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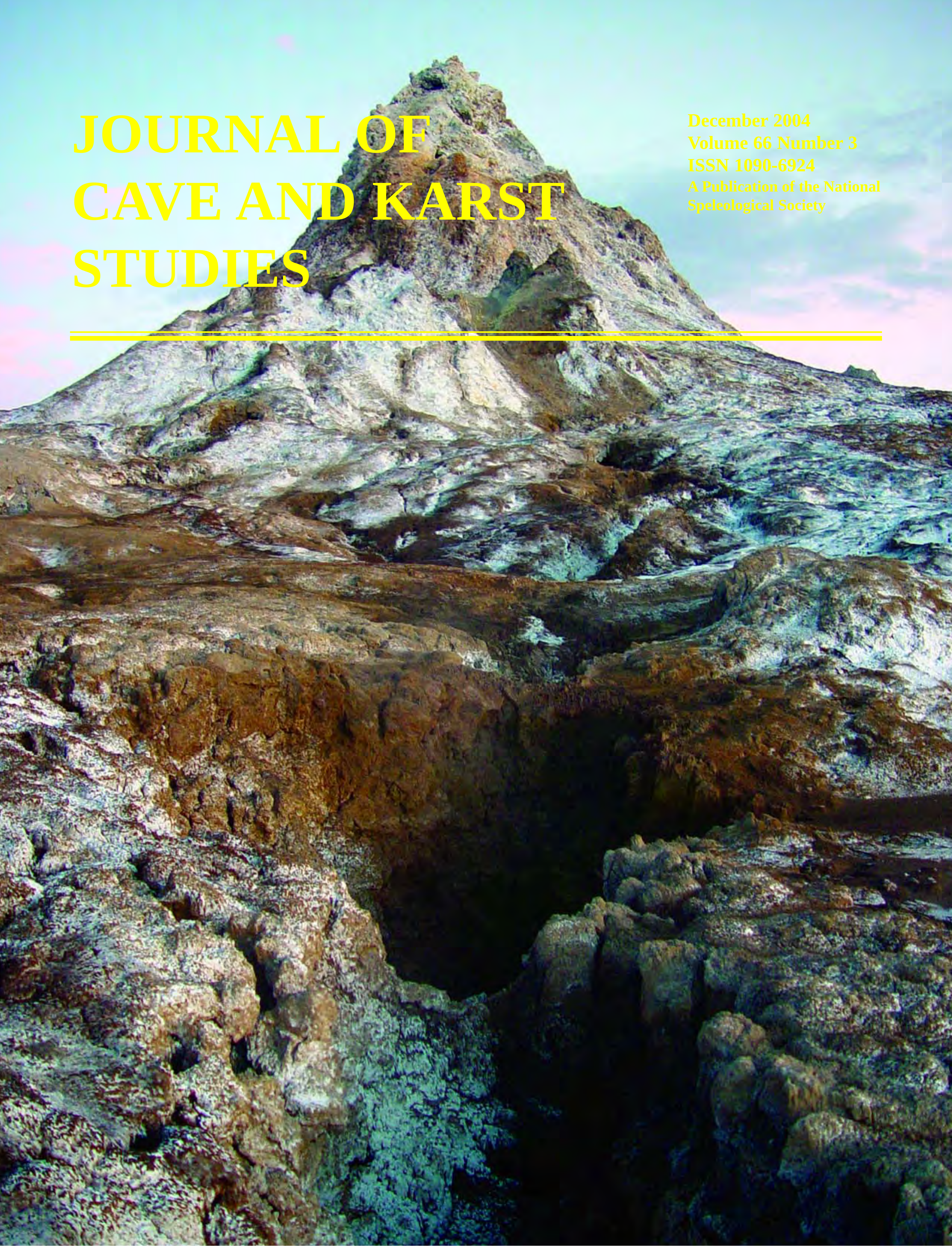

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Front cover: Lava cave on Ol Doinyo Lengai, Tanzania. See Donald A. McFarlane, Joyce Lundberg, and Frederick Belto, p. 98.

A POX ON NEW KARST TERMS

MALCOLM S. FIELD

Karst has long been recognized as having unique characteristics relative to other terranes. The dissolution process of the underlying soluble bedrock is responsible for the development of solution conduits and caves, sinkholes and swallets, springs (resurgences, exsurgences, etc.), uvalas, poljes, various types of karren, and other specific features not commonly found in other terranes.

The paragraph above contains several specific karst terms. These and many of the terms found in various karst glossaries (e.g., Cullingford 1962, pp. 559–568; Mohr & Poulson 1966, pp. 218–226; Monroe 1970; Sweeting 1973, pp. 332–335; Lowe & Waltham 1995; Field 1999; 2002) have been mostly established decades to centuries before present time because of a perceived need to be able to identify and define specific observed features or measurements. To a large degree, the development of these older karst terms was entirely appropriate. I would suggest, however, that the development of newer karst terms is not so readily warranted.

Unfortunately, there appears to be a deliberate attempt by modern karst investigators to continue establishing new karst terms. In many instances, the terms chosen appear to be not well thought-out, duplicative of older terms, overly confusing in an attempt to be "all encompassing," or based on limited observations and/or measurements. Given these problems, I suggest that would-be karst linguists step back and "take a deep breath" prior to inventing additional new karst terms.

I am not suggesting here that there aren't newly discovered features, observations, or measurements that do not warrant developing new karst terms. To the contrary, I am sure that just the opposite is true. However, as the compiler of one of several karst glossaries, I want to recommend that modern-day karst investigators put more thought into the need for one or more new karst terms rather than just the formality and complexity of the new terms.

I further recommend that would-be karst linguists take more time to look through the existing literature for one or more karst terms or combination of karst terms that already adequately describe the features, observations, or measurements that the new term is intended to describe. If no existing karst terms or combination of karst terms appear to adequately meet the investigator's current observations and/or measurements, I also recommend that karst investigators expand their observations and measurements to better verify the necessity of creating a new term. If a new karst term is determined to still be necessary, the new term should be understandable by the international community (e.g., colloquial and poorly translatable terminology should be avoided) and should have a Latin or Greek root. Lastly, as no formal body exists, I would like to put forward the idea that all newly-proposed karst terms be subject to review and approval by an acceptable "board of experts" to ensure the appropriateness of the new terms.

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Romuald J. Pomorski - *Agraphorura spelaea* n. sp. (Collembola: Onychiuridae) from North American caves. *Journal of Cave and Karst Studies*, v. 66, no. 3, p. 76-80.

AGRAPHORURA SPELAEA N. SP. (COLLEMBOLA: ONYCHIURIDAE) FROM NORTH AMERICAN CAVES

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A new Agraphorura *species is described from North American caves (Idaho, USA) and seven additional taxa are referred to this genus. The new species can be distinguished from congeners by the unusual structure of antennal III sense organ. An identification key for all of the known species of* Agraphorura *is provided.*

The genus *Agraphorura* was established by Pomorski (1998) for *Onychiurus naglitshi* Gisin, 1960. Because of structure of furcal area he placed the genus in the tribe Thalassaphorurini and listed the following set of characters as diagnostic: lack of anal spines, 7 setae in distal whorl of tibiotarsi, granulated vesicles in postantennal organ and distinct sensilla on body and antenna. Among the known Onychiurinae the following can be classified into this genus. All of them were described originally in the genus *Onychiurus* Gervais, 1841. The biogeographic regions (Christiansen & Bellinger 1995) in which they occur are inserted in brackets.

Agraphorura naglitshi (Gisin, 1960) [2a, Europe]
A. portucalensis (Gama, 1964) comb. n. [5, Mediterranean]
A. gambiaria (Murphy, 1965) comb. n. [10, Sudanese Park Steppe]
A. xenonis (Ellis, 1976) comb. n. [5, Mediterranean]
A. eisi (Rusek, 1976) comb. n. [8, Pacific North American]
A. pseudojusti (Thibaud, Massaud, 1979) comb. n. [24, Caribbean]
A. acuitlapanensis (Palacios-Vargas, Deharveng, 1982) comb. n. [24, Caribbean]
A. fernandae (Oliveira, Thibaud, 1992) comb. n. [26, Amazon]
A. mariapetrae (Thibaud, 1993) comb. n [24, Caribbean]
A. spelaea n. sp., [8, Pacific North American]
While the genus is fairly widespread all of these species appear to be very localized and rare.

Agraphorora spelaea new species (Fig. 1 A-E, 2 A-G)

Description: Color white. Length (without antennae) of reproductive males – 0.85-0.95 mm. Body shape cylindrical (Fig. 1). Granulation of body surface generally uniform and fine, antennal bases not marked. Antennae nearly as long as head. Antennal segment IV with deeply sunken and relatively long subapical organite. Microsensillum on antennal segment IV large, situated in latero-external position at level of posterior row of setae (Fig. 1B). Antennal organ III with 5 guard setae, 5 very long, digital papillae, covering 2 large, bent and distinctly swollen sensory clubs. 2 sensory rods small, slightly bent, hidden under sensory clubs (Figs. 1B-1C). Microsensillum inserted slightly below antennal organ III. Postantennal organ relatively large and long with 20-21 granulated vesicles (Fig. 1D). Pseudocelli: dorsal 32/233/3335(4)3; ventral 3/011/1212**;** subcoxae 2/3/3. Parapseudocelli: ventral 0/000/101; femora 1/1/1. Labium AB type (Fig. 2B). Thoracic terga II and III with large lateral microsensilla. Dorsal chaetotaxy nearly symmetric, poorly differentiated into meso- and microchaetae (Fig. 1A). Sensilla very well differentiated and visible on body (Figs. 1E, 2A, 2G). Sensilla formula: dorsal 2/011/111121, ventral 2/000/0001, subcoxa2 0/0/1. Head with seta d_0. Thoracic tergum I with 4+4 setae, abdominal terga IV and V without medial setae, abdominal tergum VI with one medial seta. Subcoxae with 2/4/4 setae. No setae between legs on thorax I-III. Ventral tube without basal setae and 6+6 setae on the shaft. Claw I-III without inner tooth. Empodial appendage ends bluntly short of inner edge of the claw, with large, long basal lamella. Tibiotarsi I-III with distal whorl of 7 setae (Figs. 2C-2E). Male ventral organ absent. Furca reduced to small area of fine granulation located on abdominal sternum IV near border of abdominal sternum III, with 2+2 setulae arranged in two rows (Fig. 2F). Anal spines absent.

Holotype: repoductive male (mounted on slide), (9518) USA, Idaho, Blaine Co., Wagon Butte cave, 1475 m a.s.l., 13 VII 2000, from water pools and under rocks, leg. D. Hubbard (deposited in the collection of the Department of Systematic Zoology and Zoogeography, Wroclaw University). Paratypes: unreproductive male (mounted on slide), (9518), same data as holotype. Reproductive male (mounted on slide), (9517) Lincoln Co., Pot-o'-Gold cave, 1393 m a.s.l., 12 VII 2000, from surface of water pool, leg. D. Hubbard (deposited in the collection of the Illinois Natural History Survey and Department of Systematic Zoology and Zoogeography, Wroclaw University).

Derivatio nominis: The specific name is derived from Latin word "spelaeum" – cave, the habitat of the new species.

Remarks: The shape of furcal remnant, presence of 7 setae in the distal tibiotarsal whorl of setae and lack of anal spines shows that the new species belongs to the genus *Agraphorura*. Within the genus, it is characterized by the unusual structure of the antennal III sense organ and by the general shape and proportions of the unguiculus and empodial appendage. The antennal III sense organ of *A. spelaea* has extremely enlarged sensory clubs. The claws of the new species are small and thin, while the empodial appendages are relatively large. Both characters are unique and probably are connected with the troglobitic mode of life. They never have been found in edaphic species of *Agraphorura*, even of the tribe Onychiurinae. *A. spelaea* n. sp. has an isolated position within the genus and probably is related to *A. pseudojusti* Thibaud & Massoud, 1979 and *A. mariapetrae* Thibaud, 1993 from Guadeloupe (Lesser Antilles). The new species and *A. pseudojusti* have 1+1 pseudocelli on thoracic sterna II and III, and a broad empodial lamella shows the similarity to *A. mariapetrae*.

Key to known species of *Agraphorura* (adults or subadults)

1. Antennal III sense organ with 5 papillae .... 2.
-. Antennal III sense organ with 4 papillae .... 5.

2. Abdominal terga I-III with 4+4 pseudocelli .... *A. portucalensis* (Gama, 1964)
-. Abdominal terga I-III with 3+3 pseudocelli .... 3.

3. Thoracic tergum I with 2+2 pseudocelli. Antennal III sense organ with 5 very long, digital papillae, covering 2 large, bent and distinctly swollen sensory clubs; 2 small sensory rods, softly bent, hidden under sensory clubs (Fig. 1C) .... *A. spelaea* sp. n.
-. Thoracic tergum I with 1+1 pseudocelli. Antennal III sense organ with 5 typical papillae, 2 smooth sensory clubs and 2 typical sensory rods .... 4.

4. Ventral pseudocellar formula 4/000/2222 .... *A. xenonis* (Ellis, 1976)
-. Ventral pseudocellar formula 2/000/1212 .... *A. naglitshi* (Gisin, 1960)

5. Thoracic tergum I with 4+4 setae .... 6.
-. Thoracic tergum I with 5+5 setae .... 7.

6. Ventral pseudocellar formula 3/000/0-1112, subcoxae with 1 pseudocellus, postantennal organ with 8 vesicles .... *A. acuitlapanensis* (Palacios-Vargas, Deharveng, 1982)
-. Ventral pseudocellar formula 3/000/0212, subcoxae with 2 pseudocelli, postantennal organ with 11 vesicles .... *A. gambiaria* (Murphy, 1965)

7. Abdominal sterna without pseudocelli .... *A. eisi* (Rusek, 1976)
-. Abdominal sterna with pseudocelli .... 8.

8. Ventral pseudocellar formula 3/011/122? .... *A. pseudojusti* (Thibaud, Massoud, 1979)
-. Ventral pseudocellar formula 3/000/1212 .... *A. mariapetrae* (Thibaud, 1993)
-. Ventral pseudocellar formula 3/000/2222 .... *A. fernandae* (Oliveira, Thibaud, 1992)

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I wish to thank Mr. David Hubbard (senior geologists, Virginia Division of Mineral Resources, Charlottesville) for specimens of the new species and Prof. Kenneth Christiansen (Grinnell College, Grinnell) for kind and helpful comments on the manuscript. The work was supported by Committee of Scientific Research, Warsaw, Poland (project 2020/W/IZ/01).

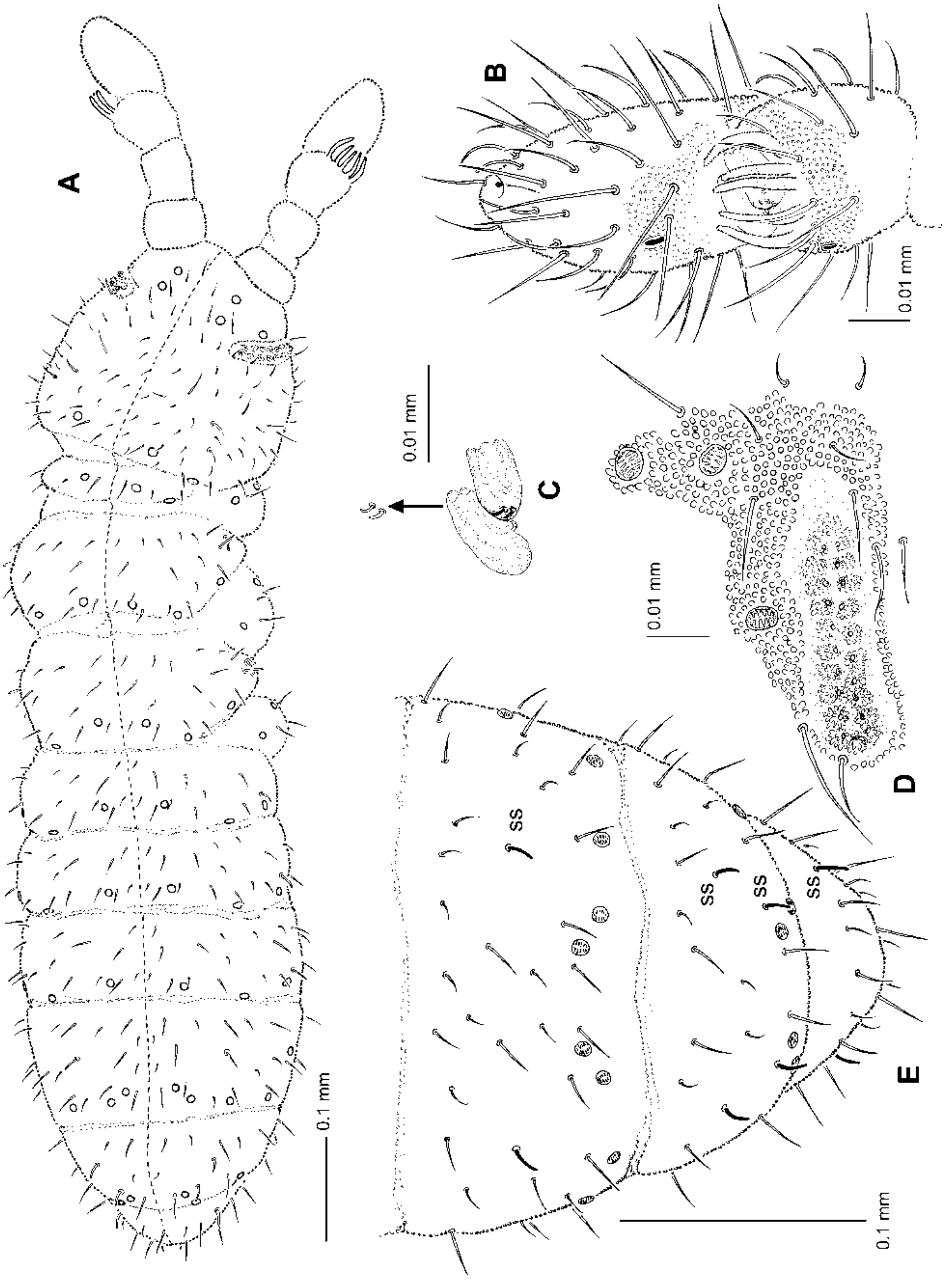

Figure 1. ***Agraphorura spelaea*** **sp. nov. A – habitus and dorsal chaetotaxy, B – antennomere III-IV with antennal III sense organ, C – antennal III sense organ – sensory clubs and sensory rods, D – postantennal organ and anterior cephalic pseudocelli, E – chaetotaxy of abdominal terga IV-VI, ss – sensilla.**

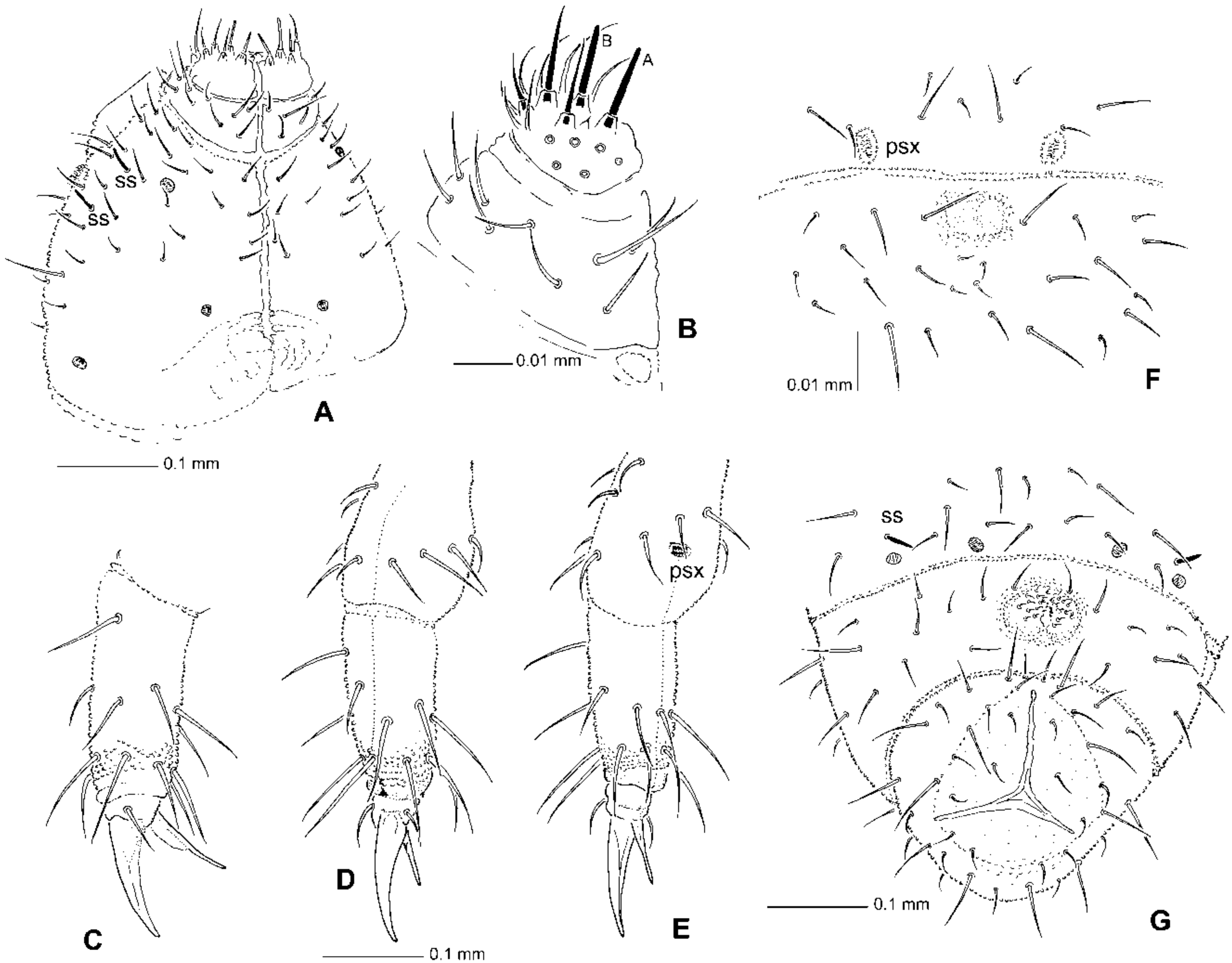

Figure 2. ***Agraphorura spelaea*** **sp. nov. A – ventral side of head, localization pseudocelli and chaetotaxy, ss – sensilla, B – right labium (AB type), C – tibiotarsal chaetotaxy and claw of hind leg, lateral view, D – femoral and tibiotarsal chaetotaxy of median leg , dorsal view, E – femoral and tibiotarsal chaetotaxy of median leg, ventral view, F – remnant of furca, psx – parapseudocelli, G – chaetotaxy of abdominal sterna IV-VI, ss – sensilla.**

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Henri M. André, Xavier Ducarme and Philippe Lebrun - New ereynetid mites (Acari: Tydeoidea) from karstic areas: True association or sampling bias? *Journal of Cave and Karst Studies*, v. 66, no. 3, p. 81-88.

