southern California Grotto continued to work toward publication of "Bulletin 13" (A. Lange, editor, 1950a, 1950b, 1951a). From mid-1950 to December 1954 I have no first-hand knowledge of these activities, having been out of the state. Richard F. Logan was chairman of the project during that time. It is evident, however, that the sheer bulk of the contributed data far surpassed both the length and content of Bulletin 10, and the ability of the N.S.S. to publish it. While still in an unfinished form, the N.S.S. sold the manuscript to the California Division of Mines and Geology. That agency considered publishing an edited version, but ultimately decided to retain it as an open-file report (McClurg, 1960). During this period, Lange and deSaussure began to oppose its publication, using the name of the Stanford Grotto.

In December 1954, as chairman of the Grottoes Committee (now the Internal Organizations Committee) I visited Stanford University to determine the status of the seemingly-inactive grotto. I met Lange and deSaussure. They acknowledged that the grotto had become inactive. They further asserted personal control of the grotto's cave files, indicating that the files no longer were "available for any NSS or private research."

As Grottoes Committee Chairman I formally listed the Stanford Grotto as inactive. The N.S.S. then attempted to recover the Bulletin 13 material, the files, and other grotto assets including the Regional Duplicate Data Repository. Lange and deSaussure refused to comply and finally dispersed the files so that the N.S.S. could not recover them through legal action (Hill, editor, 1955). DeSaussure then resigned from the Society (Hill, editor, 1955).

Most of the missing Bulletin 13 material was retrieved from various sources and was edited to the satisfaction of the California Division of Mines and Geology. The California section of the grotto files and regional repository also was largely recovered—perhaps completely so. It was replaced in the Brenner Geological Library of Stanford University (Hill, editor, 1955). The principal loss appears to have been data on Nevada caves.

After the bureau's decision to retain the "Bulletin 13" manuscript as an open-file report, part of it (Halliday, 1962) was reworked and published by the Western Speleological Survey in cooperation with the N.S.S. (Halliday, 1960b). Contrary to "secrecy movement" myths, it included no cave locations closer than the nearest square mile except for well-known caves commonly visited by the public. In the case of some especially sensitive caves, location was given only by county, and the specific locations of all caves in Sequoia National Park were omitted.

Contrary to the assertions of Hose (1992) and the mythology from which she drew these concepts—the mythology seems to have developed around 1960 (for example, McClurg, 1960)—dispersal of the grotto and regional file thus began the battle she cited. Publication of *Caves of California* was much later, and that publication itself followed the guidelines she now suggests, rather closely (Halliday, 1960a).

In 1952 SGMR published a rather apologetic statement which is worth reviewing in full (A. Lange, editor, 1952a). Referring to speleological and archaeological vandalism, Lange wrote:

> . . . the Stanford Grotto has practiced for some time now the policy of not giving exact location data on caves which hold speleological or archaeological interest. Caves will be located at least by county, and to avoid confusion with nearby caves, by nearest town or watershed where necessary. At any rate the minimum location data will be divulged, and the Grotto hopes that its readers will recognize this apparent inadequacy in the reports for what it is—a necessary conservation measure. It goes without saying, that we hope that some day in the future this restriction may be dropped without fear of scientific loss or world depreciation.

The Stanford Grotto disappeared later that year, and the dates of publication of this statement and that of grotto disappearance appear to be more than coincidental. It is at least arguable that the emergence of the "secrecy movement" destroyed this exceptional grotto in full flower. Unlike the Cascade Grotto (which also became inactive in the 1950's but soon was reorganized) the Stanford Grotto never recovered. So-called Stanford Grotto activities beginning sometime in mid-1952 are those of Lange and deSaussure, not the grotto *per se*.

W.S.I. and C.R.A. Publications

Western Speleological Institute and Cave Research Associates publications were not as available as portrayed by Hose (1952). As an example, consider the Report of the California-Nevada Speleological Survey (deSaussure, Mowat, and A. Lange, preparers, 1953), cited by Hose (1992). The terms under which I received a personal copy (Halliday, 1954) were scarcely those of peer-review science.

Restrictions on Cave Location Data Outside the "Secrecy Movement"

Accountability through free interchange of information and replication is broadly considered essential to modern science. Even limited and temporary secrecy thus is antiscientific—temporarily and to whatever degree it is practiced. Yet every field science has an obligation to protect the environment from which it draws its data, and a balance must be achieved. The National Speleological Society has adopted such a balance in its published policy on publication of cave locations. This is reflected in many speleological publications not cited by Hose, outside the "secrecy movement." Several antedated the N.S.S. policy.