NEW EREYNETID MITES (ACARI: TYDEOIDEA) FROM KARSTIC AREAS: TRUE ASSOCIATION OR SAMPLING BIAS?

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A new genus and two new species of ereynetid mites, one edaphobitic, the other troglobitic, are described from three European karst areas. Free-living species of the Riccardoella*-complex exhibit ramified barbules in guard setae associated with tarsal solenidia, whereas parasitic species lack these characters. Ramified barbules in guard setae are thus considered specific adaptations to soil habitat. Free-living species of the* Riccardoella*-complex are seemingly restricted to karstic and other calcareous-rich areas while parasitic species live exclusively on slugs and snails. The relationship between calcium and* Riccardoella*-complex mites is discussed. A key is provided for the genera of Ereynetinae.*

The genus *Riccardoella* Berlese, 1923 includes five species, most of them being parasitic on gastropod mollusks (Fain & Van Goethem 1986; Fain & Klompen 1990; Fain 2004). The only species of the most evolved subgenus, *Riccardoella*, lives exclusively on Helicidae, the most evolved family among the land pulmonate gastropods. Species belonging to the subgenus *Proriccardoella* are more primitive and colonize more primitive gastropods such as species of the Milacidae and Limacidae (Fain & Van Goethem 1986). Recently, Fain & Barker (2004) described, from New Zealand, a new genus closely related to the genus *Riccardoella* and including a single species, also parasitic on gastropods.

The only free-living species of the genus *Riccardoella*, *R. canadensis*, was collected in Canada from a mull type soil with a mixed hardwood stand in which sugar maple (*Acer saccharum* Marsh) predominated (Marshall & McE. Kevan 1964: 60). The species was recently recorded from litter sample in Ukraine (Zabludovskaya 1995: 90-92). In addition, a specimen misidentified as *R. oudemansi*, was cited from the Amateurs' Cave in the Moravian karst (Zacharda 1978). Recently, an undetermined *Riccardoella* species was listed from grassy habitats in the Slovak karst (Kalúz 1998).

During a biospeleological survey of invertebrates from Belgian caves (Ducarme *et al*. 2003), numerous mites of a new genus close to *Riccardoella* were collected. They are described hereafter, together with specimens collected from the two other European karsts. Adaptive characters of free-living species and their distribution will be discussed.

MATERIALS AND METHODS

The material studied includes the holotype and paratypes of *R. canadensis*, plus specimens of two new species collected from three European karst areas.

For the mite description, we used photographs taken with a Leica TC200 digital camera mounted on a Leica DM LB microscope equipped with phase contrast. From the 402 source pictures (2.3 Mb), 124 photographs (624 Kb) were combined with the AUTO-MONTAGE program (version 3.03.0103 by Synoptics Ltd) as explained in André & Ducarme (2003). Terminology and chaetotaxal naming convention follow André (1980). Measurements in micrometers are given as mean ± standard deviation.

DESCRIPTIONS AND KEY

Hanriccardoella n. gen.

Like *Riccardoella* and *Austreynetes*, the new genus has 3-segmented palps. However, it is different from *Riccardoella* and *Austreynetes* in lacking lyrifissure *im* and having only two setae on the palptarsus. Leg IV has more setae than all *Riccardoella* species, with two setae on the basifemur and two on the coxa. The new genus is also different from *Austreynetes* characterized by a reduced tibial chaetotaxy, nude trochanters and the absence of opisthosomal trichobothridia.

Prodorsum (Fig. 1A-C): dehiscence line procurved (Fig. 3D) although setae (*vi*) are located slightly in front of (*ve*) (Fig. 1B-C), no lens and no eyespot. Opisthosoma: Poroidotaxy: 3 (*im* missing). Setae (*l*4) trichobothridial as in the genus *Riccardoella* (Fig. 1F). Genital chaetotaxy (Fig. 1G): Ad(0,3-6-4) TN(2 or 3-4), DN(1-2), PN and Lv(0-0); aedeagus-like structure in male (Fig. 1H); epimeral formulae: Ad & TN(3-1-3-3), DN(3-1-3-2), PN(3-1-2-0), Lv(3-1-2). Legs: chaetotaxy: I(12-6-4-6-1) II(9-3-4-4-1) III(8-3-3-3-0) IV(8-3-3-(2-2)-0) in the adult, tritonymph: idem minus the ventral seta on tarsi II, II and IV, DN: I(10-5-4-5-1) II(8-2-4-4-1) III(7-2-3-3-0) IV(7-2-3-3-0),PN: (10-5-4-5-0) II(6-2-4-4-0) III(5-2-3-3-0) IV(5-0-0-0-0), larva as the protonymph first three legs; solenidiotaxy: 3 (ereynetal organ included, Fig. 2D); femur IV undivided in the larva, proto- and deutonymph but divided in the next stases. Eupathidia on tarsus I: (*ft*), (*tc*), (*it*) and (*p*). Palp: (2-0-0) (Fig. 2K-L).

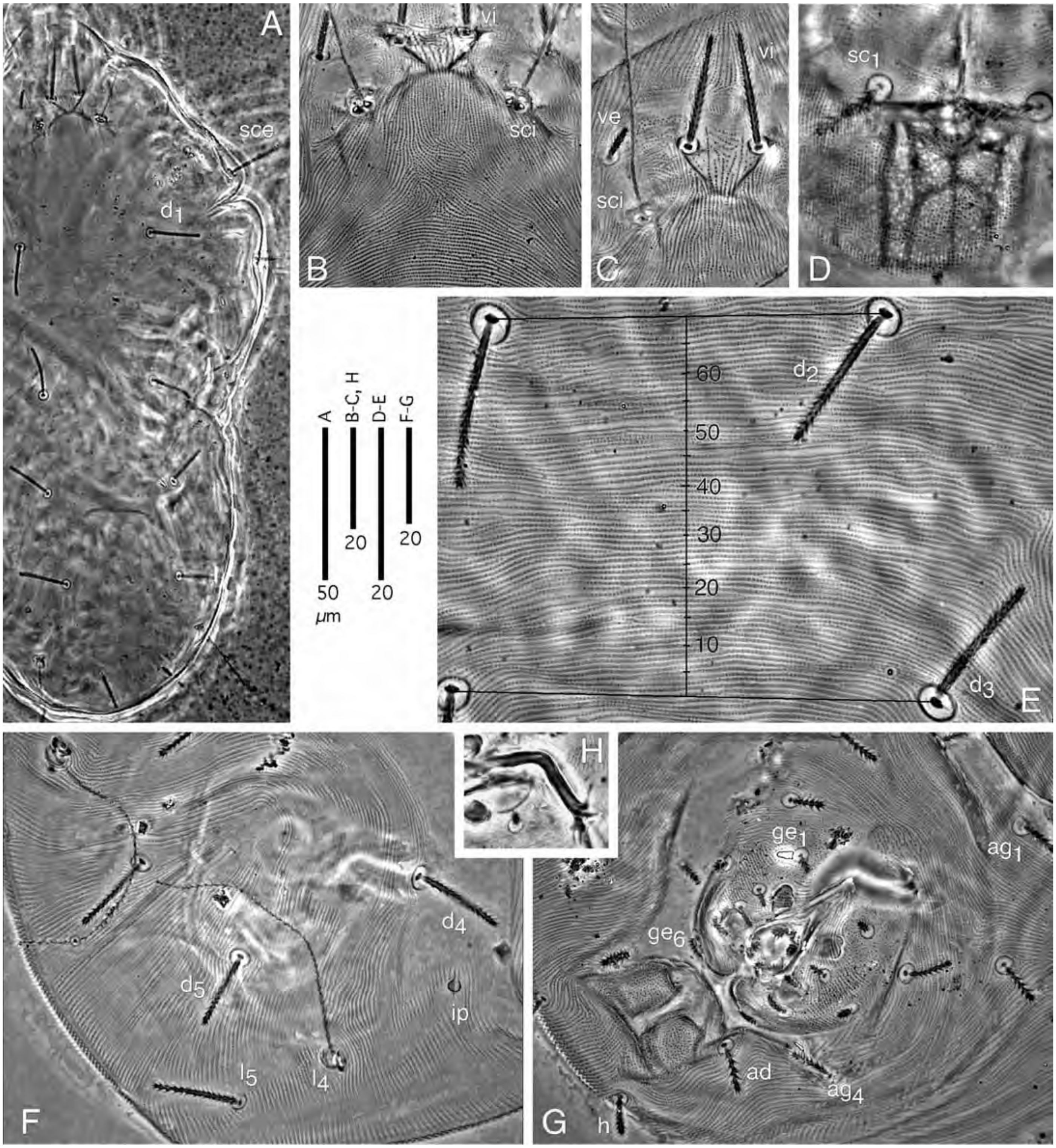

Figure 1. Idiosoma of *Hanriccardoella faini* n.gen., n.sp. adult. (A) Dorsal view. (B-C) Prodorsum. (D) Ventral ornamentation of gnathosoma. (E) Dorsal striation between (*d*2) and (*d*3). (F) Dorsal view of posterior opisthosoma. (G) Anal and genital areas. (H) Aedeagus-like structure. (A: holotype, B-H: paratypes)

Etymology: The name refers to that of the cave (Han) where the types were found. The cave is also the type locality of another Ereynetidae, *Neospeleognathopsis* (*Speleomyotis*) *bastini* (Fain 1958), parasitic in the nasal cavities of bats.

Type-species: *Hanriccardoella faini* n. sp.

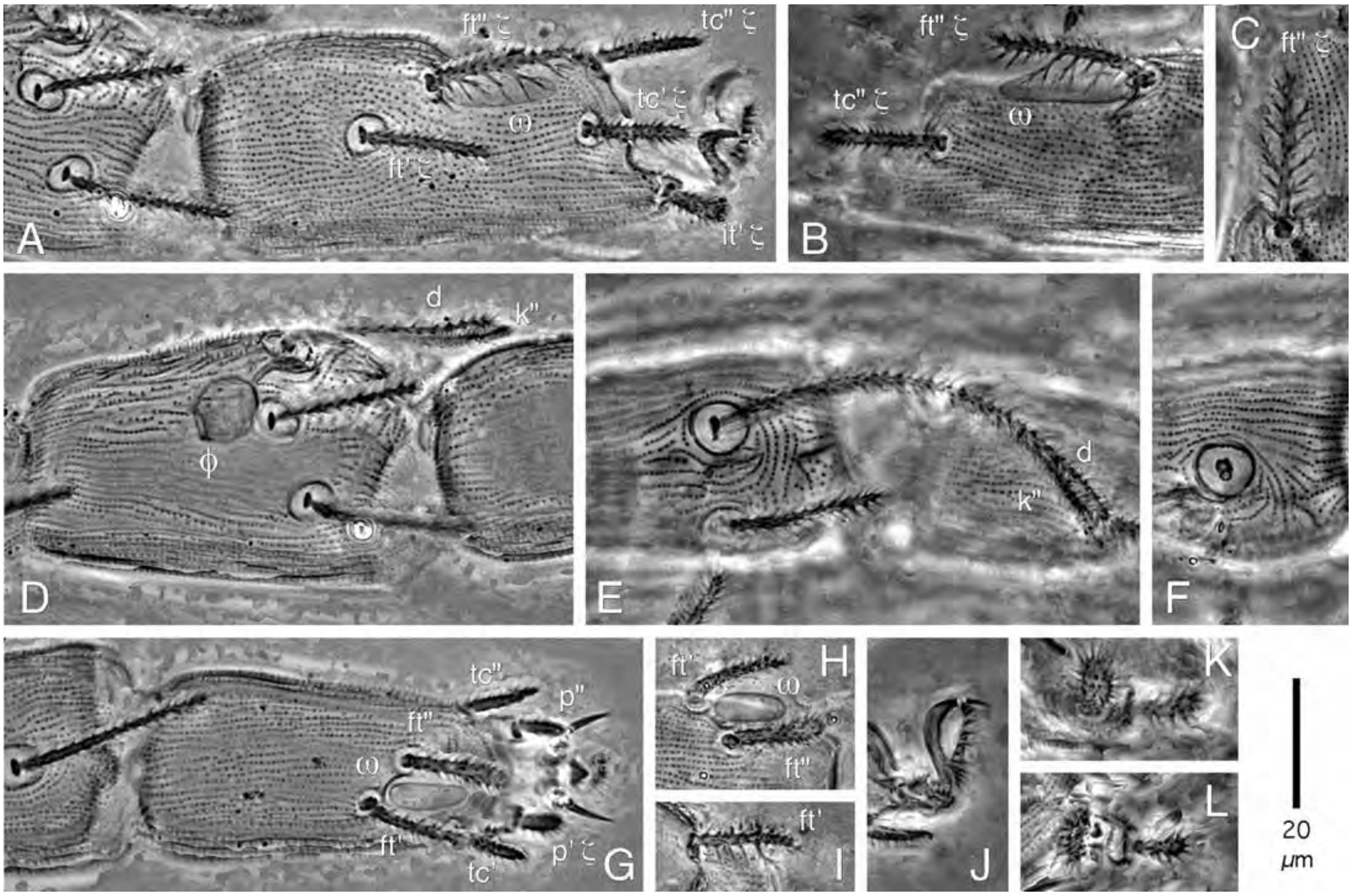

Figure 2. Legs of *Hanriccardoella faini* n.gen., n.sp. adult. (A-C) Paraxial (A), antiaxial (B) and dorsal views of tarsus I. (D-E) Tibia I with ereynetal organ (D) and duplex setae (E). (F) Same as (E) with broken setae. (G-I) Dorsal (G, I) and anti-axial (H) viewsTarsus II. (H) Apotele I. (I-J) Lateral (I) and end (J) views of palptarsus. (A-J: paratypes).

Hanriccardoella faini n. sp.

Presence of a x-shaped pattern between setae (*vi*) and (*sci*) (Fig. 1A-C); such a prodorsal ornamentation similar to the prodorsal shield observed in some *Ereynetes* has never been observed in the genera *Riccardoella* and *Austreynetes* Prodorsal striation longitudinal except in front of setae (*vi*), where striae form a rounded pattern (Fig. 1C). Gnathosoma with a 5-line pattern on the ventral face. Transverse striation on the opisthosoma (Fig. 1E), number of striae between (*d*2) and (*d*3): 69-70.

Guard setae with ramified barbules which overlie and seemingly protect solenidia ωI and ωII (Fig. 2A-C, 2G-I). Such ramifications have never been described in any ereynetid species. In *Riccardoella,* seta *ft'* moves distally beyond solenidion ωI (Fig. 4E, F) while it keeps its original location, behind solenidion ωI, in the new species (Fig. 2A).Tarsal solenidia recumbent and bent (Fig. 2H). Intertwined cluster on tibia I with *k*" as long as its guard seta, *d* (Fig. 2E). Famulus *k*" translucent and difficult to see; its base is however very distinct when the setae are broken (Fig. 2F). Empodium with 10-11 raylets (Fig. 2J).

Size: length of idiosoma: 358±19 in adults (*n*=3).

Etymology: The authors are pleased to name the new species after Prof. A. Fain who discovered and described so many ereynetid mites (111 out of 180 valid species).

Material examined: 3 females (2 with a single egg), 2 males, 5 trito-, 1 deuto- and 1 protonymphs, 1 larva. All mites were collected from the Han Cave (Rochefort, Belgium), at two sampling sites (Mamelons gallery and crossing of Mamelons gallery with “Fer de Lance”) on three dates (16 September 1999, May and November 2000).

Deposition: The holotype (female with no egg) and 4 paratypes (1 gravid female, 1 male, 1 trito- and 1 protonymph) are deposited at the “Institut royal des Sciences naturelles”, Brussels. Remaining specimens in André’s collection.

Ontogeny of *Hanriccardoella*

The earlier the stase, the more rounded is the body (body length/maximum width, L/W=1.95 in adults, 1.39 in deutonymphs (Fig. 3A) and 1.26 in larvae (Fig. 3B).

The ontogenetic bipartition of femur IV is similar to that observed in the meyerellid genus *Triophtydeus* (André 1985) but is delayed to the tritonymph.

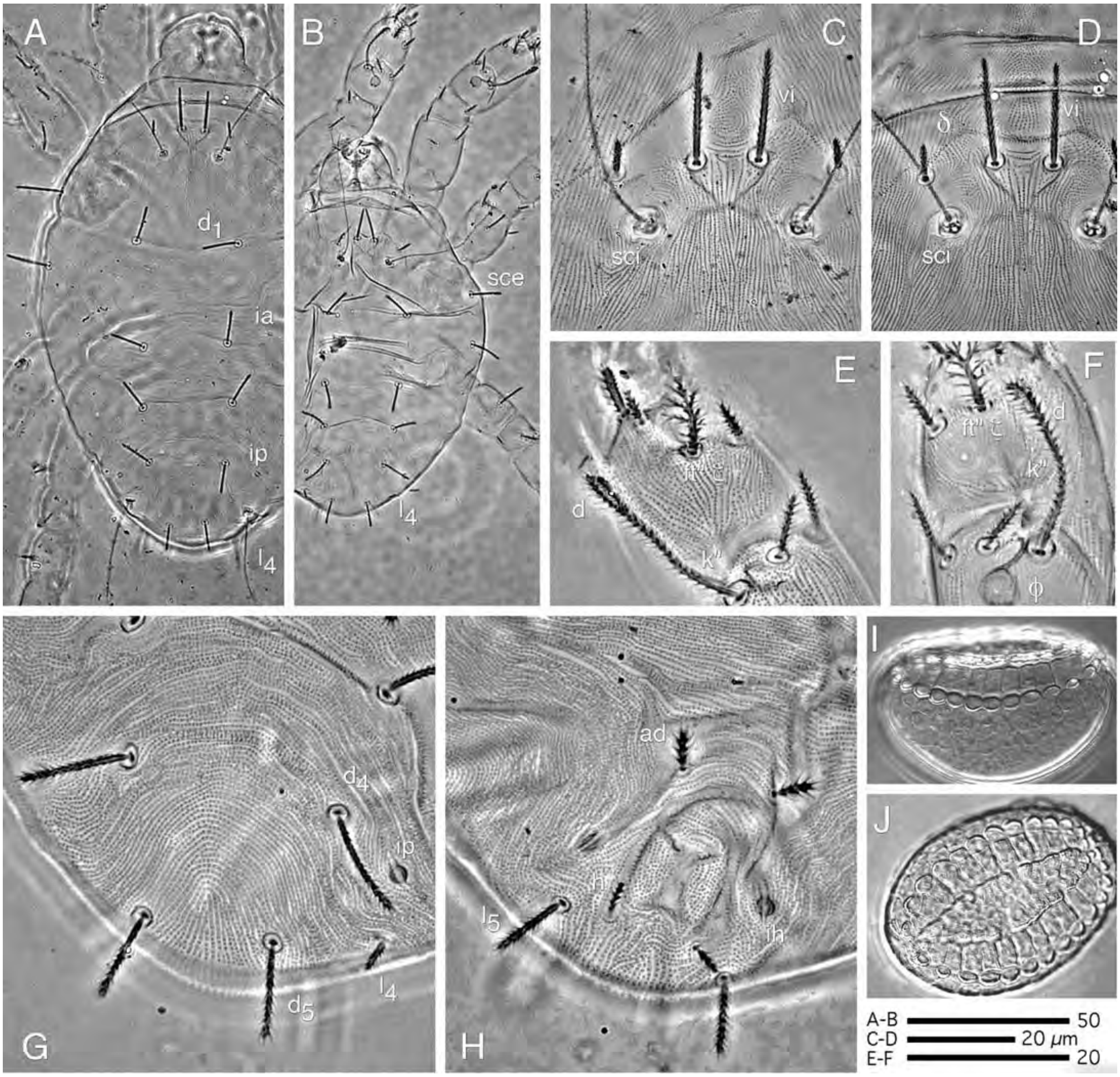

Figure 3. *Hanriccardoella faini* n.gen., n.sp. immatures. (A-B) Dorsal views of the tritonymph (A) and larva (B). (C-D) Prodorsum of the trito- (C) and deutonymph (D). (E-F) Tarsus and tibia I of the larva. (G) Dorsal view of posterior opisthosoma of the larva. (H) Anal and genital areas in the larva. (I-J) Ventral (I) and lateral (J) views of the egg. (A-J: paratypes).

The ontogeny of tarsal chaetotaxy is complex. On tarsi II to IV, tectals are present from the deutonymph while ventrals are observed only in adults. In larvae, tarsus I is regular in shape before the fastigial and tectal areas rises up to form the tarsal protuberances observed in nymphs and adult, the anabasis of tectals is simple and concerns the antiaxial seta. Translocation of *ft"* already present in the larva (Fig. 3E, F). Setae *ft'* and (*tc*) eupathidial in the protonymph and onwards. Iterals appear in the tritonymph and become eupathidial in the adult.

Trochanteral II is present in the deutonymph of *Hanricardoella* but not in that of *Riccardoella oudemansi*.

The genital chaetotaxy as detailed in the description of the genus. Posterior bothridia absent in the larva (Fig. 3H).

The egg presents ornamentation (Fig. 3I, J) contrary to that of other ereynetid species which are quite smooth.

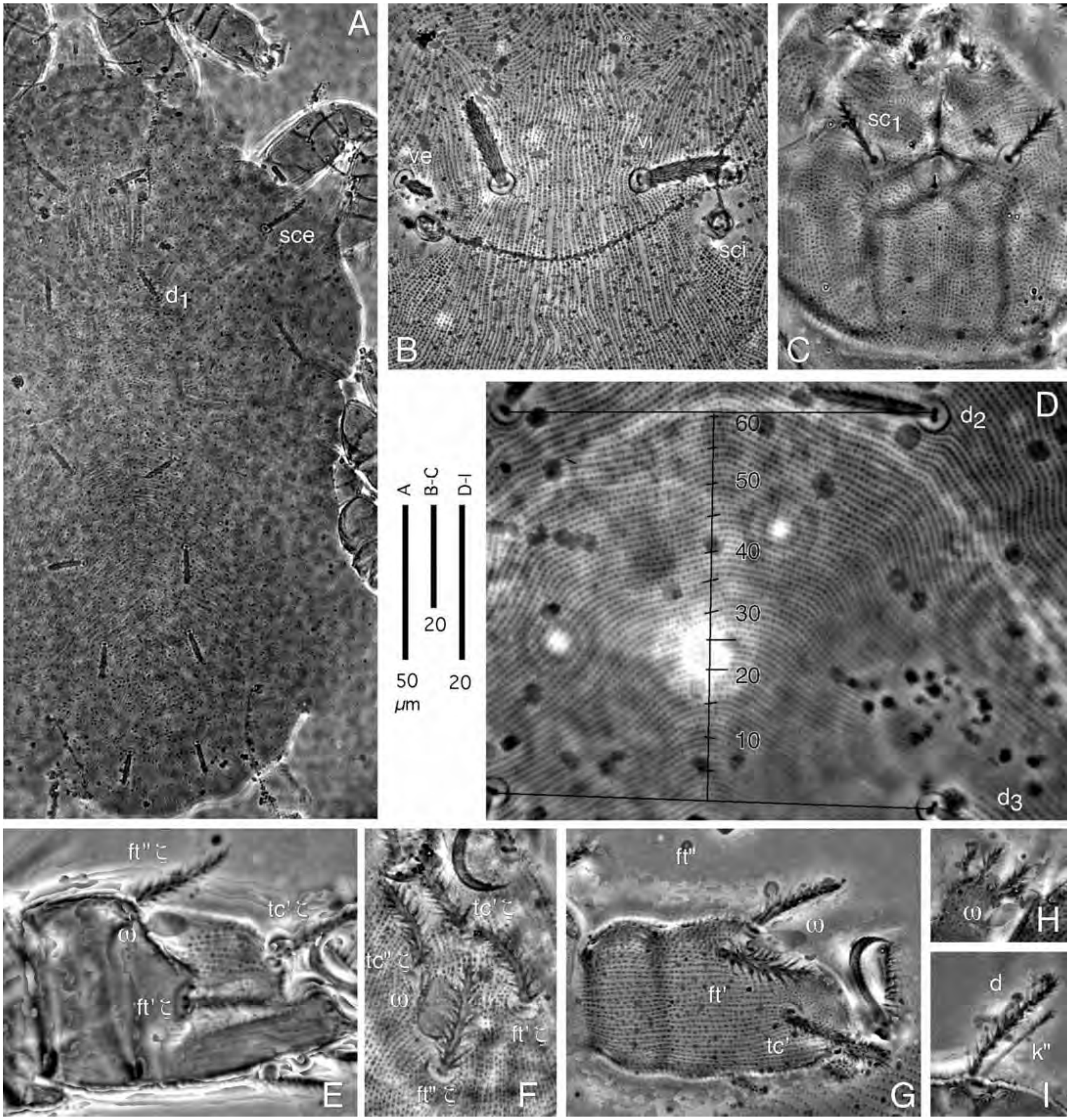

Figure 4. *Riccardoella zadeliensis* n. sp. adult. (A) Dorsal view. (B) Prodorsum. (C) Ventral ornamentation of gnathosoma. (D) Dorsal striation between (*d*2) and (*d*3). (E-F) Antiaxial (E) and dorsal (F) views of tarsus I. (G) Antiaxial view of tarsus II. (H) Palptarsus. (I) Duplex setae of tibia I. (A-I: paratypes).

Riccardoella zadielensis n. sp.

The new species displays the chaetotaxy of the subgenus *Proriccardoella* as defined by Fain and Van Goethem (1986). It is close to *R. triodopsis* as it also has four setae on the palptarsus (Fig. 4H) and a simple 2-line pattern on the ventral face of the gnathosoma (Fig. 4C). The tarsal solenidia of the new species are more or less ovoid (Fig. 4E-G) whereas they are elongate in *triodopsis*. The dorsal setae are rather wide (Fig. 4B, D) and similar in shape to those of *R. oudemansi*. The new species differs from the only other free-living *Riccardoella* by the shape of solenidion ωII, which is globulous in *R. canadensis*. Famulus *k*” is shorter than seta *d* (Fig. 4I). Striation pattern between setae (*d*2) and (*d*3) is inverse v-shaped and the number of striae is approximately 60 (Fig. 4D). Ereynetal organ is similar to that of *H. faini*. Empodium with 13-14 raylets (Fig. 4J).

The specimen from the Amateur’s Cave identified as *R. oudemansi* by Zacharda (1978) appears to belong to the new species.

Size: length of idiosoma: 359±30 in adults (*n*=9).

Etymology: The name refers to the field collection site, the famous Zádiel Gorge.

Material examined: 11 females (2 with a single egg), 2 males, 2 larvae from the Zádiel Gorge, Zádiel (Slovakia), 2 June, 8 August, 14 October 1988; 1 male from Silická l’adnica Chasm, Silica (Slovakia), 16 September 1987; 1 male from Amateur’s Cave (Czech Republic), 12 February 1974.

Deposition: The holotype (female) and 2 paratypes (1 female and 1 male) (all from the Zádiel Gorge) are deposited at the Slovak National Museum in Bratislava. Remaining specimens in André’s collection.

DISCUSSION

Compared to *Riccardoella*, the new genus presents a mixture of plesiomorphic (“primitive”) and apomorphic traits. Plesiomorphic features include the anterior position of setae (*vi*), proximal location of *ft* on tarsus I, presence of two setae on basifemur IV (vs one in *Riccardoella*) and of three setae on epimeron IV (vs two in *Riccardoella*). In contrast, apomorphic traits include the ornamentation of eggs, presence of an aedeagus-like structure (absent in *Riccardoella*), reduced chaetotaxy of the palptarsus, loss of lyrifissure *im*, and the development of ramified barbules on guard setae associated with tarsal solenidia. Actually, the last character is shared by two other species, *R. zadeliensis* and *canadensis*. Ramified barbules on guard setae associated to tarsal solenidia are thus adaptations associated with free-living species in contrast to parasitic species deprived of such associations and barbules (see recent SEM published by Ueckermann & Tiedt in 2003). The biological meaning of such an adaptation remains to be understood. It probably is related to life in the soil and soil-like material, more precisely to life in the porosphere, which is the substrate

Key to the genera of Ereynetinae (adults only)

1. Palp seemingly 5-segmented with a strong distal seta, opisthosoma with one pair of trichobothria, femur I with 7 setae .... *Ereynetes*
-. Palp with less than 5 segments, femur I with 6 setae or less........ 2.
2. 4-podomere palp, opisthosoma without trichobothria, tibia I with 5 setae........ *Pseudotydeus*
-. 3-podomere palp........ 3.
3. Opisthosoma without trichobothria, tibia I with 4 setae, all trochanters nude........ *Austreynetes*
-. Opisthosoma with trichobothria, tibia with 6 setae, trochanteral I present........ 4.
4. Lyrifissure *im* present, femur IV with 3 setae........ *Riccardoella*
-. Lyrifissure *im* absent, femur IV with 4 setae........ *Hanriccardoella*

Table 1. Distribution and habitats of free-living species of the *Riccardoella*-complex.

Species	**Habitat**	**Geology (1)**	**Location**
Hanriccardoella faini	Han Cave, sediment	Calestienne karst, DL	Belgium, Rochefort
Riccardoella canadensis	Mull, Farmington Loam	Limestone bedrock	Canada, Ste Anne de Bellevue
	Humus, Chernozem	$CaCO_3$ at depth	Ukraine, Askania-Nova
zadeliensis	Grassy soil	Slovak karst, DL	Slovakia, Zádiel Gorge, Zádiel
	Soil	Slovak karst, WL	Slovakia, Silická l’adnica Chasm, Silica
	Amateur’s Cave, clay	Moravian karst, DL	Czech Republic, Suchy zleb-valley

(1) DL: Devonian limestone; WL: Wetterstein limestone.

region of water films occupied by bacteria, protozoa, and nematodes and of channels between aggregates occupied by microarthropods and the aerial hyphae (Vannier 1987, Beare *et al*. 1995). This is also supported by the presence of the same structure in the closely-related genera, *Ereynetes* (Grandjean 1939, Fig. 1B; Fain & Camerik 1994, Fig. 18) and *Pseudotydeus* (André & Ducarme 2003, Fig. 10) which are also soil-dwelling species.

Although the two new species were collected from karstic areas, their habitats differ markedly. *Riccardoella zadieliensis* turns out to be an edaphobite, *i.e*. a soil inhabitant that also occurs in caves. All specimens but one were found in grassy soil. The remaining specimen was collected in Amateur's Cave. In contrast, all specimens of *H. faini* were collected from the Han Cave. Of paramount importance is the absence of *H. faini* from the survey carried out at the soil surface overlying the cave (146 samples scattered over three seasons; Ducarme *et al*. 2005). As the species was collected from the cave from five different samples on three dates and it was represented by all stases from the larva to the adult, one can reasonably conclude that it is troglobitic.

Records of free-living *Riccardoella* and *Hanriccardoella* are rare, particularly if their distribution is compared to that of free-living species of the sister-genus *Ereynetes* (Fig. 5). Still more surprising is that their distribution is restricted to karstic and other calcareous-rich areas (Table 1). *Riccardoella canadensis* was first collected from mull under sugar maple (Marshall & McE. Kevan 1964). Yet, sugar maple is commonly associated with alluvial or calcareous soils (Pearson 1962, Fralish 1976, Great Plains Flora Association 1986) and occurs on soils with high exchangeable calcium (Bigelow & Canham 2002). Marshall (1963) added that these samples came from loam of the Ste-Rosalie Series. However, Christina Idziak, curator at the Morgan Arboretum, compared the sampling map in Marshall's (1963) thesis to the soil map of the arboretum and concluded that the mites came from Farmington Loam, a calcareous loam formed by the *in situ* weathering of limestone bedrock (C. Idziak, personal communication 2004). *Riccardoella canadensis* specimens recorded by Zabludovskaya (1995) were collected from humus under elder (*Sambucus*) at the Askania-Nova botanical garden. Zabludovskaya (personal communication 2004) reported to us that the soil consisted of chernozem. Chernozems, also called 'Calcareous Black Soils', are characterized by the presence of calcium carbonate at depth in the soil profile.

The hypothesized association between calcium and the *Riccardoella*-complex is all the more compelling if it is remembered that parasitic species of the complex are only known to occur on slugs and snails, obviously good reservoirs of calcium. However, the biological meaning of this relationship remains unclear. The richness of calcareous grasslands in both plant and animal species is well documented (Dolek & Geyer 2002, Kahmen *et al*. 2002, Wallis De ries *et al*. 2002) and the distribution of invertebrate species they shelter is usually explained through two factors. First, calcareous grasslands are known to support some plant-specific insects, like the Silver-spotted Skipper, *Hesperia comma* (L.), because its larvae feed on Sheep's Fescue, *Festuca ovina* L. (Thomas *et al*. 1986, Hill *et al*. 1996). Dependence on a food-plant does not apply to *Riccardoella* as the parasitic species are hematophagous (Baker 1970) and free-living forms are thought to be predators (Krantz 1978). Calcareous grasslands are also known to support thermophilic species, especially in butterflies (Thomas *et al*. 1986) and spiders (Hänggi 1996). This explanation does not clarify the distribution of mites of the *Riccardoella* complex living either in caves or in deep soils whose temperatures are low. A third explanation for the hypothesized association is that calcareous grasslands shelter a high diversity of bacteria (Clark 1967) that might account for the distribution of free-living *Riccardoella* if they were bacteriophagous. No data on the feeding habits in *Riccardoella* support this third explanation. Lastly, Norton & Behan-Pelletier's (1991) observation that calcium carbonate and calcium oxalate are cuticular hardening agents in oribatid mites does not apply to soft-bodied mites such as Ereynetidae.

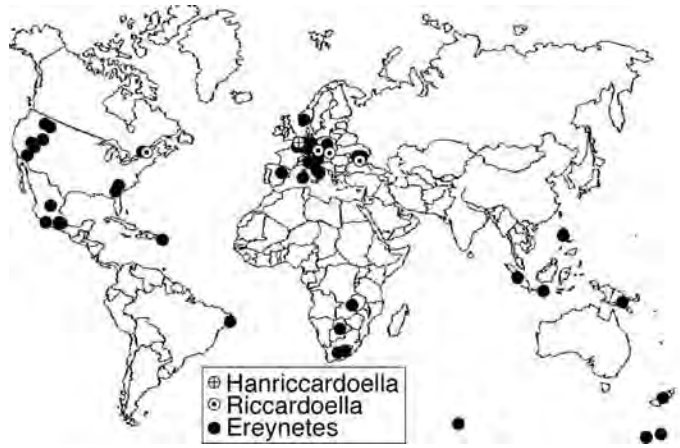

Figure 5. Distribution of free-living species of the genera *Hanriccardoella* and *Riccardoella* compared to free-living species of the sister-genus, *Ereynetes*.

Records of free-living *Riccardoella* are still rare, and we cannot exclude sampling bias as an alternative explanation for the apparent association with karst and other calcareous-rich areas. More research is thus needed to confirm that mites of the *Riccardoella*-complex are really associated with calcium salts and to elucidate the true nature of the association. As demonstrated by recent surveys (Welbourn 1999, Lewis *et al*. 2003, Ducarme et al. 2003), mites have been largely ignored in speleological studies, probably due to the lack of taxonomic expertise and adequate sampling methods. We hope this study will help raise interest of biospeleologists in mites, a highly speciose group including about 500,000 to 1,000,000 species.

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Kevin Allred - Some carbonate erosion rates of southeast Alaska. *Journal of Cave and Karst Studies*, v. 66, no. 3, p. 89-97.

SOME CARBONATE EROSION RATES OF SOUTHEAST ALASKA

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As a way to determine the erosion rate of carbonate bedrock surfaces in Southeastern Alaska, an instrument was designed to directly measure the lowering of rock surfaces relative to fixed stainless steel bolts epoxied into the rock. A total of 582 measuring points were set in 31 measurement sites. Dissolution was found to be the predominant mode of erosion at most stations. Dissolution rate increased with thicker humus soil, but the presence of silty soil limited dissolution, even with deep humus. After deforestation of karst landscapes there was a preliminary dissolution rate increase from 38 mm/ka to 46 mm/ka. Bare rock erosion rates ranged from 31 mm/ka under old growth forests, to 38 mm/ka in alpine settings. Both bare and soil covered site results were similar to measurements elsewhere in the world where precipitation is comparable. However, Alaskan runoff from acidic peat bogs produced dissolution rates up to 1.66 m/ka, which are some of the highest known anywhere.

Southeastern Alaska, also known as the Panhandle, contains one of the few temperate rain forests in the world. Annual precipitation in the areas of this study average 1752 mm on Chichagof Island and over 2540 mm on Prince of Wales Island. The extent of karst development is still unknown, because some regions have been poorly mapped geologically or not at all. Exploration and inventory of the caves and karst topography of the Alaska Panhandle has intensified since 1988.

This study was inspired, in part, by use of the more precise Micro-Erosion Meter (MEM) by High and Hanna (1970) in Ireland, which is similar in technique and challenges to the one described in this paper. Their system consists of a dial indicator mounted on a large triangular plate that is placed on three fixed stainless steel studs in the rock. A measurement of the lowering of the bedrock surface was then possible. In 1993 this author began a monitoring study of the erosion rates of Silurian limestone and marble on Prince of Wales Island and Chichagof Island. In this paper, the term erosion includes the lowering of bedrock surfaces by both corrasion and dissolution. The goals of the study were to more fully understand the rate of karstification in the Alaska Panhandle and to determine how conditions and land use affect the rate. The rate was measured directly at 582 points at 31 sites (Figure 1) over seven to nine years.

Figure 1. The REM study areas of the Alaskan Panhandle. Numbers represent measurement sites of this study. Drawing by C. Allred based on a United States Forest Service map.

METHODS AND PROVISIONS

The Rock Erosion Meter (REM) was designed by the author to measure the lowering of rock surfaces adjacent to 7.94 mm × 38.10 mm (5/16 inch by 1 1/2 inches) stainless steel bolts that were epoxied into drilled holes in the bedrock (Figure 2). The REM system provides simple and quick installation and measurement at the stations. The measuring tool was built from a Brown and Sharp model 608 one to three inch depth micrometer. It was chosen over metric types because the metric micrometers lacked the carbide-tipped measuring rods needed for durability. The instrument is compact and fits into many constricted and irregular places. A hexagonal socket was precision mounted on the base of the micrometer with copper wire harness and epoxy putty allowing the instrument to be fitted over the fixed stainless bolt heads for taking measurements. The bolt heads had been radially ground so that their top surfaces were slightly concave, and then deburred. Facets

Figure 2. The Rock Erosion Meter at measuring site #95-29. The instrument can be slipped into six different measuring positions for each bolt. By rotating the large knurled handle, the measuring rod moves in and out. Photo by C. Allred.

were ground into the threaded portion for better epoxy adhesion. The REM can be indexed around each fixed bolt to as many as six measuring positions if no rock projections interfere. The positions are designated as 12 O'clock, 2 O'clock, 4 O'clock, and so on. The 12 O'clock position was identified from a prick punch mark on each measuring bolt. Quick-setting epoxy glue was usually used in setting bolts. A small stick or wire was always used to smear the epoxy into the inside surface of each hole for maximum adhesion. After seven to nine years, none of the stations had been heaved by frost action, and the epoxy had taken on a brownish tint, apparently from tannin in the water.

After four years, a gap between the rock and apron of overflowed epoxy was noticed at a small number of stations. In some cases, the gap appeared to far exceed the average erosion of the station. When the stations were set, there was no concern about cleaning rock dust off or drying any dampness around the entrance of the drilled holes, which resulted in poor adhesion of the overflowed excess epoxy. Close observation of one such station revealed that the apron was detached from the rock and bolt; likely a result of frost wedging. The loss of the aprons in these instances had no effect on the function of the stations.

The REM scale is graduated in 0.025 mm (0.001 inch) but readings were estimated to 0.0025 mm (0.0001 inch). Readings had to be taken with care because the instrument has an inverted scale. In some instances the measuring rod contacted the rock at an angle, making measurements difficult and more inaccurate. On some oblique measurements, inconsistencies up to 0.05 mm occurred, but most measurements were repeatable to within 0.0025 mm.

It was critically important that the instrument be seated firmly against the two facets closest to the measuring point. A very delicate touch was necessary when making measurements. The rod tended to crush the delicate outer most crystals until enough resistance was felt to get a consistent reading. A test was run with two stations in a marble rock to determine erosion caused by the measuring process. Total Erosion was 0.012 mm after measuring nine times. To minimize such erosion from frequent measurements, it was decided to delay remeasurement a minimum of five years and avoid any corrections for measuring rod erosion. This would also allow vegetation and soils above some stations to stabilize and function as naturally as possible. A large number of stations were installed at some sites in order to average in differences in rock purity, drainage, and soils.

There was an initial concern that temperature changes might affect the measurements because of expansion and contraction of the rock, stations, and the REM. After the two stations set in the marble mentioned above were measured at 25° C, the rock and REM were held overnight at –4° C, then measured at the latter temperature. Heated for the same time period, they were checked for measuring rod erosion with none detected. Measurements increased an average of 0.005 mm when cold. Because the normal operating temperature range was only one tenth of the test range, the expected error is far beyond the accuracy of the instrument. Thus no corrections were made for temperature changes.

Five rain gauges were placed in a Western Hemlock and Sitka Spruce old growth forest approximately 400 m from site 93-21 at 60 m elevation. The gauges were moved periodically, monitoring canopy interception of rain and snow as compared to precipitation in an adjacent area of deforestation (clearcut).

REM MEASUREMENT SITES

Five karstified land settings were chosen for measurement sites: caves, sub-alpine, alpine, old growth forest, and clearcuts (deforestation). Stations were set in bare rock, under organic (humus) and silt soils, or just under organic soils (Tables 1 & 2). A station in andesitic basalt, which has negligible solubility, was used as a standard for the instrument and checked twice in a month and then after nine years for possible bolt movement or instrument damage.

DISCUSSION AND RESULTS

Brief descriptions of the site characterizations can be found in this section and in the appendix. All carbonate sites were on Silurian limestone and marble. Monitoring of the rock proved quite complex and challenging because of the large number of environmental variables. For example, one site might happen to be shielded from significant rainfall by the orientation of a single tree bough 30 m above. Subtle irregularity in soil makes acidity and water flow inconsistent. Notwithstanding the hundreds of measuring points of this study, the results should be taken as preliminary. However, the system is still an important tool for measuring epikarstic erosion directly.

Measurements were very inconsistent between points of stations with rock containing abundant veins and bodies of

Table 1. Silurian limestone erosion rates.