Caves of California (Halliday, 1962) was the first of a series of publications on caves of far western states. Others included *Caves of Washington* (Halliday, 1963), *Introduction to Idaho Caves and Caving* (Ross, 1969), *Bibliography of Nevada Speleology* (McLane, 1974), *Caves of Oregon* (Larson, 1975), *Caves of Montana* (Campbell, 1978) and others. These and the serial publications of the Western Speleological Survey maintain at least the degree of secrecy as did *Caves of California* and Hose's 1992 guidelines. Some other western publications were less sensitive (for example, W. Lange, 1969), but their authors or editors were quickly persuaded that this was unwise and did not repeat their approach. As for Hawaii, restriction of information on cave burials in Hawaii Speleological Survey publications has been and continues to be at least as strict as anything cited by Hose.

CONCLUSIONS

The history of the "secrecy movement" is demonstrably different from that cited by Hose, and her paper fails to consider western speleological concepts outside the "secrecy movement." The data base supports other approaches, as cited.

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Louise D. Hose—Some Comments on Secretive Cave Exploration: Reply: *NSS Bulletin* **56:** 53.

SOME COMMENTS ON SECRETIVE CAVE EXPLORATION: REPLY

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Halliday (1993) has provided valuable documentation of the events leading to the onset of the policy of secrecy in the western speleological community in the 1950s. He also gives us a good insight into why members of the Stanford Grotto were on the forefront of the movement. He tells us that the resistance to publishing a *Caves of California* coincided with the NSS losing control of the final product by selling the manuscript to the California Division of Mines. Yet, at approximately the same time according to Halliday, the NSS was trying to force Lange and deSaussure into relinquishing cave locations and other sensitive information so that it could be provided to this independent agency. I believe this information will help many readers better understand the earliest roots of the policy of secrecy.

Halliday (1993) also claims that the Stanford Grotto may have been destroyed by the emergence of the "secrecy movement." However, the Stanford Grotto almost entirely relied on student membership. I can not think of any student grotto in the western (west of the 100th meridian) U.S. that has survived more than a few years. Students move away, especially from a residential campus like Stanford University. Halliday, himself, tells us that a very active member, George Moore, had moved to Colorado before the ultimate collapse. The Stanford Grotto's activities met the normal life expectancy of a western, student grotto.

While Halliday opens his comments with the statement "a strong body of western speleological opinion rejects the 'secrecy movement'. . ." He later cites as evidence six publications and says, "These and the serial publications of the Western Speleological Survey maintain at least the degree of secrecy as . . . Hose's 1992 guidelines." He goes on to say that other, less secrecy-oriented, publications in the West were persuaded to not reprint and that his own work in Hawaii as "at least as strict as anything cited by Hose." Thus, Halliday, himself, shows us that the philosophy and considerations that grew out of the *Caves of California* controversy now permeate nearly all western speleological publications.

I thank Dr. Halliday for further enlightening us on the pertinent events of the early 1950s and for providing documentation of the impact of the philosophy of secrecy on the publishers of cave lists and bibliographies in the 1960s and 1970s. Clearly, the development of the alternative model of exploration and documentation that we commonly call "secrecy" has had a major impact on all elements of the western speleological community.

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Halliday (1993) has provided valuable documentation of the events leading to the onset of the policy of secrecy in the western speleological community in the 1950s. He also gives us a good insight into why members of the Stanford Grotto were on the forefront of the movement. He tells us that the resistance to publishing a *Caves of California* coincided with the NSS losing control of the final product by selling the manuscript to the California Division of Mines. Yet, at approximately the same time according to Halliday, the NSS was trying to force Lange and deSaussure into relinquishing cave locations and other sensitive information so that it could be provided to this independent agency. I believe this information will help many readers better understand the earliest roots of the policy of secrecy.

Halliday (1993) also claims that the Stanford Grotto may have been destroyed by the emergence of the "secrecy movement." However, the Stanford Grotto almost entirely relied on student membership. I can not think of any student grotto in the western (west of the 100th meridian) U.S. that has survived more than a few years. Students move away, especially from a residential campus like Stanford University. Halliday, himself, tells us that a very active member, George Moore, had moved to Colorado before the ultimate collapse. The Stanford Grotto's activities met the normal life expectancy of a western, student grotto.

While Halliday opens his comments with the statement "a strong body of western speleological opinion rejects the 'secrecy movement'. . ." He later cites as evidence six publications and says, "These and the serial publications of the Western Speleological Survey maintain at least the degree of secrecy as . . . Hose's 1992 guidelines." He goes on to say that other, less secrecy-oriented, publications in the West were persuaded to not reprint and that his own work in Hawaii as "at least as strict as anything cited by Hose." Thus, Halliday, himself, shows us that the philosophy and considerations that grew out of the *Caves of California* controversy now permeate nearly all western speleological publications.

I thank Dr. Halliday for further enlightening us on the pertinent events of the early 1950s and for providing documentation of the impact of the philosophy of secrecy on the publishers of cave lists and bibliographies in the 1960s and 1970s. Clearly, the development of the alternative model of exploration and documentation that we commonly call "secrecy" has had a major impact on all elements of the western speleological community.

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DISCUSSION AND REPLY

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