Type	Site	Elevation (m)	Number of stations	Number of points	Time lapse (TL) years	Erosion during TL (mm) Minimum	Maximum	Percentage carbonate purity	Erosion rate (mm/1000y)
Muskeg streamlet inflow cave	94-22 Bear's Plunge, 2 cm above low water.	180	1	6	8.77	7.5920	20.9397	- - -	1669.34
Muskeg streamlet inflow cave	94-23 Bear's Plunge, 3 cm above low water.	180	1	6	8.77	7.7038	12.7177	- - -	1078.31
Seasonal cave trickle	93-13 Slate Cave, 45 m inside.	304	1	6	9.00	1.4198	1.8059	- - -	180.62
Resurgence cave	93-5 Cataract Cave, 30 cm above low water.	36	1	6	8.97	1.2446	1.9050	95.30	166.06
Resurgence cave	93-6 Cataract Cave, 35 cm above low water.	36	1	5	8.97	0.9474	1.5697	- - -	137.21
Alpine, bare rock	93-7 El Cap Peak, slope of heel print karren.	670	1	6	8.97	0.2209	0.3276	99.18	30.86
Alpine, bare rock	93-8 El Cap Peak, flat of heel print karren.	670	1	5	8.97	0.2108	0.2844	- - -	26.10
Alpine, bare rock	93-9 El Cap Peak, bottom of meandering karren.	670	1	1	8.97	0.4089	0.4089	- - -	45.57
Alpine,bare rock	93-10 El Cap Peak, rounded knob.	670	1	6	8.97	0.1295	0.4140	- - -	29.72
Alpine, bare rock	95-33 (1,4) El Cap Peak, steep below vegetated mat.	670	2	11	6.92	0.2108	0.9499	- - -	62.51
Alpine, soil covered	95-33 (2,3,5,6,7,8) El Cap Peak, thin, vegetated mat.	670	6	35	6.92	0.0025	0.3251	- - -	23.09
Old growth forest, bare rock	93-4 El Cap, wind throw.	109	1	6	9.00	0.1879	0.5511	- - -	38.95
Old growth forest, bare rock	93-12 River's End, wind throw.	152	1	6	8.99	0.0990	0.3327	- - -	23.71
Old growth forest, soil covered	93-11 River's End, 4cm humus.	152	1	6	8.99	0.1727	0.3098	98.50	27.66
Old growth forest, soil covered	93-17, 93-18 Bridal Veil, 6 cm humus.	243	2	12	8.96	0.0508	0.3937	99.35	25.49
Old growth forest, soil covered	95-26 (1,2,3,4,5,6,7) Cavern Lake, horizontal, 2 cm humus.	91	7	34	6.95	0.0000	0.5308	- - -	29.62
Old growth forest, soil covered	95-26 (8,9,10) Cavern Lake, vertical, 2 cm humus.	91	3	20	6.95	0.0025	0.2514	99.38	11.80
Old growth forest, soil covered	95-31 Bridal Veil, 17cm humus.	274	10	60	6.93	0.1244	0.5511	99.69	52.47
Old growth forest, soil covered	95-32 Bridal Veil, 5cm silt under 10 cm humus.	274	10	58	6.92	0.0457	0.4673	- - -	32.07
Old growth forest, soil covered	93-3 El Cap, 5cm silt under thin humus.	109	1	5	9.00	0.1752	0.2463	96.27	23.14
29-36 year clearcut, soil covered	95-27 Starlight, 5cm silt under 30 cm humus.	167	10	50	6.92	0.0330	0.5232	99.37	35.30
29-36 year clearcut, soil covered	95-28 Starlight, 30 cm humus.	167	10	56	6.93	0.1905	0.8483	- - -	71.60
2-9 year clearcut, soil covered	95-29 Bridal Veil, 2 cm silt under 10 cm humus.	304	10	59	6.93	0.0000	0.4445	98.51	32.81
2-9 year clearcut, soil covered	95-30 Bridal Veil, 10 cm humus.	304	10	59	6.93	0.0787	0.5054	- - -	43.90

impurities. There were no apparent influences from the differences in overall carbonate purity (Tables 1 & 2).

Soil depth and water-flow rates were significant influences on the dissolution rate. By plotting dissolution at measuring points around respective stations on a radar graph, elliptical shapes generally appear displaced to one side, indicating increased runoff along the downward side of bare slopes and those under acidic soils (Figure 3).

A light brown silt layer containing tiny clasts of silt is often found between carbonate rock and under organic humus and moss (Figure 4). This silt occurs throughout the Alaska Panhandle karst and appears to be insoluble residue left from carbonate dissolution. A sample (02-1) taken from a road cut near Bridal Veil (site 95-30) was tested and its insoluble oxides recalculated without the carbonate content. Table 3 compares

Table 2. Andesitic basalt and Silurian marble erosion rates.

Type	Site	Elevation (m)	Number of stations	Number of points	Time lapse (TL) years	Erosion during TL (mm) Minimum	Maximum	Percentage carbonate purity	Erosion rate (mm/1000y)
Cave stream	93-15 Basket Bay, littoral zone.	0.0	1	6	9.16	2.6720	3.2562	99.24	326.85
Sub-alpine, bare overhang	93-19 Blue Marble area.	518.0	1	4	8.96	0.9398	3.1800	- - -	200.50
Sub-alpine, soil covered	93-20 Blue Marble area 5 cm humus.	518.0	1	6	8.96	0.3276	0.4876	- - -	47.00
Old growth forest, soil covered	93-1 Leaning Tree, 5 cm moss.	112.0	1	6	8.99	0.0711	0.3048	- - -	22.59
Open, bare rock	93-2 Leaning Tree, road cut, steep rock.	106.0	1	6	8.99	0.2057	0.3048	99.28	27.68
Old growth forest, soil covered	94-24, 94-25 Annie's, 7 cm silt under 5 cm humus.	274.0	2	12	7.95	0.0609	1.9126	95.55	116.28
Open, bare rock	93-14 Trap Bay, lichen-covered talus.	15.0	1	6	9.25	0.2540	0.5334	- - -	32.38
Littoral, bare rock	93-16 Basket Bay, solution pan.	1.2	1	6	9.16	0.2387	0.4597	- - -	37.98
Andesitic basalt, bare rock	93-21 Haines standard	1.2	1	6	9.06	0.0000	0.0965	- - -	3.40

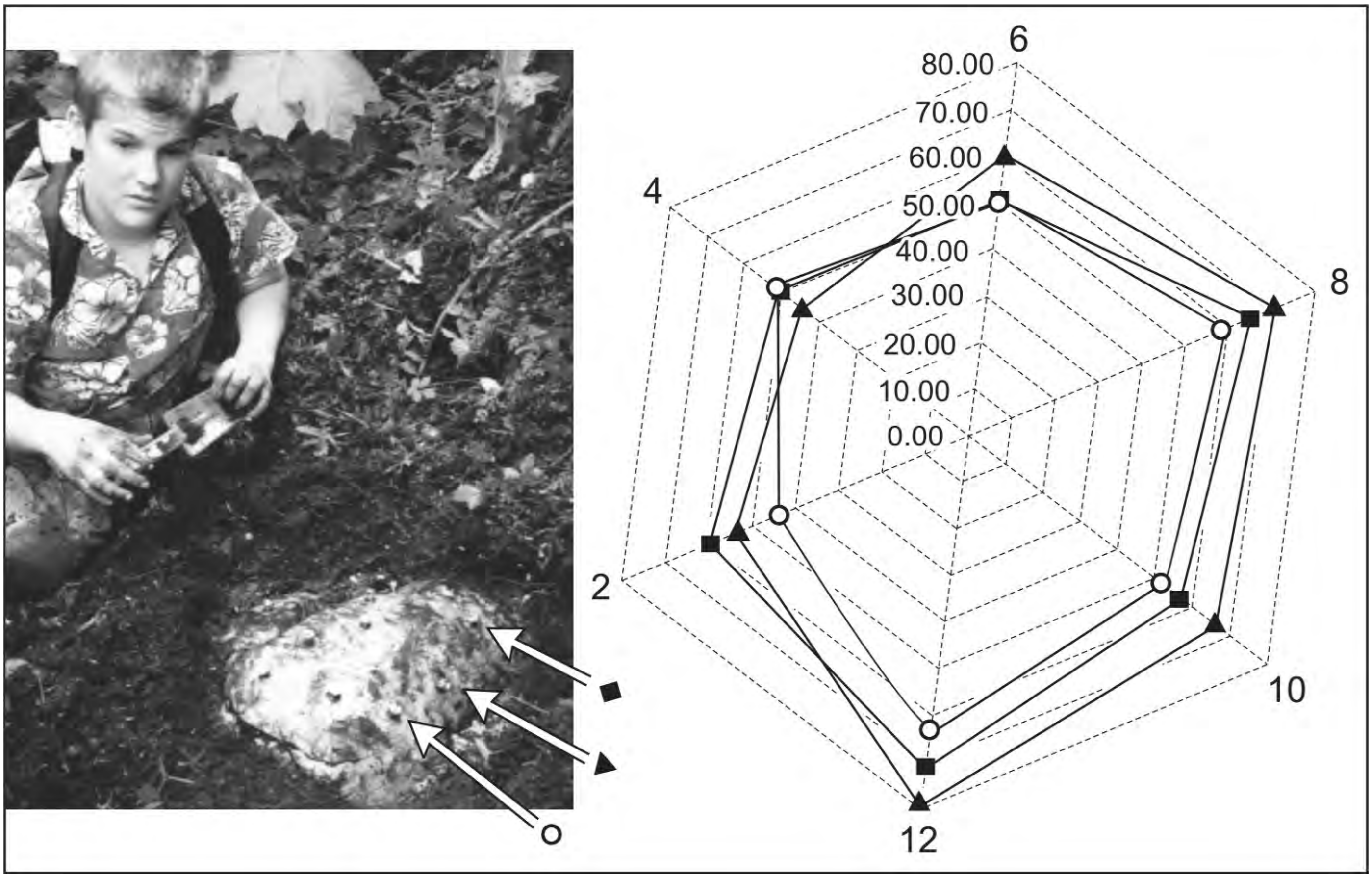

Figure 3. The excavated site #95-31. The measuring points of the three noted stations along the slope of the hump are plotted in mm/ka, showing uneven dissolution rates. The 12 O'clock position of the graph is oriented to the respective stations in the photo. Photo by C. Allred.

the silt to the insolubles of sample 93-3, which had the closest signature of 12 carbonate samples analyzed. Dissolution rates were limited beneath these silty soils regardless of humus depths or water-flow rate (Figure 5). Conversely, deeper organic soils without silt layers showed increased dissolution rates (Figure 6).

Table 3. Whole rock analyses of silty aggregate (sample 02-1) and limestone sample 93-3. Both were recalculated without Ca, MgO, and CO_2. All columns are percentages.

Sample name	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI	Total %
02-1												
Whole rock	29.98	23.19	5.12	1.179	1.07	0.64	1.31	0.85	0.512	0.16	35.79	98.80
Insolubles only	48.9	37.82	8.35	0.292	- - -	- - -	2.13	1.38	0.835	0.26	- - -	99.96
93-3												
Whole rock	2.25	0.69	0.42	0.025	0.78	53.84	0.09	0.19	0.017	0.01	40.85	99.16
Insolubles only	60.94	18.68	11.37	0.677	- - -	- - -	2.43	5.14	0.460	0.27	- - -	99.96

Figure 4. REM site #95-29. Note the silty soil adhering to the center portion of the humus peeled off the rock. The foreground bedrock had been exposed during deforestation.

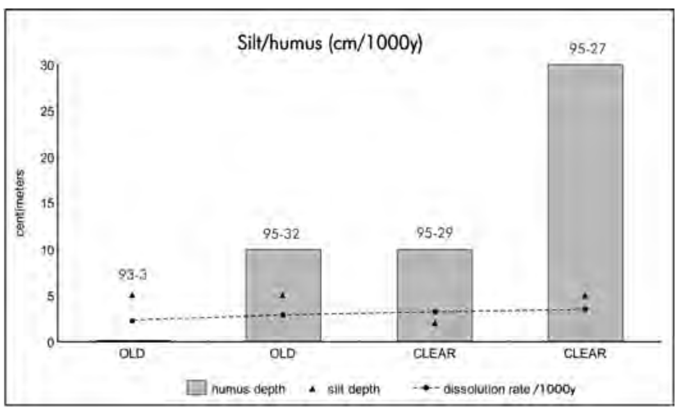

Figure 5. Silt and humus depths plotted with dissolution rates in old growth forests and clearcuts. Silt severely limits dissolution, even with greater humus depths. A total of 172 measuring points were used for this graph.

It is speculated that thick silt accumulation would result in a decrease in exposed rock surfaces and sinkhole depths in the long term because silt limits dissolution rates. Some epikarst terranes may have escaped glaciation for long periods and evolved into less rugged topography. These karstlands are typically mantled with deep silty soils, yet continue to drain to the subsurface. Soil piping may play an important role.

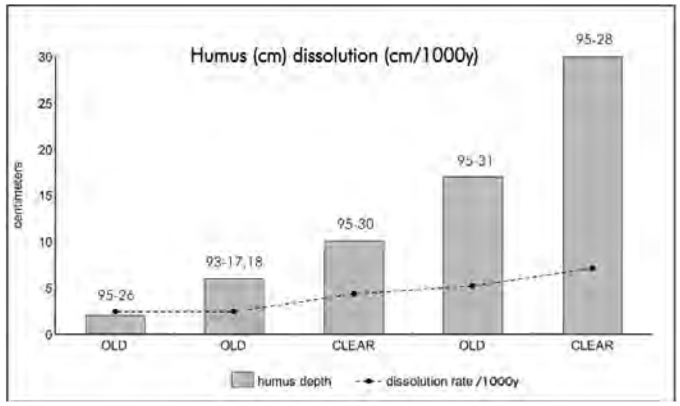

Figure 6. Humus depths plotted with dissolution rates in old growth forests and clearcuts. The dissolution rate shows a slight increase after deforestation. A total of 241 measuring points were used for this graph.

Eight REM sites were on marble (Table 2). The averaged erosion rate was 32 mm/ka at bare rock sites. Some marble on Prince of Wales Island had higher erosion rates than those of limestone. This was due to the tendency of surfaces of this area to break down into sand, perhaps by frost action. In other instances, erosion rates were less than limestone averages, suggesting that dissolution was the prime factor in erosion. In contrast, none of the limestone sites had discernible corrasion.

OLD GROWTH AND CLEARCUT SETTINGS

Two clearcuts of different ages were chosen to compare dissolution rates with nearby old growth forests. The silty stations were unsuitable for this comparison because dissolution was so limited. The old growth forests had three proximate sites with 126 points, with an average dissolution rate equaling 34 mm/ka. These were sites 93-17/18, 95-26, and 95-31. The two- to nine-year-old clearcut (site 95-30) had 59 points with an average dissolution rate equaling 43 mm/ka dissolution. This clearcut had not yet been overgrown by brush or second growth conifers. The 29-36-year-old clearcut (site 95-28) had 56 points with an average dissolution rate of 71 mm/ka. Brush and moss had been killed at the site by the shade of second growth conifers. The stand had been thinned about 20 years after clearcutting. Clearcuts with humus soil experienced an 11% dissolution rate increase over old growth sites with humus

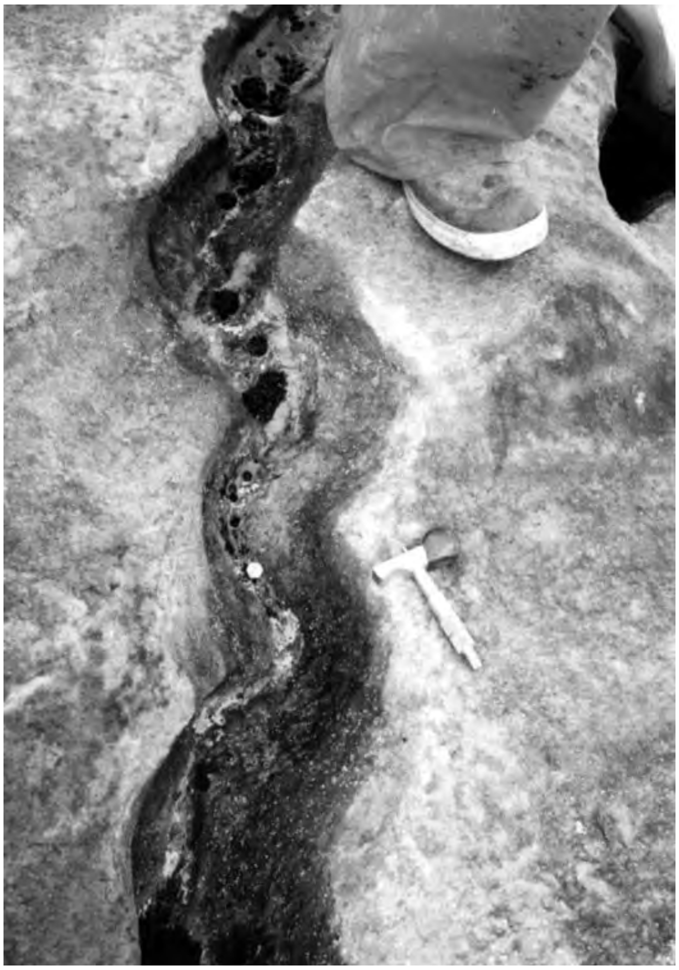

Figure 7. REM site #93-9 in the bottom of an alpine meandering karren. Photo by C. Allred.

Figure 8. REM sites #93-7 and #93-8 on an alpine heelprint karren. Photo by C. Allred.

soil (Figure 6). This is based on the linear interpolation of humus sites and suggests a tentative conclusion. The overall average dissolution rates for all of the old growth and clearcut sites were 38 mm/ka and 46 mm/ka, respectively.

The increased dissolution rate in deforested areas may be due, in part, to decreased canopy interception, reduced transpiration of precipitation, or change in the pH of the water. Old growth foliage interception is less than 35% in wetter, overcast weather according to Wilm (1949). This study showed an average interception of 17% during a mostly rainy period from September 21 to December 31, 2002. The interception ranged from extremes of 100% to −8%, depending on the exact spot of interception, foliage drainage, and amount of rainfall and wind. Of the sites, 14% of the total clearcut precipitation occurred in cases where rain gauges were situated under closed canopy. The remainder of the old growth testing was done under very open canopy. Transpiration values remain an unknown. An attempt was made to determine if canopy drainage was significantly more acidic than direct rain water. One single sample of Western Hemlock canopy drainage was tested and found to have a pH of 6.3 compared to a nearby clearcut with a pH of 6.4.

Toppled old growth trees often peel away the thin soils from bedrock, making bare rock measurements possible. Sites 93-4 and 93-12 were of this type, and had an average erosion rate of 31 mm/ka.

ALPINE AND SUB-ALPINE SETTINGS

On the alpine karst, the average bare rock dissolution rate was 38 mm/ka. At site 95-33, six stations were set under a thin organic mat on a sub-horizontal surface with two additional stations on steeper bare rock adjacent to and below the six stations. Surprisingly, the bare rock stations yielded 2.5 times greater dissolution than the covered stations. It is speculated that the mat of heather and other small alpine vegetation absorbed much of the precipitation, but other influences not yet recognized or understood may also be important. The other bare limestone measurements (Table 1) were 19.5% higher than the forested bare rock measurements and may have been influenced by increased precipitation, turbulence, concentrated flows, or persistent snow (Figures 7,8,9). Both of the sub-alpine sites were in marble subject to significant corrasion and had an average erosion rate of 124 mm/ka.

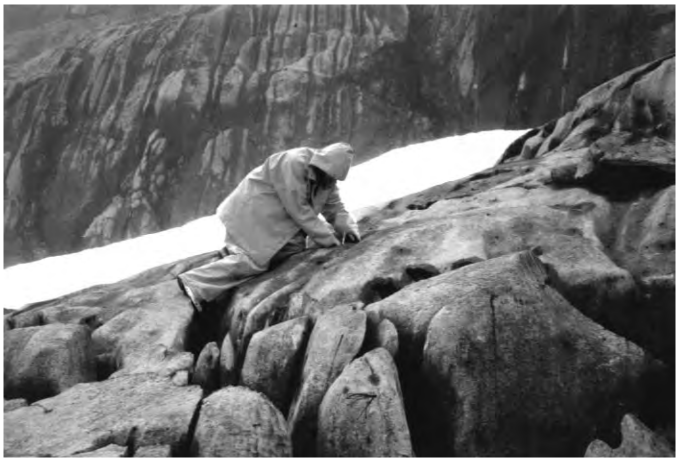

Figure 9. Abundant precipitation coupled with an absence of soils results in classic alpine karren forms. REM sites #93-7 and #93-8 only just recently became free of snow when measured on July 4, 2002. Photo by C. Allred.

Figure 11. Soon to fall out, station 94-23 is increasingly exposed by highly acidic muskeg drainage over the limestone. The apron of overflowed epoxy is at the former level of the rock surface.

Figure 10. The author at REM sites #94-22 and #94-23. The muskeg runoff first makes contact with the limestone in front of author's left boot, flows past the measuring sites, and then into the 42.6 m pit. Photo by C. Allred.

Figure 12. Re-measuring stations #93-5 and 93-6 in Cataract Cave during low water flow. Photo by C. Allred.

CAVE SETTINGS

Many caves in the Alaska Panhandle form where highly acidic waters flow onto carbonates from peat lands, locally called muskegs. Water with a pH as low as 2.4 has been measured (Aley *et al.* 1993). The four cave sites had an average erosion rate of 507 mm/ka.

Bear's Plunge is a 42.6 m deep pit receiving a small streamlet from a muskeg. Two stations were placed just above the low water level at the brink of the drop, and less than 0.3 m from glacial till, which seals the limestone bedrock from the muskeg (Figure 10). One station (94-22) was slightly lower, and both are estimated to be in the streamlet less than 75% of the time. The lower station showed an average dissolution rate of over 1.66 m/ka and the other at over 1.07 m/ka. After nearly nine years, aggressive dissolution had created a large space between the rock and overflowed epoxy aprons (Figure 11). The bolts are expected to fall out in approximately eight years. To date, these dissolution rates are some of the highest documented anywhere (High & Hanna 1970; Spate *et al.* 1985; Cucchi *et al.* 1987).

A station (93-13) was set about 45 m into the inflow at the entrance of Slate Cave. The site is subject to seasonal trickling estimated at about 75% of the year. Water flowing into the cave might have become less acidic than the Bear's Plunge because of filtering through the limestone breakdown of the entrance portion. The average dissolution rate was 180 mm/ka. Corrasion at the station (93-13) was unlikely because the station was protected by a large boulder.

Cataract Cave has a large perennial resurgence flowing through a spacious passage. Two stations (93-5 and 93-6) were set in a vertical wall about 0.3 m above the low water level, and 30 m inside the cave (Figure 12). After nearly nine years these bolts were found coated with a black film (manganese oxide?) similar to that deposited on non-carbonate surfaces in cave streams. Vigorous rubbing only partially removed this film. Dissolution rates averaged 153 mm/ka. Estimated time under water was 50% based on weather observation and comparison to other streams in the area. All the dissolution is believed to be from the stream rather than condensation corrosion, because there are speleothems showing no dissolution approximately three meters above the stations.

A station was set in the sloping side of a marble stream bed of a short cave located downstream from a series of longer river caves and karst windows (93-15). The site is littoral, but brackish water probably does not reach the site much of the time because of stream out-flow. Estimated time under water was 75% based on the time of year visited and local weather conditions. The average dissolution rate was 326 mm/ka.

Very little is known of glacial advances in southeastern Alaska. Further REM monitoring may help clarify some glacial prehistory. Original polished or striated carbonate surfaces have been found perfectly preserved after thousands of years sealed under deposits of glacial clay. Without the clay, dissolution plays a large part in quickly transforming the land. Supposing that the most recent glaciation in the area was 15,000 years BP (Baichtal *et al.* 1997) and the climate has remained consistent, some cave floors could have been lowered over 25 m from even seasonal acidic muskeg runoff. However, many caves have evidence of much greater stability. Chambers containing fossil animal bones dating over 40,000 years BP (Heaton *et al.* 1996) appear to have undergone little recent modification.

COMPARISONS WITH EROSION RATES ELSEWHERE

Jennings (1985) summarizes studies of pedestals under glacial erratics, estimating erosion of between 10 to 42 mm/ka. No pedestals have been reported so far from the Panhandle, but the alpine karst REM stations averaged 33 mm/ka. In Ireland, High and Hanna (1970) reported stream erosion of 50mm to 500mm/ka that was thought to be partly due to corrasion. The Bear's Plunge dissolution rates are approximately three times the Irish maximum erosion rate. The Slate Cave trickle site was similar to their cave stream measurements. Spate *et al.* (1985) reported MEM based erosion data from cave stream sites in New South Wales, Australia yielding a combination of dissolution and corrasion many orders of magnitude less than our REM results. Their average 6mm/ka measurements on bare limestone from New South Wales, Australia compare to 29 mm/ka for this study. Precipitation in New Wales averages 950 mm/y (Ford and Williams 1989). The average Australian erosion rate under 25 cm of soil was 21 mm/ka compared to 52 mm/ka and 71 mm/ka under similar depths in the Alaska Panhandle (Table 1). Kraufmann and Braun (2001) comment that Italian erosion rates of 20 mm/ka with 1442 mm/yr precipitation were higher at 30 mm/ka with 2800 mm/yr precipitation. However, Cucchi *et al.* (1987) found no short term relationship between Italian precipitation rates and biyearly dissolution rate measurements. The reason for this is unclear. Bogli (1980) determined erosion rates of 81 mm/ka from soil-covered Silvan Switzerland karst with a precipitation of 2200 mm/yr. Many REM erosion measurements were similar to those elsewhere in the world if precipitation differences are taken into account. However, the Alaska Panhandle rates were much higher when subject to runoff from acidic muskegs.

CONCLUSIONS

Considerable precipitation coupled with very acidic drainage from muskegs contribute to some of the highest dissolution rates yet documented. Dissolution rates varied considerably in limestone and marble containing veins and clasts of impurities even from adjacent measurement points. Other contributing factors to erosion rates were corrasion, soil cover type, and soil depth. Preliminary comparison indicates dissolution rates are greater in clearcuts than old growth forests. Additional sites would improve the average data for both in future work.

Additional data should be gathered by setting more REM stations in a number of varied places, both in and out of Panhandle caves. Many other carbonate types could also be measured. As yet, diffuse dissolution rates are unknown from Alaskan cave walls. A more accurate REM could incorporate a dial indicator which might also result in less crushing of the rock surface during measuring than the present system. Given the large dissolution rates, this would allow for more frequent measurements. Correlated work on water chemistry would be useful.

APPENDIX

ADDITIONAL REM SITE DESCRIPTIONS (SILURIAN LIMESTONE)

94-22, 23 The Bear's Plunge lip was originally covered with non-carbonate cobbles and was not subject to increased flooding from deforestation. The lip was cleaned off for safety during the first exploration of the pit. A few large cobbles were placed around the stations and left in place during the measuring period. These stations were measured once more using a longer measuring rod six months later because the REM was no longer able to reach the radically lowered rock in a few places.

93-13 The trickle water source was estimated to be about 40 gpm in the month of May, 1990. The stream comes from a muskeg atop slate above the entrance. The limestone is somewhat impure and the streamlet subject to increased flooding from deforestation.

93-5,6 Cataract Cave is subject to increased flooding from partial deforestation of the recharge area above the cave. The stations were located off the bedrock floor of the stream bed, and therefore not subject to corrasion. The average stream flow is 630 gpm (Winfield Wright, personal communication). The limestone is brecciated with moderate amounts of impurities.

93-7,8 The flats of heelprint karren were of a darker color due to thicker lichen growth. This coating was sparser on the slopes where the dissolution rate increases.

93-10 was not subject to flow from adjacent surfaces and was lichen-coated.

93-33 The vegetated mat was peeled back in one piece in order to expose the rock, then pressed back into place after measuring. No lichen growth had occurred under the mat and the limestone was clean.

93-4 was located on an outcropping exposed from an uprooted tree and under an old growth canopy without an understory.

93-12 was located on rounded brecciated limestone exposed by a large uprooted tree. The station was partially protected by the root wad of the tree and understory growth.

93-11 The station was located at the edge of the same bare area as 93-12. It was covered by an open old growth canopy. The limestone is brecciated.

93-17,18 These stations were located on the lip of a swallet receiving inflow near Bridal Veil Cave. They were covered by an old growth canopy with some understory growth.

95-26 was protected under an old growth canopy with some understory growth. The forest is a band only about 30 m wide bounded by deforestation, and may be more subject to periodic drying. One station (number 1) was situated so that it was nearly exposed under a thin moss covering. Dissolution rates of 36.13 mm/ka. were measured. The stations averaged 2 cm of humus covering.

95-31 was under an old growth canopy. Blueberry bushes were replanted. It was located on a rounded hump submerged under 15-20 cm of dark brown humus above a thin layer of black humus.

95-32 was in limestone breccia on a mossy slope protected by an old growth canopy. The soil was 5 cm silt aggregate containing minor amounts of clay, covered by 10 cm of dark brown humus, then moss. A blueberry bush was re-planted on top.

93-3 was located on a small ledge in a bare outcropping. The rock was exposed by the roots of a fallen tree. Since exposed, only small amounts of humus had accumulated on the surface.

95-27,28 were located on rounded humps. Some adjacent areas in this clearcut still contained brush. Nearby soil depths were undetermined. The humus soil was laced with roots, limbs, and bole fragments.

95-29 was located on a flat, sub-horizontal, concave area adjacent to a grike. The brecciated limestone contains visible siltstone clasts and bands. Adjacent to this site were tree stumps and grikes partially covered in bushes.

95-30 was oriented on the top of a slightly rounded hump of brecciated limestone with minor visible impurities. The site was under an open spot used by bedding deer, and surrounded by tree stumps and bushes. The stations were covered in reddish rotten wood over a thin layer of black humus.

ADDITIONAL REM SITE DESCRIPTIONS (SILURIAN MARBLE)

93-15 was located on scalloped marble several feet above the clastic-covered stream bed. It was re-measured under 0.3 m water at low tide, with a strong downstream fresh water current.

93-19 was on the crumbling grainy surface of an overhang, and was subject to minor water seepage from above. Two of the measuring points were on an exfoliation which had been frost-heaved outwards and had a hollow sound when tapped. These points were not used. The exposed cliffs in the general area are rounded from decomposition and have large recent accumulations of sand and larger debris at their bases.

93-20 was only 5 m from 93-19 on a ledge of marble. Even though humus-covered, it was subject to frost action, judging from the granular, crumbly appearance of the rock and the aggressive erosion.

93-1 was set in the southern moss-covered lip of the upper main entrance of Leaning Tree Cave. The site was subject to periodic drying, because it is adjacent to a road. It was protected by an old growth canopy with no understory.

93-2 was on bare rock, yet overhung by thick bushes next to a logging road. The site could receive flow from the rock above.

94-24,25 were at the edge of a ledge above a solution gully. They were partially covered by a rotten root. The rock surface had a granular texture and adjacent exposures were crumbly.

93-14 was set into the top of a large marble boulder. The lichen covering was a “leaf” variety rather than a fine, dark coating. The lichen was scraped from one measuring point with a fingernail during the re-measurement. The measurement did not change after scraping.

93-16 was the bottom of a 30 cm diameter solution pan about 10 cm deep. The smooth flat floor was covered in algae.

93-21 was located on top of a large boulder above high tide where there were no lichens.

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AN UNUSUAL LAVA CAVE FROM OL DOINYO LENGAI, TANZANIA

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A new type of lava cave is described from the summit crater of Ol Doinyo Lengai, a unique active carbonatite volcano in Tanzania. This and other similar caves on Ol Doinyo Lengai are formed by thermal erosion and aqueous dissolution of otherwise solid spatter cones. Meteoritic water and endogenous condensates act to form speleothems of complex mineralogy up to 3 m in length. We propose the new classification of "polygenetic spatter cone cave".

Ol Doinyo Lengai (or Oldo Inyo Lengai), Tanzania (2.751°S, 35.902°E), the Masai "Mountain of God", is a unique, 2890 m, active stratovolcano in the East African Rift Valley. Current eruptive activity in the summit's north crater produces a natrocarbonatite lava at relatively low temperature (540 to 593° C; Pinkerton *et al.* 1995), and low viscosity (flows of 1-5 m/s have been observed; BGVN 13:06, 1988). The primary constituents of the natrocarbonatite are nyerereite ($Na_2Ca[CO_3]_2$) and gregoryite ($\{Na,K,Ca\}_2CO_3$) (Mitchell 2000), anhydrous carbonates of high solubility.

The geomorphology of the crater interior is dominated by a field of sub-cones (Figs. 1 and 2) ranging from a meter or two to more than 10 m in height. Extensive flows of carbonatite lava cover the crater floor, and exhibit small scale features typically associated with basaltic pahoehoe flows, including lava tubes of ~0.5 m diameter. Carbonatite lava is frequently ejected from the summit vents of the cones, or occasionally released in larger flows resulting from structural collapse of the cones.

THE CAVE AND ITS DECORATIONS

In June 2003, the cone designated T45 (Figs. 1 & 2), which probably formed in 1997, (BGVN 23:09, 1998) was observed to be breached near its northwestern base by a hole approximately 1 m square. Although a cave could be seen, at that time active de-gassing through the cone precluded entry; by early August 2003 a marked increase of de-gassing made it difficult to see into the cave at all; however, entry and examination was possible in July of 2004. The cone was revealed to be thin-walled (<0.75 m in places) and hollow. The resultant cave had a very simple circular plan and dome-shaped cross-section with relatively flat floors and rather delicate walls (Fig. 3).

The cave is fragile and dynamic. The breached base of T45 is the first sign of the inevitable structural failure of the cone's flank as the cave grows. This is evident in another example: in July 1998, a 3 m² section of the flank of cone number T40 (BGVN 27:10) collapsed into its interior cave (BGVN 23:09, 1998). The T45 cave, by 1 July 2004, had been partially filled by lava flows originating from T56B and possibly other sources. The floor of the cave was about one meter below the crater floor. The cave contained stalactites up to 3 m long. The summit vent of T45 formed a skylight into the cave. The cave's floor, composed of recent pahoehoe lava, was littered with small blocks that had fallen from the ceiling. On the afternoon of 15 July 2004 the cave's entrance was obliterated by a large lava flow from a newly formed vent, T58C. In view of the thin walls and low structural integrity of weathered natrocarbonatite, it should be noted that these caves present some danger to people climbing on the cones.

The cave was well ornamented with stalactites and columns up to 3 m. in length (Fig. 4). These are not the endogenetic lava stalactites that are common to volcanic caves and indeed occur in other parts of Ol Doinyo Lengai. For example, in July 2000 'lavatites' were seen around the inner rim of the active vent in cone T51 (BGVN 25:12, Fig 68). They were rapidly formed by the dripping of liquid lava ejected onto the cone's rim from a lava pond within the cone. Their formation process is identical to that seen in lavatites and lava drip pendants in typical basaltic lava tubes (Wood 1976; Hill & Forti 1997). The stalactites and columns of T45 cave are instead crystalline deposits from dripping water, composed of hydrated sodium carbonate (trona; $Na_3(CO_3)(HCO_3)2H_2O$) with smaller quantities of sodium and potassium sulfates, chlorides and fluorides; specifically, bands of aphthitalite $(K,Na)_3Na(SO_4)_2$ and kogarkoite $Na_3(SO_4)F$ with traces of sylvite (KCl) and halite (NaCl) (Mitchell, R., pers comm; determined by xray diffraction). Stalactites near the cave's entrance were observed to be dripping every 2-4 seconds. They form in the manner of most meteoric water stalactites, by deposition of a rim of crystals around a drip to form the initial straw stalactite that may later become thickened into more substantial stalactites and columns.

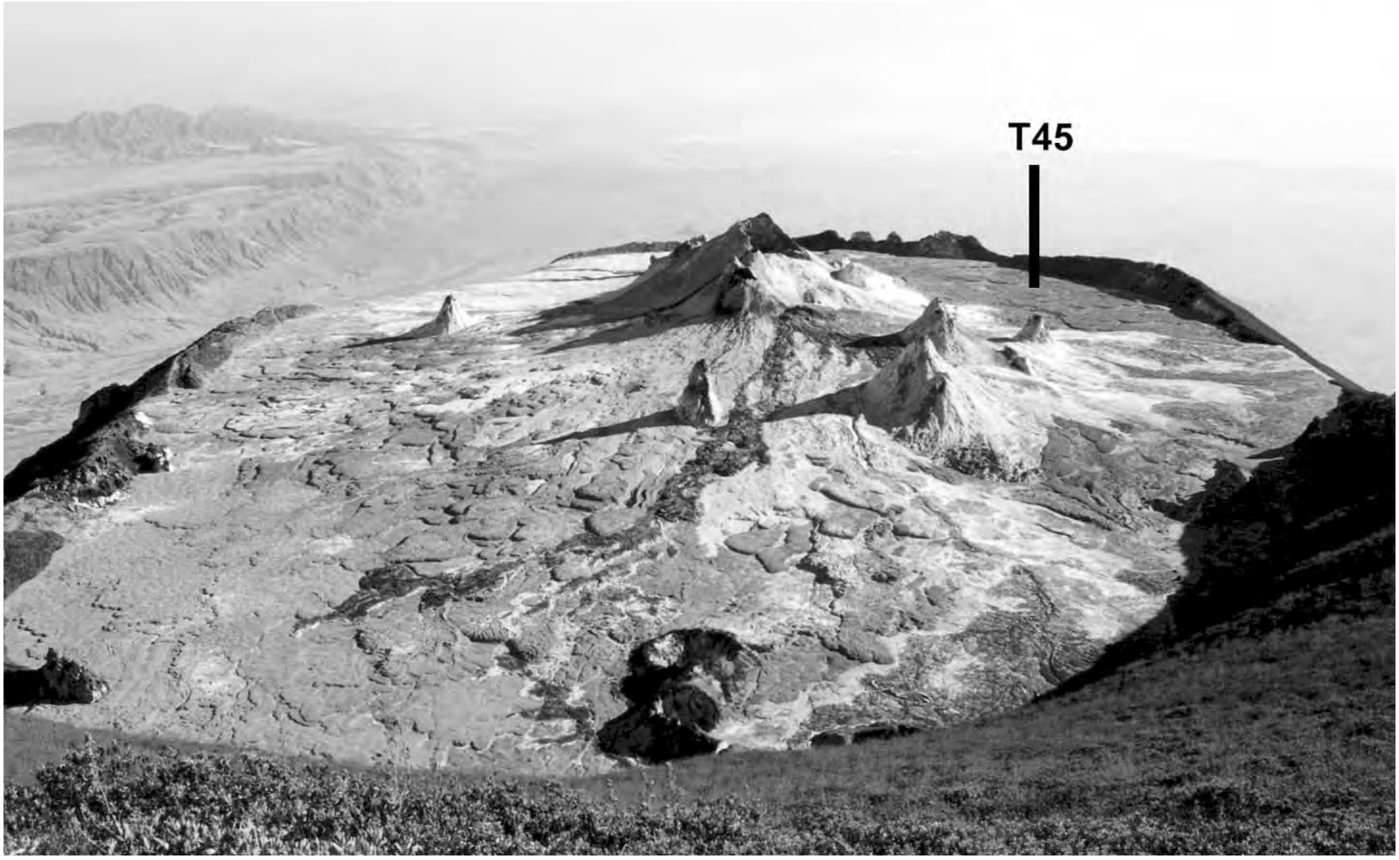

Figure 1. Interior of the active crater on Oldo Inyo Lengai, August 2004.

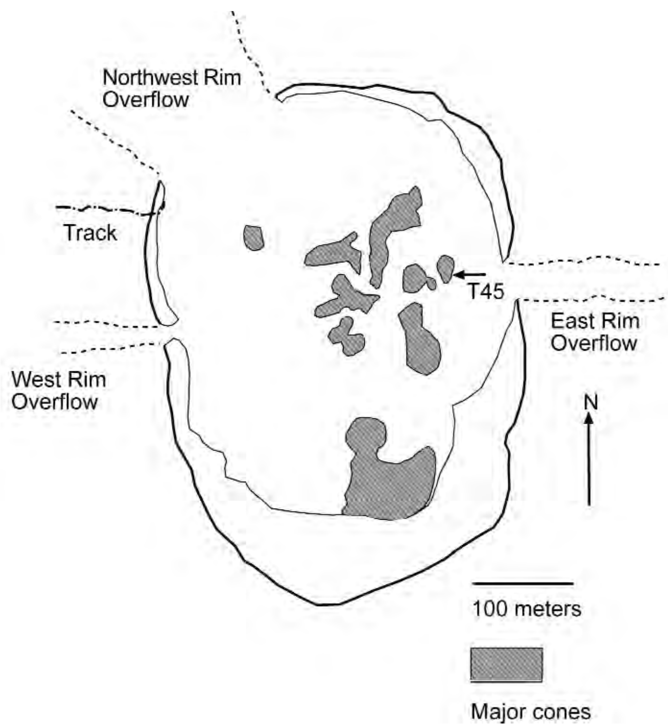

Figure 2. Plan of the summit crater, Oldoinyo lengai, showing T45. Adapted from a 2002 plan by F. Belton.

Speleogenesis

The dome-like cave described here differs from the variety of other lava caves previously reported (see classification in Wood, 1976). The crater of Ol Doinyo Lengai does have some narrow conduits associated with paths of lava flows that are clearly small lava 'tubes', but this cave does not fit that category. It also does not fit the category of lava 'blister' because it did not form from the surface cooling and solidification of a lava bubble. It seems to fit into the category of 'spatter cone' cave, yet it has a more complex morphology and speleogenesis. A simple spatter cone cave was described by Ollier (1967) from Mt. Eccles, Australia, that consisted of only an endogenetic evacuated vertical conduit. Most of Ol Doinyo Lengai's sub-cones form as spatter cones and are presumably solid with a central hollow conduit during growth (Fig. 5, 1-2). Some remnant vertical conduits from spatter cones are quite narrow, but it has been observed that wider conduits, such as this one, also form. These appear to be formed as the result of spatter from de-gassing of an interior lava lake rather than an isolated pipe of lava (Fig. 5, 3). If the lava lake level drops, a wide conduit or basin, large enough to be called a cave, remains inside the cone and may extend a number of meters into the crater floor beneath the cone, with one or more horizontal passages branching off to the sides (BGVN 23:09, 1998).

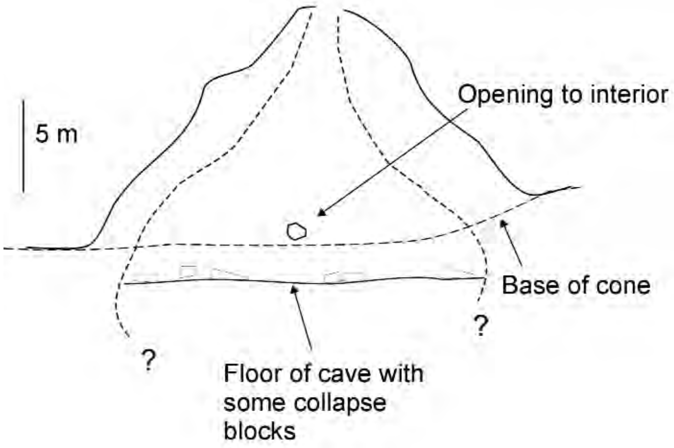

Figure 3. Profile of T45; interior profile is estimated.

This process is only the initial step in the speleogenesis. We hypothesize that renewed activity of a lava lake within a cone can further expand the hollow interior through the process of thermal erosion (Fig. 5, 4). Such erosion may progress rapidly and has been observed in carbonatite lava channels on Ol Doinyo Lengai progressing at rates of 2 mm/min (Dawson *et al.* 1990; Pinkerton *et al*. 1990; BGVN 27:10, 2002). Hollow cones have been observed to rapidly refill with fluid natrocarbonatite lava, and rates of degassing are highly variable.

A third speleogenetic process then takes over: it appears that senescence also contributes to the growth of the hollow interiors. We hypothesize that rainfall and frequent heavy dews penetrate the outer surface of the cone, increasing the size of the hollow interior by carbonate dissolution (Fig. 5,5). The Ol Doinyo Lengai caves can thus be considered to be significantly exogenetic features. Drip water entering the cavity may precipitate out sodium carbonate as speleothems (Fig. 5, 6), according to the interior microclimate of the cave, which fluctuates rapidly. Steam from within the cone may also contribute to the amount of water available for the process. Although the thermal diffusivity of natrocarbonatite is low (Pinkerton *et al.* 1995), the thin walls of the subcones and the low ambient air temperatures (~ 5° C at night) are likely to generate a significant temperature differential between the interior wall and the cave atmosphere, resulting in substantial condensation corrosion.

The continued growth of a cave within a cone will eventually result in structural failure of the cone's flank. The precise reason for a specific collapse event is often impossible to determine, but changes in eruptive activity have been observed to cause structural failure of cones. For example, in Aug 2003 the hollow cone T58B (BGVN 27:10) collapsed after a period of intense steam emission from a vertical crack in its flank. Clearly the event was caused by unsustainable gas pressure within the cone. The collapse was followed after a few seconds by strong strombolian activity which eventually rebuilt the cone.

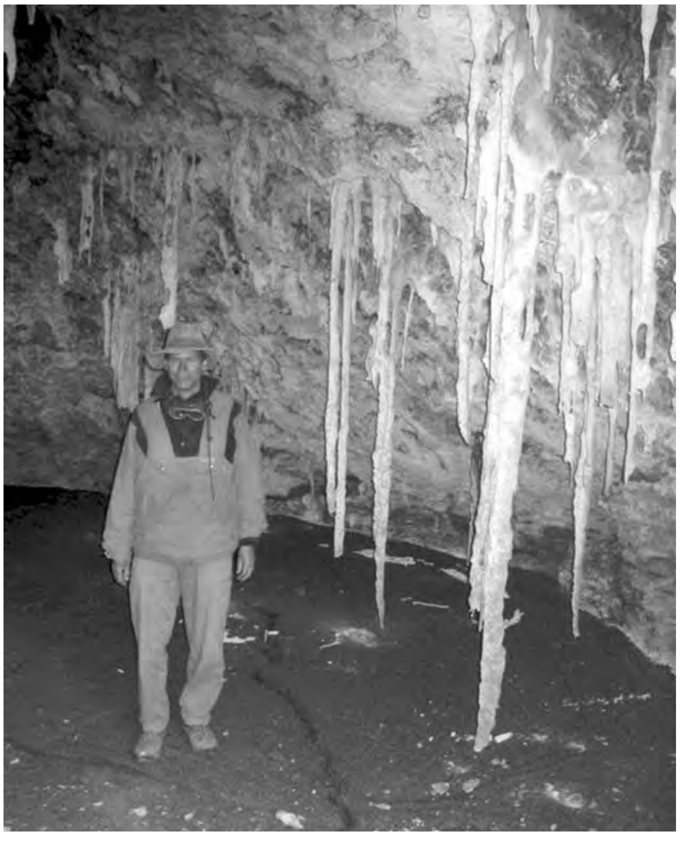

Figure 4. Sodium carbonate speleothems, T45 Cave, Ol Doinyo Lengai.

CLASSIFICATION

Since the processes of formation of these caves are more complex than other lava caves described in the literature, we propose to designate them polygenetic spatter cone caves, essentially a sub-type within the category of spatter cone caves. It is likely that this model of speleogenesis is rare because the circumstances, a combination of active eruption and thermal erosion of a highly soluble, very low viscosity lava, are presently only found on Ol Doinyo Lengai.

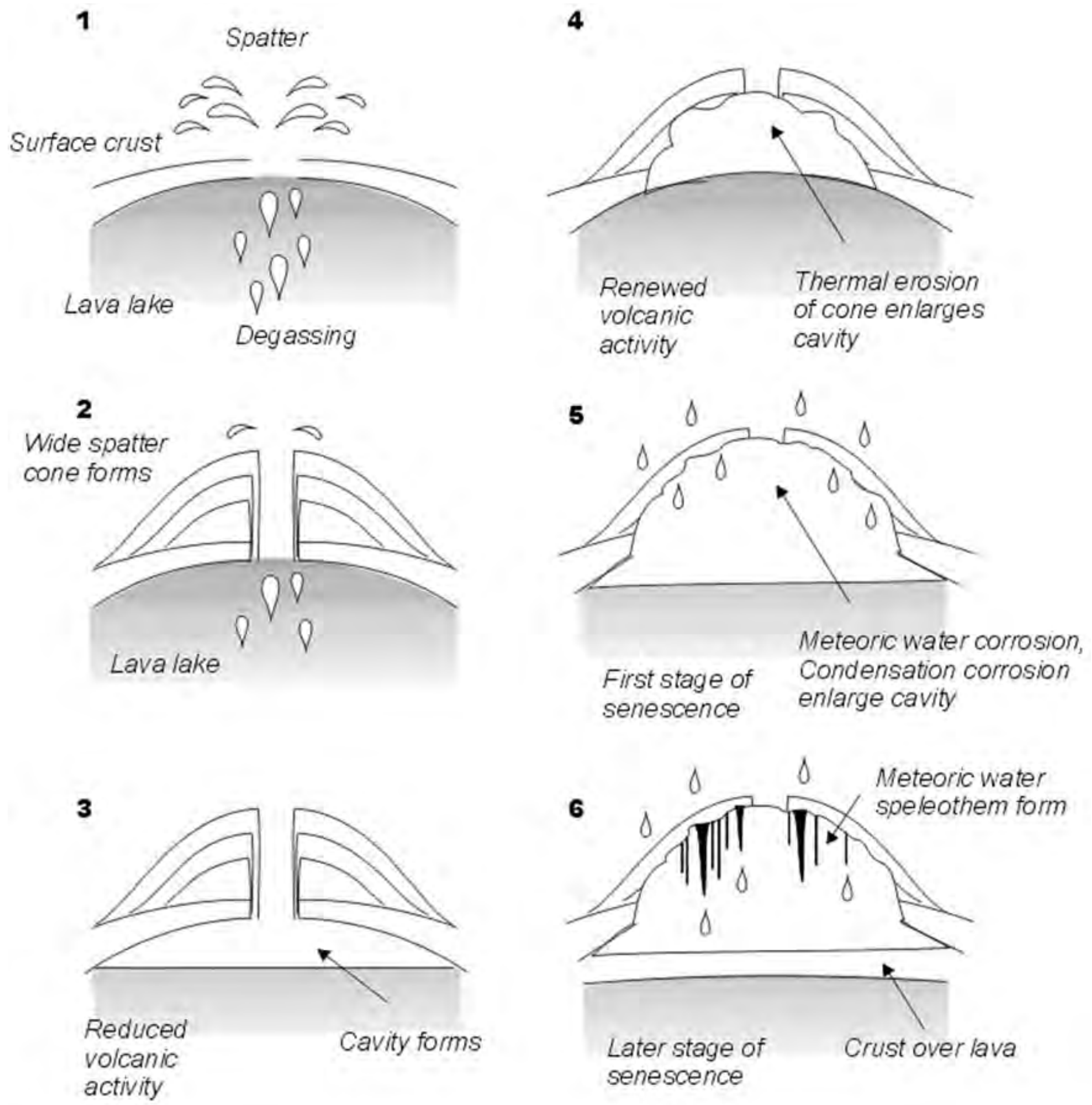

Figure 5. Speleogenetic sequence: 1. degassing of lava lake breaks through surface crust; 2. wide spatter cone forms; 3. reduced volcanic activity creates cavity under cone; 4. renewed volcanic activity causes thermal erosion of cavity walls; 5. reduced volcanic activity combined with meteoric water corrosion and condensation corrosion of cavity walls; 6. deposition of meteoric water stalactites.

Acknowledgements

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Andrea J. Hunter, Diana E. Northup, Clifford N. Dahm, and Penelope J. Boston - Persistent coliform contamination in Lechuguilla cave pools. *Journal of Cave and Karst Studies*, v. 66, no. 3, p. 102-110.

PERSISTENT COLIFORM CONTAMINATION IN LECHUGUILLA CAVE POOLS

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Despite designated trails, limited access, water pitchers, and other low-impact caving techniques, coliforms, a bacterial indicator of fecal contamination, are found in the drinking-water pools of Lechuguilla Cave, Carlsbad Caverns National Park, New Mexico. Researchers, concerned cavers, and Carlsbad Caverns National Park Service staff have restored contaminated areas; nevertheless, coliforms persist over time. Investigation of the problem showed that water-siphoning tubing supports strong biofilm growth in the same pools in which coliforms are present, suggesting that the biofilm is a factor in coliform persistence. We took a three-pronged approach in exploring this problem: 1) Identification of coliform presence and persistence using +/- coliform indicator quantification tests, 2) Culturing of coliforms in the presence and absence of biofilm to test whether the biofilm enhances coliform growth, and 3) Assessment of biofilm growth on tubing by suspending tubing of varying chemical compositions in cave water. Results indicated that coliform levels exceed those set by the Environmental Protection Agency for drinking-water. Additionally, coliform populations increased in the presence of the biofilm. VWR Tygon showed the heaviest biofilm development while silicone and Teflon tubing did not support any visible biofilm growth in lab experiments. Remediation efforts and management recommendations for the current problem are discussed.

Lechuguilla Cave, located 5.6 km WNW of Carlsbad Cavern in Carlsbad Caverns National Park, Eddy County, NM, contains numerous pools with unique microbial communities that have been subjected to impact by human visitors (Mallory *et al.* 1995, Northup *et al.* 1997). The discovery in 1986 of Lechuguilla's extensive passages beyond the entrance area provided scientists a spectacular cave in which to study speleogenesis, unusual speleothems, and geomicrobiological interactions (Boston *et al.* 2001, Provencio & Polyak 2001, Cunningham *et al.* 1995, Dawson 1996, Hill 2000, Northup *et al.* 2000, Palmer & Palmer 2000, Polyak & Provencio 2000, Turin & Plummer 2000). As the deepest cave in the continental United States, with a total surveyed length of 170 km and a depth of 475 m (Turin & Plummer 2000), Lechuguilla also showed potential as an analogous environment for extraterrestrial life (Boston 2000).

Lechuguilla's pristine nature and numerous possibilities for science and discovery have encouraged various conservation measures including the establishment of camps, designated trails, urine dumps, and drinking sources, and limiting of organic carbon enrichment (Northup *et al.* 1992). Despite preservation efforts, human contact with the ground waters has led to unintentional contamination of Lechuguilla's sources of drinking-water, posing an unusual importance due to the limited access (Boston 1999, Northup *et al.* 1997, Northup *et al.* 2000; Fig.1).

Figure 1. Red Lake study area, located in the Western Branch of Lechuguilla Cave, has been closed due to coliform contamination in the water source. Photo by Val Hildreth-Werker.

COLIFORM PRESENCE AND PERSISTENCE

Coliforms within Lechuguilla were first discovered in 1995 within urine disposal areas and nearby trails in one case (Northup *et al.* 1997). Subsequent studies also found positive coliform results in several soils and drinking source locations, revealing a notable problem (Boston 1999). Coliforms are

Figure 2. Biofilms from siphoning hoses, found in cavers' water bottles. Photo by Val Hildreth-Werker.

important indicator organisms for potential pathogens responsible for waterborne diseases. Waterborne diseases arise when pathogens living in water are transmitted through ingestion or contact with water (Shagam *et al.* 2000), although some can enter through the skin (Chapra 1996). Short-term effects such as fever, vomiting, bloody diarrhea, cramps, nausea, headaches, fatigue, jaundice, and in some cases, kidney failure can appear if pathogenic organisms are present. Coliforms may not just be indicators, but like enteropathogenic *E. coli*, can also be serious pathogens themselves (Todar 2002). Originating only from the intestines of warm-blooded animals (Chapra 1996), coliform presence within Lechuguilla Cave is related to either human introduction or surface infiltration (Turin & Plummer 2000).

Several studies of pool chemistry in Lechuguilla Cave have found low total organic carbon/dissolved organic carbon levels, establishing the oligotrophic, low-nutrient nature of Lechuguilla pools (Dawson 1996, Northup *et al.* 1992, Turin and Plummer 2000). Given the natural low carbon/nutrient availability and isolation for long periods of time from perceived high nutrient sources (i.e. human contact), persistence of non-native, high nutrient-requiring organisms such as coliforms was hypothesized to be limited. However, coliforms are still present in Lechuguilla's pools.

BIOFILM ENHANCEMENT OF COLIFORM GROWTH

Slime-like biofilms present within siphon hoses in Lechuguilla water sources may act as a potential carbon/energy source for introduced coliform bacteria. When a liquid and a surface come into contact, bacteria present within that liquid are attracted and adhere to the surface forming a glycocalyx or carbohydrate coat bonded to proteins and lipids (Lappin-Scott & Costerton 1997). Microcolonies then form and organic and inorganic matter are trapped within the glycocalyx where nutrients can become very concentrated (Lappin-Scott & Costerton 1997). The microbial biofilm can act as a nutrient reservoir, increasing the chances of survival for potential pathogens, causing considerable concern within the drinking-water and food industries (Lappin-Scott & Costerton 1997).

Figure 3. Biofilm sampled from water siphoning hose at Red Lakes Pool located in the Western Branch of Lechuguilla Cave. This figure also demonstrates flowstone shoes, Tyvek suits, and other sterile techniques used during sampling. Andy DuFrane left, Andrea Hunter right. Photo by Val Hildreth-Werker.

Cavers using Lechuguilla water sources have also found the threat of disease to be a concern when large amounts of biofilm are found floating in their water bottles (Fig. 2).

Lechuguilla Cave pools contain dimorphic prosthecate bacteria (Boston 1999, Northup *et al.* 1992), morphologically similar to *Hyphomicrobium* and *Caulobacter* spp. (Poindexter 1992), as well as *Escherichia coli* introduced by humans (Boston 1999, Northup *et al.* 1997). The nutrient requirements and metabolism of these two microbial communities may act in a synergistic (non-obligatory) relationship. Although *Hyphomicrobium* and *Caulobacter* spp. are indigenous to many pools in Lechuguilla Cave, the introduction of water hoses into the cave has provided a place for these species to form biofilm communities and thrive (Boston 1999; Fig. 3). The persistence of coliforms in pools with biofilm-covered tubing has led to the speculation that the biofilm produced on the tubing may serve as a carbon/energy source aiding the persistence of coliforms.

BIOFILM GROWTH ON TUBING

Some types of tubing contain chemicals that leak low-molecular-weight carbon compounds (C1, C2, C3) over time after submersion in water (Budde 1995). These types of tubing may provide a carbon source for oligotrophic microbes like *Hyphomicrobium* and its relatives that are able to scavenge very low quantities of organic compounds in solution (Hirsch and Conti 1964a, b, Whittenbury *et al.* 1970, Sperl and Hoare 1971, DeBont *et al.* 1981, Suylen *et al.* 1986).

VWR brand Tygon tubing was initially installed in Lechuguilla as a siphoning hose in both Deep Secrets and Red Lake, while the Big Sky water source had vinyl tubing (Figs.

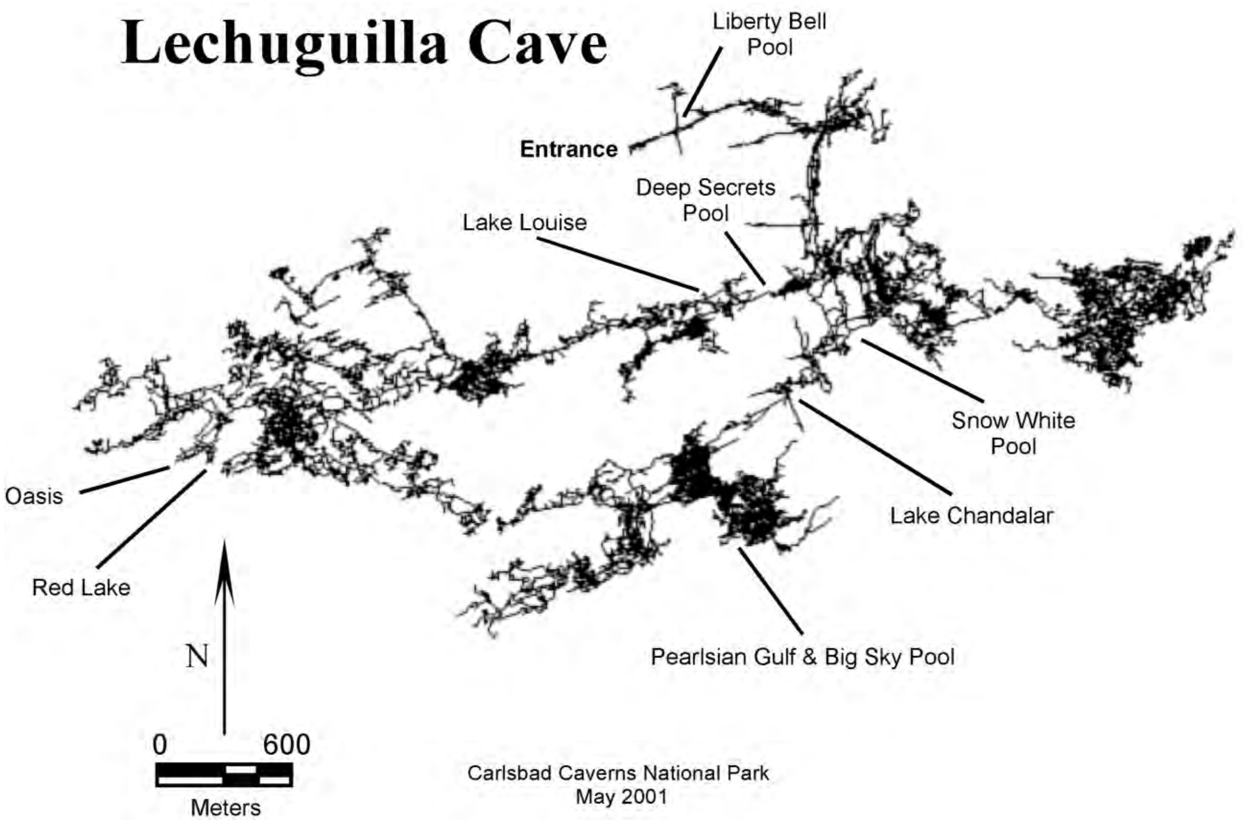

Figure 4. Plan view map of Lechuguilla Cave and study sites. Map by Stan Allison, Carlsbad Caverns National Park, May 2001.

3 & 4). These types of tubing were installed for both convenience and conservation. Some of the pools are located in awkward places, so using a siphoning hose to access water has proven to be both beneficial and convenient for cavers. The placement of hoses also helped to conserve areas surrounding the pools since direct pool access was no longer necessary. However, these hoses may be poor choices as they may act as nutrient sources for large amounts of microbial biofilm. We hypothesized that native organisms (e.g. dimorphic prosthecate bacteria such as *Hyphomicrobium* spp.) prefer the use of low-molecular-weight carbon compounds leaking from siphoning hoses and their formation of high-molecular-weight carbon compound biofilms serve as an energy source for introduced coliforms that prefer complex carbon compounds as nutrient sources. The presence of siphoning hoses inflates native organism populations, which in turn may prevent rapid die-off of coliforms and lead to coliform growth.

METHODS

FIELD TECHNIQUES

Coliform presence was tested at Liberty Bell Pool, Snow White Pool, Deep Secrets Pool, Lake Louise, Red Lake, and Oasis Pool in Lechuguilla Cave (Figs. 3 & 4). Pools that contained siphoning hoses, water pitchers or no water-aiding devices at all (differences noted in Tables 1 and 2) were tested for the presence or absence of total coliforms using LaMott Company coliform indicator test kits model TC-5 (Table 1). Five individual vial tests plus a control were used at each site. Ten mL of pool water were aseptically poured into each media vial and left motionless for 48 hours. If the media became orange-yellow with bubbles, the test was considered positive for total coliforms; a red was indicative of a negative test.

Coliforms were quantified from Deep Secrets Pool, Lake Louise, Red Lake, Pearlsian Gulf, Lake Chandalar, and Big Sky Pool (Fig. 4). Standard United States Geological Survey protocols were used to select for total coliforms (Webb *et al.* 1998, Myers & Sylvester 1998). Samples were aseptically collected and brought back to Deep Seas camp within four hours to be aseptically processed using the most probable number method during January 1999 tests (Koch 1994) and the membrane filtration technique during January 2001 tests (Myers & Sylvester 1998). Samples were filtered onto pre-made media plates that select for total coliforms and were then placed into an on-site incubator at 35°C for 24 hours. Colonies that were red, round, raised and smooth with a golden-green metallic sheen were considered positive and counted.

Biofilm samples were cultured and collected from pools containing siphoning hoses (equally coated with biofilm both in and out of the water), including Deep Secrets and Red Lake located in the Western Borehole and Big Sky Pool in the Southwest Branch (Fig. 4). It was determined from Boston's 1999 experiments that *Hyphomicrobium* spp.-like organisms isolated from Deep Secrets pool showed a nutrient preference towards low quantities of organic compounds in solution, such as C1, C2, and C3 carbon compounds (Boston, personal communication, 2000). For this purpose, the Atlas protocol for *Hyphomicrobium* medium (specific to urea and methanol) was

Table 1. Coliform +/- results from Lechuguilla pool drinking sources (# positive/# total tests).

Date	Red Lake[b]	Lake Louise[a,c]	Deep Secrets[a,b]	Liberty Bell	Snow Wt. Passage	Oasis[c]
1/15/1999 (P.Boston)	(3/8) (Sm.Pools) ND (Lg.Pool)	ND	ND	ND	ND	ND
1/15/2000 (A.Hunter)	(1/5) Lg.Pool	(4/5)	(0/5) Lg.Pool	ND	ND	ND
11/18/2000 (A. Hunter)	(0/5) Lg.Pool	(4/5)	(1/7) Sm.Pool (3/5) Lg. Pool	ND	ND	ND
1/26/2001 (A. Hunter)	(2/4) Lg. Pool	(4/6)	(4/6) Lg. Pool	(0/5)	(0/5)	(1/5)

[a] Denotes current drinking water source. Others have been used in the past during early exploration and rescue situations or have been closed for research purposes or contamination.
[b] Represents pools with water siphoning hoses during 2001.
[c] Represents pools with water pitchers or dipping cups during 2001.

prepared for organism collection within Lechuguilla's pools during 2000 and 2001. Using aseptic techniques, 1 ml inoculating loops were used to scrape off one loop-full of tubing biofilm cells to inoculate the solid medium in vacuum vials. Sterile syringes were then placed into the vacuum vial and excess air was extracted, creating a near anoxic environment. An additional 5 mL of visible biofilm from tubing was collected using a sterile syringe. The biofilm was then placed into a sterile vial containing pool water, transported out of the cave and stored in the lab refrigerator for use in laboratory experiments.

Water was collected aseptically in sterile bottles from Deep Secrets and Lake Louise for use in laboratory experiments. Water samples were stored at 20°C during transport to the lab where they were immediately used in the tubing experiment. Aseptic or clean techniques, including the use of Tyvek suits, sterile gloves, flowstone shoes (clean, rubber-soled slippers) and anti-bacterial wipes, were used at all sites while collecting samples at pool ledges to minimize contamination (Fig. 3). Water samples from Deep Secrets were not collected directly near the siphoning hose.

LABORATORY TECHNIQUES

Total coliform medium was prepared using protocols from the United States Geological Society (Myers and Sylvester 1998). The medium, containing 4.8 grams of m ENDO broth MF, 1.5 grams of Bacto agar and 100 mL of 2% ethanol solution, was boiled at 95–96°C then cooled, poured aseptically into 50 mm petri dishes, and stored in the refrigerator.

Coliform growth preference was tested by counting the number of coliform colonies grown in the presence and absence of biofilm over time. Plates containing LB medium plus ampicillin were used to grow ampicillin-resistant *E. coli* (Sambrook *et al.* 1989). LB medium was prepared by adding bacto-tryptone, bacto-yeast extract, sodium chloride and Bacto agar to double-distilled water (Sambrook *et al.* 1989). One ml of full-strength ampicillin was added to every one mL of LB solution. It was necessary to use ampicillin-resistant *E. coli* so that other organisms not resistant to ampicillin would be killed and would not grow on the LB media plates. Three sets of vials containing seven vials each (one for each day) were prepared as follows. One set of vials containing 20 mL of *Hyphomicrobium* medium (American Public Health Association 1989, Atlas 1995) plus 0.2 mL of glucose (giving a 1% glucose solution) with one loop of ampicillin-resistant *E. coli* (1 inoculating loop = approximately 1,000,000 cells) served as the control (Fig. 5). The second set of vials served as the culture experiment containing 18 mL of *Hyphomicrobium* medium plus a 1% glucose solution, 2 mL of *Hyphomicrobium* culture, and one loop of ampicillin-resistant *E. coli* (Fig. 6). The third set of vials served as the biofilm experiment containing 20 mL of *Hyphomicrobium* medium plus glucose, one loop of slime from cave tubing and one loop of ampicillin-resistant coliforms (Fig. 5). All vials contained an equal number of ampicillin-resistant *E. coli* cells. The vials were placed on a shaker while incubating at 20°C for 15 minutes. Serial dilutions using sterile cave water were then performed giving a 10^{-6} dilution. After 24-hours of incubation, 0.1 mL from the 'day 1' vials in each 10^{-6} dilution set was spread onto triplicate LB plates, creating nine new plates per day. All plates were quantified at 0 CFU on Day 0 (Fig. 6). The plates were then incubated for 24-hours at 30°C. Coliform colonies grown on plates were counted after each 24-hour period and plates were discarded. This procedure was repeated daily for one week plating 'day 2' vials on day 2, etc., each day representing its respective vial and corresponding amount of incubation time (Fig. 6).

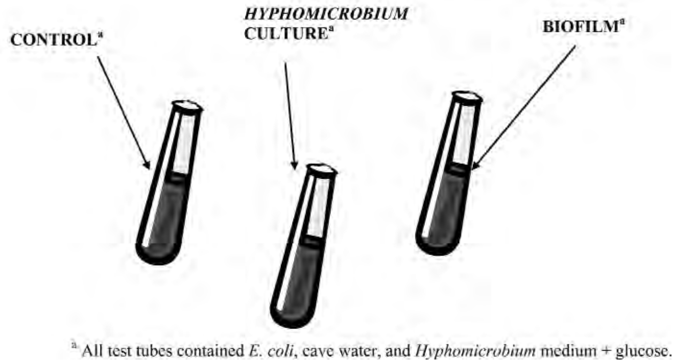

Figure 5. Contents of original dilution tubes used in coliform growth with/without biofilm experiment.

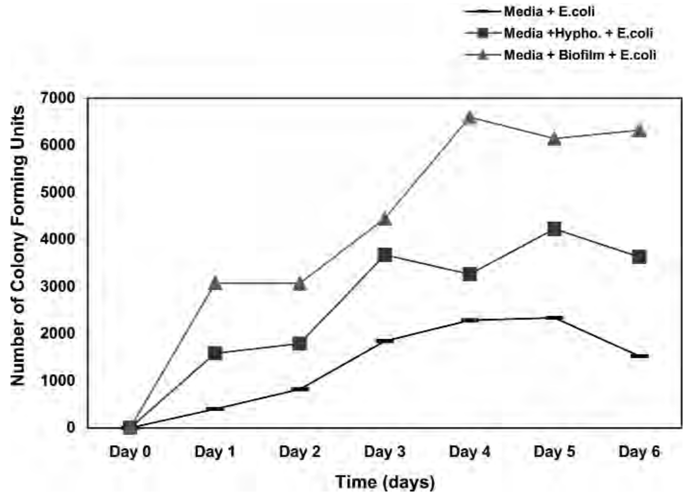

Figure 6. *E. coli* growth in the presence of *Hyphomicrobium* culture and biofilm from 1/100,000 dilutions of original cultures. 1) Cave Water and Media 2) Cave Water, Media, and *Hyphomicrobium*-Culture, and 3) Cave Water, Media, and Biofilm.

Microbial preference for growth on certain types of tubing was determined by suspending a variety of hoses with differing chemical compositions and amounts of organics in water taken from cave pools. Tubing types included in the experiment were natural rubber latex (Cole-Parmer Catalog number P-06402-10); silicone (platinum-cured) Masterflex (Cole-Parmer Catalog number 96410-15); Norton Tygon R-1000; Teflon (FEP, fluorinated ethylene propylene; Cole Parmer Catalog number P-06406-12); Nalgene Premium Tygon 180; and VWR Brand Tygon (Cole-Parmer catalog number 40-80000090). Pieces of tubing were sterilized for 30 minutes in a 121°C autoclave at 10 atm. Tubing was suspended using sterile fishing line in sterile test tubes containing 40 mL of unsterilized cave water with native microbial communities for five months using sterile fishing line. Vials with tubing were covered in tin foil and placed in a dark incubator at 20°C to replicate cave temperature and darkness. The tubing was examined for signs of visible growth after 6, 8 and 20 weeks of incubation.

STATISTICAL ANALYSIS

Colony count data from the *E. coli*/*Hyphomicrobium*/ biofilm experiment were analyzed using the analysis of variance (ANOVA) procedure in the SAS software release 6.12 (SAS Institute, Cary, NC, USA). Data were considered significant at $P < 0.05$.

RESULTS

Presence/absence coliform tests revealed the presence of coliforms in most drinking-water pools in the Western Borehole (Table 1). Red Lake, Lake Louise, and Deep Secrets pools consistently had positive coliform results; Liberty Bell and Snow White Passage remained negative. Pools with siphoning hoses, dipping cups, or water pitchers are noted in Tables 1 and 2. On average, pools with siphoning hoses contained more colony forming units/100 mL than those with dipping cups or water pitchers. Pools that tested positive for coliforms had quantification tests run, determining the level of severity. Coliform counts showed that as of January 2001, the large pool at Red Lake had the highest number of colony forming units (27 organisms/100 mL) of the sites tested (Table 2). Lake Louise had the second highest number (19 organisms/100 mL). All counts taken during January 2001 except for Deep Secrets (reported as ideal colony count) were non-ideal colony counts. A non-ideal colony count is the terminology used by the United States Geological Society to represent less than 20 colonies counted in a 100 mL sample. An ideal colony count represents 20–60 colonies counted in a 100 mL sample (Myers & Sylvester 1998).

A lab experiment testing whether coliforms grew faster in the presence of cave biofilm given the same amount of organic carbon and nutrients showed that coliforms significantly preferred growing with the biofilm ($P=0.0001$; Fig. 6). Coliforms also favored medium containing biofilm over medium containing cultured *Hyphomicrobium*-like organisms (Fig. 6).

Results from the experimental testing of microbial biofilm growth on various tubing over five months were consistent. Silicone (platinum-cured) Masterflex, Norton Tygon, and Teflon (FEP, fluorinated ethylene propylene) showed no visible growth of biofilm at any time during the experiment. Nalgene Premium Tygon 180, and natural rubber latex produced visible moderate biofilms at 6 weeks and remained constant for the remaining 24 weeks. VWR Brand Tygon showed visible heavy biofilm growth at 6 weeks and remained constant throughout the entire five-month period. The experiment showed rapid colonization to reach maximum growth of biofilm in all types of tubing in 6 weeks.

Table 2. Coliform quantification results from Lechuguilla pool drinking sources.

Date	Deep Secrets Pool (CFU/100mL)[a,b]	Lake Louise (CFU/100 mL)[a,c]	Red Lake (CFU/100mL)[a,b]	Pearlsian Gulf (CFU/100 mL)[a,c]	Lake Chandalar (CFU/100mL)[a,c]	Big Sky Pool (CFU/100 mL)[a,b]
1/15/99 (P.Boston)	ND	ND	5400 (Sm. Pool 1) 2200 (Sm. Pool 2) 0 (Lg. Pool)	ND	ND	ND
1/26/01 (A.Hunter)	4	19	27 (Lg. Pool)	3	2	0.4

[a] Denotes abbreviation: CFU: Colony Forming Unit.
[b] Represents pools with water siphoning hoses during 2001.
[c] Represents pools with either a dipping cup or water pitcher during 2001.

DISCUSSION

PRESENCE AND PERSISTENCE OF COLIFORMS

As indicators for fecal contamination and disease-causing bacteria, coliforms are useful representative species for which to test in potentially disturbed environments like the drinking pools in Lechuguilla Cave, New Mexico. Confirmed presence of coliforms in these pools has indicated fecal contamination, and consequent closure of some of the drinking-water sources available to cavers, researchers and explorers. Since the extent of coliform contamination was not recognized until 2001, no pre-2001 data are available for most pools listed in Table 2 with the exception of Red Lake, a prime concern and the only pool tested in 1999. Currently, Lake Louise and Deep Secrets are the only drinking-water sources in the Western Borehole due to other pools either being contaminated or off-limits due to research (Fig. 1). Red Lake, for instance, has been closed for several years due to coliform contamination and Oasis Pool has been secluded for microbiological research (Allison, personal communication, 2001). Pools in Liberty Bell and Snow White Passage were used as drinking-water sources during the 1991 rescue of an injured caver, and not used as microbiologically safe and reliable sources (Allison, personal communication in 2001). Lechuguilla's drinking pools are few and far between and should be regarded as both valuable drinking-water resources and research study sites. If coliform contamination in these environments persists, then the resources may have to be put off limits to avoid negative human health and safety issues. Alternative methods for controlling coliform introduction and amelioration of the techniques employed to obtain drinking-water from cave pools may make such draconian measures unnecessary. However, such management decisions are complex.

In addition to the major concern for the presence of coliforms in Lechgulla's low-nutrient pool environments, there is also a well-dispersed presence of fecal contaminants in the soils of some camps and urine dumps. We presume that cavers and their boots have tracked coliforms from the contaminated soil areas onto the flowstone slopes leading to the pool environments (Fig. 3). This was shown when mud from cavers' boots was found in some of the small pools located on the flowstone slope above the large pool at Red Lake. Currently, the Safe Drinking-Water Act and Environmental Protection Agency (EPA) national primary drinking-water standards for total coliform detection are set at a maximum contaminant level goal of 0 organisms/100 mL (Environmental Protection Agency 1999). Coliform contamination (2,200 to 6,600 organisms/100 mL) in these small pools also exceeds the accepted coliform level for recreating in public waters set by the Environmental Protection Agency. For example, the state of New Mexico has set recreational standards for fecal coliforms at 100 organisms/100 mL for Dry Cimarron River, 200 organisms/100 mL for the San Francisco, San Juan, Canadian, Pecos and Gila River Basins, and 1000 organisms/100 mL for the main corridor of the Rio Grande above American Dam to below Percha Dam (State of New Mexico 1995). Albuquerque's reclaimed water discharge has a maximum daily fecal coliform limit of 200 organisms/100 mL, however, some parts of the Rio Grande allow 2000 organisms/100 mL for one sample (Shagam *et al.* 2000). The Environmental Protection Agency has set criteria for swimming at fewer than 200 organisms/100 mL; 1000 organisms/100 mL for fishing and boating and 2000 organisms/100 mL for domestic water supplies (Boston 1999). Coliform concentrations in Red Lake's small pools (2,200 to 6,600 organisms/100 mL) were higher than all of these standards. While high coliform concentrations were found in Red Lake's small pools in January 1999, the large pool at Red Lake was negative at that time, but two years later it was positive when retested in January 2001. The Red Lake area had been closed to cavers during that time, suggesting that coliforms might have migrated from the heavily contaminated small pools downward into the larger water source traveling in fluid overflow down flowstone slopes.

Other Lechuguilla pools containing much smaller numbers of coliforms also should be viewed with concern. If located on the surface, most of the tested Lechuguilla water sources would be suitable for swimming, fishing or boating. However, only those with negative results would be considered potable sources of water for human consumption. Lechuguilla pools are indispensable in supplying water to visiting humans and are critical habitats for native microorganisms (Mallory *et al.* 1995). Therefore, addressing the coliform and fecal contamination problem is critical for health, safety, and introduced organics.

Sampling procedures also tested very small volumes of water near the siphoning hoses in pools where siphoning hoses were present. Spatial variance of coliform numbers could therefore be dependent on where coliforms concentrate. If coliform bacteria prefer biofilms and concentrate near them, coliform quantification test results from other parts of the pool will be lower. Regardless of the spatial distribution within the pools, coliforms continue to persist in some pool environments. The persistence of total coliforms in Lechuguilla Cave after a one-year closure indicates there may be an energy source within the pools supporting sustained coliform presence. The persistence is hard to explain otherwise.

BIOFILM ENHANCEMENT OF COLIFORM GROWTH

Public understanding of microbiology, the use of indicator organisms and the risks to human health from microorganisms is often poor (Shagam *et al.* 2000). Microbes maintain nutrient cycles, decompose organic material, and support the growth of plants and animals. Certain microbes like coliforms, however, can be indicators of microbes harmful to human health, especially where microbial numbers are enhanced by anthropogenic activities.

Why are coliforms surviving in an environment such as Red Lake that has been closed to human access? What energy sources are they using to replace those obtained in the human digestive tract? Previous research has shown carbon compounds are secreted from hose materials which can provide nutrients for the survival of select microbes (Budde 1995). Additional research indicates soil material at Huapache camp in the Western Branch to be rich in clay minerals (Spilde, personal communication in 1999). Clay is known to protect microorganisms and organic compounds from environmental factors (Van Veen and Kuikman 1990, Scott *et al.* 1996, Hassink 1997, Vettori *et al.* 2000). Therefore, the possibility exists that coliforms may reside in clay-rich soils and may be transported via cavers' boots to other soils and water sources within the cave. Secondly, normal underground living conditions often results in cavers leaving behind organic substances such as fecal matter, hairs, skin particles, fingernails, sputum, food constituents and lint from clothing that could provide organics which might support coliform survival.

The growth of coliforms is also enhanced in the presence of biofilms and cultures of *Hyphomicrobium*-like organisms. Results from laboratory experiments indicate that the heaviest coliform growth occurred on diluted cave water samples containing biofilm. Cave pools with siphoning hoses that support biofilm growth thus appear to be supplying additional carbon and nutrients to the water and may contribute to the persistence of coliforms within the biofilms. When a growth medium (e.g. cave water) is rich in nutrients, bacteria will attach randomly to any available surface; however, bacteria will preferentially attach to a nutritive surface in oligotrophic, nutrient-poor conditions such as those in Lechuguilla pools (Watnick and Kolter 2000). Therefore, introducing a leachable, energy-rich hose into an oligotrophic environment will cause native bacteria to accumulate on the hose surface and possibly increase the persistence of introduced organisms such as coliforms. Hoses in Lechuguilla Cave are currently increasing the numbers of both native bacteria and introduced coliforms. However, by replacing the tubing with a more inert thermoplastic that reduces or eliminates biofilm growth, we hypothesize that the coliforms will no longer have a nutrient and energy source and will not persist.

BIOFILM GROWTH ON TUBING

VWR Tygon is the tubing currently used in Lechuguilla's drinking-water resources. Unfortunately, this tubing also promoted the heaviest biofilm growth of the six hose materials tested. VWR Tygon contains polyvinylchloride (PVC), polyurethane, and phthalates, which are added to make tubing soft and bendable. Plasticizers also aid in the flexibility of these tubing types. The oily, organic-rich compounds within plasticizers support bacterial and fungal growth. Tubing promoting moderate growth after five months also contained several additives that could have supported biofilm growth. Lipids and fatty acids, for instance, are present in natural rubber latex, which can leach when tubing is left in water for long periods of time (Beacon Pharmaceuticals 2001). Nalgene Premium Tygon 180 also contains PVC and plasticizers that might support microbial growth (Cole-Parmer 1998). Although Norton Tygon did not promote biofilm growth, we are not recommending use of this hose for siphoning water in cave pools. Norton Tygon tubing contains PVC resin and can emit plasticizers that could enhance microbial growth over longer periods of time than were tested in this study or even present a toxicity risk to native microorganisms.

Because cave water was used and the tubing was left to grow in a dark Lechuguilla-temperature laboratory incubator, similar results can be expected in Lechuguilla cave pools. The tubing results might also be applicable to other buffered, oligotrophic water conditions outside cave environments such as distilled water lines in biological/chemical laboratories, medical and dental hoses, and possibly food and beverage dispensers where biofilm communities are a problem (Tall *et al.* 1995).

Silicone Masterflex and Teflon FEP (fluorinated ethylene propylene) tubing did not support microbial growth in lab experiments and would be good alternatives for siphoning hoses within Lechuguilla pools. These hoses do not contain plasticizers and each has fungus-resistant properties, preventing fungal growth on the inside and outside of the tubing. Silicone platinum-cured tubing contains water-based materials and is composed of siloxane polymers and amorphous silica, non-nutritive substances. Additionally, the platinum curing provides a lower level of protein binding with fewer potential leachable compounds. Teflon is the most resistant fluorocarbon and the most chemically inert thermoplastic known. It is very stiff tubing, and the added FEP used in manufacturing discourages microbial growth (Cole-Parmer 1998).

RECOMMENDATIONS

We suggest several changes in current practices to correct human-associated microbial contamination problems at water sources and camp/urine locations in Lechuguilla Cave. Ultimately, these recommendations should help resolve the persistence of coliforms and other non-native bacteria in cave pools. Past remediation techniques in the Red Lake area have included using small amounts of hydrogen peroxide on flowstone where coliforms are suspected and scrubbing to remove boot marks (Boston 1999). Recommendations to eliminate food caching, circumventing the need to swim pools to cross them, and eliminating bivouacking in random areas have been noted in past documents as ways to reduce contamination (Northup *et al.* 1992). Limiting travel in the cave to essential surveying, exploration, and scientific trips, and encouraging cavers to have clean clothes, hair and boots when entering the cave also have been suggestions to help reduce the amount of organic carbon and number of new microorganisms introduced into Lechuguilla Cave (Northup *et al.* 1992).

Current recommendations stemming from this research include routine use of positive/negative total coliform indicator test kits at all water locations. This will help Carlsbad Caverns National Park Service personnel to monitor human impact at pool locations. Human impact can be further reduced by using boot covers at urine dumps and drinking-water sites, sterile gloves (especially when dipping water pitchers into pools), and clean Tyvek suits when approaching more pristine drinking-water pools (e.g. Red Lake, Deep Secrets Pool, Oasis, Pearlsian Gulf, Big Sky Pool). Packing out all fecal and urine waste in properly sealed containers would also help reduce new sources of contamination. Removal of the current VWR Tygon tubing from the pools and insertion of silicone Masterflex (Cole-Parmer catalog # 96410-15) or Teflon-FEP tubing (Cole-Parmer catalog # P-06406-12) should keep biofilm populations from proliferating on drinking-water hoses. Another consideration might include replacing hose spigots with material similar in composition to the recommended hoses (silicone or Teflon). Additionally, iodine tablets or a water purification system should be used when drinking from contaminated pools where coliform numbers are above 0 organisms/100mL. These precautionary measures will ultimately reduce human impact and hopefully eliminate or reduce human-associated bacteria from water sources and other pristine locations over time.

CONCLUSIONS

Coliform presence is currently a problem in water sources within Lechuguilla Cave. Most tested pools contain coliforms in numbers that are unacceptable under the Environmental Protection Agencies limits for potable water. Remediation techniques and area exclusion seem to have had limited success in efforts to eliminate these organisms. Coliform persistence in some water sources continues. Pools with siphoning hoses appear to offer coliforms an additional organic food source in the form of biofilms residing on tubing used for water collection. Lab experiments show coliform growth to be enhanced in the presence of biofilm, preventing the die-out of coliforms in pools with siphoning hoses. Using an alternative siphoning hose such as silicone or Teflon that have limited, leachable organics and lack plasticizers will reduce biofilm growth.

Adding new materials such as siphoning hoses in a pristine environment can be risky business if they have not been previously tested. Consequences range from disturbing native microflora and enhancing non-native human-introduced organism populations to introducing biological and chemical pollutants into a habitat that has remained secluded from surface interference for long periods of time. It is important to take precautions when adding anthropogenic materials to pristine environments. Reducing human impacts and contamination to cave soils and water sources is essential both for human health and for answering scientific questions regarding natural microbial communities within deep karstic environments.

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SELECTED ABSTRACTS FROM THE 2004 NATIONAL SPELEOLOGICAL SOCIETY CONVENTION IN MARQUETTE, MICHIGAN

BIOLOGY

THE NATIONAL CAVE AND KARST RESEARCH INSTITUTE: EARLY HISTORY, EVOLUTION, AND CURRENT PROGRESS

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Several Acts of Congress between 1988 and 1998 led to the creation of the National Cave and Karst Research Institute under the initial direction of the National Park Service. In July 2000, an Interim Director was hired to begin development of the Institute and to build collaborative relationships with a variety of federal agencies and other organizations. New Mexico Institute of Mining and Technology and the City of Carlsbad formed a partnership with National Park Service to establish the Institute. A Federal Working Group was created with representatives from six federal agencies to provide recommendations for Institute goals and priorities. Through contracts and cooperative agreements, the Institute began supporting cave and karst research projects. The National Cave and Karst Research Institute is intended to be a multidisciplinary institute, covering all aspects of cave and karst science. Many of the early projects were in geology and hydrology, but some biology projects were sponsored. In December 2002, a permanent director was hired. Extensive contacts with government agencies, universities, and non-profit organizations continued, and in October 2003, representatives of all these interests participated in a Vision Building Workshop to discuss the Institute's operational and administrative future. Near future administrative plans for the Institute include construction of a new building in Carlsbad, movement toward a New Mexico Institute of Mining and Technology–administered operation, and creation of a corporation with a board of directors. The future of biological research and data compilation through the National Cave and Karst Research Institute will depend on input from biologists.

STUDIES OF BACTERIAL COMMUNITIES FROM FOUR WINDOWS CAVE, EL MALPAIS NATIONAL MONUMENT, NEW MEXICO

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One of the striking features of some lava tubes is the extensive bacterial mats that cover the walls. In Four Windows Cave, these bacterial mats occur in the twilight zone adjacent to algal mats and in the dark zone. In an effort to phylogenetically characterize bacterial community members, we extracted DNA from wall rock communities, using a soil DNA extraction technique developed at Los Alamos National Laboratories. The DNA was purified, the 16S rRNA gene was amplified using PCR, amplification products were cloned, and 30 clones were sequenced in their entirety. Comparison of our sequences with those in the Ribosomal Database II revealed that the Four Windows bacterial sequences group with actinomycetes, *Acidobacterium, Verrucomicrobia, Betaproteobacteria, Gammaproteobacteria,* Flexibacter, Planctomyces, and Leptospirillum/Nitrospira groups. These results reveal a diverse community of bacteria and the presence of several novel bacterial species. To test whether these bacteria had lost their resistance to ultra-violet radiation, we cultured mat and surface bacteria on to R2A and subjected cultures to ultra-violet radiation in a biological safety cabinet. Bacteria cultured from these mats and surface soils on R2A medium showed a general trend in which microbes isolated from the lava tube were much more ultra-violet sensitive than the microbes isolated from the surface.

DISTURBED VERSUS PRISTINE MICROBIAL COMMUNITIES IN TIMPANOGOS CAVE NATIONAL MONUMENT

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Timpanogos Cave National Monument is studying how visitation within its confined cave trail is affecting the cave's microbial communities. Samples have been collected from the disturbed areas near the cave's tourist trail and pristine non-impacted areas such as buried cave sediments and imputing water drips. Relative microbial community diversity and abundance are being evaluated using molecular techniques based on isolation of 16S rDNA from environmental DNA extractions. Preliminary data indicate that disturbed sites are dominated by *Gammaproteobacteria* and *Acidobacteria* sequences, although representatives from *Alphaproteobacteria, Nitrospira,* Planctomycetes, and the Bacteroidetes/Chlorobi group were also retrieved. Additionally, a large mat community of an environmental species of *Yersinia* was found associated with discarded food found near the trail. Once these microbial communities have been characterized, the impacts from tourism can be monitored and restoration techniques be can be evaluated.

PHYLOGENETIC INFERENCES OF THE PARASITIC BAT FLIES STREBLIDAE AND NYCTERIBIIDAE (DIPTERA: BRACHYCERA: CALYPTRATAE)

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A phylogenetic study of the evolution of the parasitic bat flies, Streblidae and Nycteribiidae, has been initiated. The relationships within and among these families has been investigated using molecular data from the nuclear 18S rDNA gene and the mitochondrial 16S, cytochrome oxidase II, and cytochrome B genes, for a total of 3048 molecular characters. Phylogenetic trees were reconstructed using maximum parsimony, maximum likelihood, and Bayesian methods. Some previous hypotheses indicate that streblids and nycteribiids are sister families, with the nycteribiids, which exhibit more extreme morphological changes associated with the parasitic lifestyle (i.e. loss of wings, dorsally shifted head and leg insertion), as the older lineage of the two. However, the results of these analyses indicate that the streblids are the older group, and that the nycteribiids are nested within the streblid clade. Additionally, the nycteribiids remain a monophyletic group. While support for the nodes delineating relationships of the three main clades of bat flies (nycteribiids, Old World streblids, and New World streblids) is poorly supported, there remains evidence for two independent invasions of this group into the New World, once within the nycteribiid lineage, and once in the paraphyletic streblid lineage (subfamilies Nyctyerophiliinae, Streblinae, Trichobiinae). Future research will compare the evolution of this group with the radiation of the bat hosts.

SPEODESMUS

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Speodesmus millipedes are small, white, troglobitic polydesmids, probably descended from soil-burrowing forms that inhabited mesic, southwestern forests in the past. Currently there are four described species: *S. echinourus* Loomis, 1939, from central Texas; *S. tuganbius* (Chamberlin 1952), re-described by Shear (1974), from New Mexico and West Texas; *S. bicornourus* Causey, 1959, from central Texas; and *S. aquiliensis* Shear, 1984, from Colorado.

Elliott's 1976 morphometric study of numerous specimens from Texas employed extensive multivariate analyses in search of species-specific characters. As in most millipedes, the male gonopods provide good characters, because of their lock-and-key relation to the female genitalia. Females have extensible cyphopods. Some small species (7-10 mm long) still burrow in soil, while large species (20 mm) evolved gigantism in humid cave environments. Large and small morphs of *S. bicornourus* are geologically isolated from each other. *Speodesmus* has speciated many times into interesting biogeographic patterns related to karst areas bounded by faults, streams and lithologic changes.

New species recognized by Elliott include six from Texas, one from Arizona, and one possible from Nevada. Elliott has in-press descriptions of four of the new Texas species: Species c from Fort Hood, Bell and Coryell counties; Species f from Camp Bullis, north central Bexar County; Species r from Government Canyon State Natural Area, Helotes and other points in northwestern Bexar and northeastern Medina counties; and Species i from Camp Bullis and San Antonio, Bexar County, and Comal County. The closest relative of Species c is *S. bicornourus*, from caves in Williamson, Travis, and Burnet counties, Texas. Species f and r are relatives of *S. echinourus*, which is distributed across the Edwards Plateau and parts of the Balcones Escarpment. Species i is a soil-burrowing form, similar to a new species from Val Verde County. Another new species from Hays and southern Travis counties is a more troglomorphic relative of *S. echinourus.* Preanal setae, previously thought to distinguish species groups of *Speodesmus*, are somewhat variable. Gonopods remain the most suitable structures for separating species groups until DNA studies can be employed.

GEOLOGY

SPELEOTHEMIC MINERAL DEPOSITS FROM FUMES AND STEAM, 1919 LAVA FLOW, KILAUEA CALDERA, HAWAII

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The 1919 "Postal Rift" lava flow in Kilauea Caldera contains about 200 caves. Included are lava tube caves, hollow tumulus caves, drained flow lobe caves, and others. While a single body of magma is believed to underlie the entire caldera, significant differences in the fumes of different areas are detectable by human senses, on and beneath the surface. A significant minority of its caves are at least intermittently hyperthermal, with varied patterns of steam and fume emissions and varied speleothem deposition along hot cracks and in other locations on ceilings, walls, floors, and lava speleothems. Working conditions include up to 100% relative humidity and temperatures up to 55° C, but as a result of thermostratification, temperatures as high as about 80° C can be measured in speleothemic areas. Sulfates, chlorides, and (rarely) elemental sulfur are believed to be present. An initial project of mineral identification foundered with the termination of the position of Cave Specialist at Hawaii Volcanoes National Park. A new project is strongly indicated.

MAZE DEVELOPMENT IN HAWAI`I LAVA TUBES: A STATISTICAL ANALYSIS

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Over the past two decades, the Hawai`i Speleological Society has documented more than 1,000 cave entrances and accumulated nearly 200 miles of survey. Twenty of these caves range from 1 to 40 miles in length. These form the study group for the project. Many are rather simple straight-line drainage tubes, while others form extremely complicated maze systems. Cavers have long wondered why there is such a radical difference in caves that are all formed by the same volcanoes.

This study uses the Compass cave program to analyze a line plot of each cave. Two separate analytical techniques placed the sample caves into three distinctive groups: Linear, Transitional, and Maze. The next step in the study was to correlate each cave with the characteristics of the individual flow unit within which it occurred. The intent was to establish the major criteria that influenced maze development. Six characteristics were tested:

Geologic Age
Volcano–Hualalai, Mauna Loa, Kilauea
Slope–average angle of incline
Volume–average passage diameter
Environment–rift zone, caldera, or cinder cone
Morphology–shielded vs. open air

Maze development was most strongly correlated with large volume flow events. These are more common along rift zones on the taller, steep-sided mountains of Hualalai and Mauna Loa. There is also the impression that maze development formed in relatively short, open-air events.

MICROBIAL CONTROLS ON SULFURIC ACID SPELEOGENESIS

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The sulfuric acid speleogenesis model, proposed in the early 1970s from observations of Lower Kane Cave, Wyoming, considered a cave-enlargement process that was based almost entirely on chemical oxidation of H_2S to sulfuric acid. Sulfuric acid reacted with limestone at the water table or on subaerially exposed cave-wall surfaces where gypsum replaced the limestone. Reduced sulfur compounds (e.g., H_2S), however, also serve as energy sources for microorganisms living in these caves, including Lower Kane Cave. Using uniquely applied geochemical and microbiological methods, a surprisingly complex consortium of microorganisms was found to form thick subaqueous microbial mats in the cave. Several evolutionary lineages within the class "Epsilonproteobacteria" dominate the mats. Compared to the total flux of sulfide into the cave, little H_2S volatilizes into the cave atmosphere or oxidizes abiotically in the anaerobic spring water. Instead, the primary sulfide loss mechanism is from subaqueous microbial sulfide oxidation. Despite the cave waters being slightly supersaturated with respect to calcite, the "Epsilonproteobacteria" generate sulfuric acid as a metabolic byproduct, depressing pH at the limestone surfaces. This acts to focus carbonate dissolution near the attached filament, locally changing the saturation index. The H_2S that volatilizes into the cave air is oxidized at the walls where interactions between cave-wall microbiological (biofilms development) and physicochemical (biofilms hydrophobicity) factors influence subaerial speleogenesis. The recognition of the geomicrobiological contributions to subaqueous and subaerial carbonate dissolution fundamentally changes the model for sulfuric acid speleogenesis and the mechanisms for subsurface porosity development.

BIOVERMICULATIONS: LIVING, VERMICULATION-LIKE DEPOSITS IN CUEVA DE VILLA LUZ, MÉXICO

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Black, grey, brown, beige, blue, and purple wall and ceiling coatings comprising bacteria, fungi, and minor amounts of sub-aerially deposited clay in the sulfide-rich Cueva de Villa Luz, Tabasco, México, visually resemble vermiculations. The mushy colonies occur ubiquitously on exposed, sub-aerial limestone that is not subjected to flowing water. They manifest in a variety of forms ranging from dendritic to discrete spots to massive mats, mimicking all vermiculation morphologies documented by Parenzan (1961), and more. The biovermiculations exhibit pH values from 3.0 to 7.5. The colonies disappear near entrances during the dry season, leaving only an extremely thin layer of gypsum and/or clay, and re-grow during the wet summer and fall seasons. A 3-by 3-centimeter patch within a massive deposit was scraped to bare limestone in 1998. Biovermiculation colonies re-populated with "pimple-like spot" biovermiculations within weeks. The patch continues to fill in with "elongate spots" and by the edges of the massive deposit extending inward.

Epifluorescent microscopy of samples stained with acridine orange revealed a variety of bacterial shapes including large, cigar-shaped rods, stalked bacteria, and cocci. DNA extracted from these deposits demonstrated the presence of fungi and different kinds of bacteria, including *Acidobacterium* and actinobacteria.

While vermiculations occur in a variety of caves worldwide, they are particularly common in active and formerly sulfide-rich environments. These observations suggest that some "mud and clay" vermiculations formed as subaerial clay particles accumulated onto the sticky surfaces of active biovermiculations in a manner similar to stromatolite deposits.

PATTERNS OF STRUCTURAL SEGMENTS AND THEIR INFLUENCE ON PASSAGE MORPHOLOGY IN FRIARS HOLE CAVE SYSTEM, WEST VIRGINIA

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Early flow paths in caves can follow single fractures, fracture intercepts, or zones of closely-spaced fractures. Inferred early fracture conduits (structural segments) can be identified in many kilometers of passages in the Greenbrier caves of West Virginia, especially in Friars Hole Cave System. Detailed three-dimensional mapping of the structural segments shows that the patterns of the early segments exert significant influences on modern passage morphology in certain hydrogeologic settings, particularly in those in which early tubes and fissures were preserved in the ceilings of passages which underwent significant entrenchment by low-volume vadose streams. In plan view, segments and groups of segments exhibit the following common patterns: linear (mostly joint and bed-joint segments); sinuous (bed and fault segments); en echelon (N 60-75 E set joints); and offset (where flow switches segment types, e.g., joint to bed to joint). In profile view, segments exhibit three-dimensional looping, primarily on systematic joints or thrust faults. The details of the fracture geometry and the geometry of the early conduits strongly influence the subsequent growth and morphology of the canyons and tubes that constitute the modern passages. For example, many passages consist of sequences of alternating tubes and isolated vadose trenches. Two additional significant factors affecting the growth and morphology of the passages are (1) minor variations in lithology and (2) the introduction of armoring clastic sediments. Impure units impede entrenchment and can lead to wider lower parts of canyons, or to vertical offsets in canyon profiles where passages change levels and headward erosion is impeded.

MORPHOLOGY AND CLASSIFICATION OF CONDUITS IN THE UNCONFINED FLORIDAN AQUIFER SYSTEM OF WEST-CENTRAL FLORIDA

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Conduits within the unconfined Floridan Aquifer of west-central Florida include both horizontal and vertical components. Vertical portions of conduits visually correlate to fractures, and these fractures dominate conduit directionality as shown by a collection of several Florida cave maps. Length-weighted rose diagrams of passage directions reveal a northwest–southeast and northeast–southwest pattern of conduit directions statistically similar to results found in remote sensing studies. Horizontal elements occur at consistent horizons as shown by cave surveys and observations at quarries. These patterns further demonstrate that horizontal solution features can be pervasive and laterally continuous. Their control is presently unknown but is potentially the result of some combination of lithology, fracture density, and water-table position.

Conduit morphology is traditionally classified from observations in telogenetic karst. In telogenetic karst aquifers, matrix permeability is low, and secondary permeability is provided by fractures and bedding planes. Classification is based upon the type of recharge to the aquifer (allogenic or hypogenic) and whether conduits are controlled by fractures or bedding planes. Recent observations in eogenetic karst (for example, Bahamas) do not fit these classifications. In eogenetic karst, matrix permeability is high—up to four orders of magnitude greater than in telogenetic karst. We suggest that a more appropriate classification scheme of karst would incorporate diagenetic maturity of the rock, as well as recharge type and fracture density. In such a scheme, conduits of the unconfined Floridan Aquifer represent a mid-point in a range between Plio-Pleistocene karst on young carbonate islands and Paleozoic karst in the Appalachian lowlands.

HYDROGEOLOGY OF THE SINKING VALLEY KARST AND THE NSS TYTOONA CAVE NATURE PRESERVE.

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Sinking Valley, Blair County, Pennsylvania, is a 17-kilometer-long anticlinal valley. It has the shape of an inverted V, open to the northeast and bounded on the east and west sides by Brush Mountain which follows the plunging fold of the anticline to form the apex of the V. The northern boundary, crossing the open end of the V, is the Little Juniata River which crosses the structure at right angles and defines regional base level. Upper Ordovician cavernous limestone outcrops along the base of the mountain. Mountain runoff sinks along the perimeter and drains internally to Arch Spring, the head of Sinking Run. Tytoona Cave is a master trunk consisting of segments of open channel connected by sumps. Dye tracing shows a connection between Tytoona Cave and Arch Spring and also a connection directly to the Juniata River. Analysis of surface drainage, channel and cave profiles, the dye trace, and reports of divers, indicate a complex history for Tytoona Cave: first a master conduit, then an abandoned upper level, then reactivation to its present use as an overflow route. Evidence for a previous dry phase is provided by stumps of massive stalagmites now nearly buried in the sediment of the active stream. Divers have found the final sump to descend to at least 25 meters, close to regional base level. A lower level flooded conduit is predicted, extending to the Juniata River, 3 kilometers away. What seemed to be a simple master trunk system has a much more complex history.

PLEISTOCENE MIXING ZONE CAVES IN A CARBONATE EOLIANITE PENINSULA, VARADERO BEACH, CUBA

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Varadero beach, on the northwestern coast of Cuba, extends approximately 20 kilometers northeast into the Straits of Florida and averages 1 kilometer wide. North-northeasterly winds have deposited carbonate eolianites, composed primarily of bioclasts derived from the erosion of fringing coral reefs. In addition to near-beach active eolianites, the core of the peninsula is composed of late Pleistocene eolianites reaching elevations of 5 to 8 meters.

We documented notches and four caves within these eolianites. Many of the notches and all of the caves display the morphologies and distribution typical of flank margin-style caves formed in freshwater-saltwater mixing zone environments seen in carbonate eolianites of carbonate islands. One of the caves, Cueva Ambrosio, is at least partially fracture-controlled.

Because of the intimate physical association of the karst with the large hotels on the peninsula, the interplay of the tourism industry and the karst features is dramatic. Some notches and possible caves have been extensively developed for use as storage closets and break rooms or converted to fountains by hotels. One flank margin cave, Cueva de Pirata, is presently used as a cabaret bar. Nearby Cueva de Musulmanes and Cueva Ambrosio are protected on an ecological preserve.

These caves represent the only documented flank margin style caves observed on Cuba thus far. The absence of an overlying paleosol-dune package and the presence of large caves in the dune lead us to speculate that these eolianites represent deposition during the oxygen isotope substage 5e transgression.

HYDROLOGIC STUDY OF THE COLDWATER CAVE GROUNDWATER BASIN

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The Coldwater Cave groundwater basin is located within a highly karstified landscape where water moves directly and at high velocities into the groundwater system. Land use practices include farming and livestock. Individual farm residences use shallow septic systems for human waste disposal. The basin under study encompasses 80 square kilometers in northeast Winneshiek County, Iowa, and southeast Fillmore County, Minnesota. The rock units containing this hydrologic system form the Galena Aquifer, which is one of the major agricultural water sources for most of the region. The Coldwater Cave system is the major conduit for the groundwater basin. The cave system, which is dendritic in nature, is developed in the Ordovician-aged Dunlieth Formation and has been mapped to 27 kilometers with survey work in progress. The groundwater basin underlies the Pine Creek and Cold Water Creek watersheds. Streams from both of the watersheds lose water to the subterranean drainage system. Numerous sinkholes in the study area may also contribute water to the groundwater basin. The subterranean stream resurges into Cold Water Creek via Coldwater Spring, which has a discharge rate of 33,500 liters per minute during base flow conditions. Cold Water Creek flows into the Upper Iowa River located a kilometer to the southeast. The Upper Iowa River flows to the northeast and eventually joins the Mississippi River located 60 kilometers southeast of the study area. The combination of surface and subsurface drainage in the Coldwater Cave drainage basin shows a complex interaction between the surface and subsurface streams.

Recent Karst Hydrology Investigations in Pulaski and Montgomery Counties, Virginia

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Dye trace studies were performed in Pulaski County and Montgomery County, Virginia, to determine potential impacts to conservation sites containing caves with globally-ranked, critically imperiled fauna. GIS-based "Consites" provide details for environmental planners and managers regarding at-risk conservation areas while safeguarding sensitive information including cave entrance locations.

Between March and August 2003, an investigation was performed to determine the subsurface flow paths of storm water discharge from the New River Valley Commerce Park in Pulaski County. Numerous sinkholes, sinking streams, caves, and springs surround the Park. Activated charcoal samplers were placed at 16 locations–including nine springs, one cave stream, and several surface streams–and background fluorescence was determined. One pound each of Eosine, Fluorescein, and Rhodamine WT was injected into three sinking streams receiving New River Valley Commerce Park storm water. All three dyes were recovered within two days on charcoal samplers and in water samples from Railroad Spring, approximately 6.5 kilometers east of the injection sites.

Another dye-tracing project performed between January and March 2004 provided data for defining boundaries of the Slussers Chapel Conservation Site. Charcoal samplers were placed at 19 sites–including seven springs, three cave streams, and several surface streams–and background fluorescence was determined. One-half pound of Eosine injected into the stream in Fred Bull #2 Cave and one pound of Fluorescein injected into a nearby sinking stream were recovered one kilometer to the east in the trunk stream in Slussers Chapel Cave before flowing southeast an additional two kilometers and emerging from Mill Creek Cave Spring two days later.

Ground Water Tracing in La Vergne, Tennessee, to Help Solve Sinkhole Flooding Problems

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La Vergne is located in the Central Basin with sinkholes and springs developed on the very gently folded Ordovician-aged Lebanon Limestone. Serious sinkhole flooding occurs in some areas of the city nearly every year. Ten successful ground water traces were conducted for the purpose of understanding direction of ground water flow and delineation of ground water (spring) basin size. Four separate spring basins were delineated. Two traces went a distance of nearly two miles. Some travel times exceeded one mile per day. With the tracing results and site visits to areas prone to flooding, methods to reduce or eliminate flooding have been investigated. A few injection wells exist in the area, but were constructed at ground level and thus have largely filled with sediment. Cleaning of these Class V injection wells and constructing standpipes and filtration fabric to eliminate sediment and debris inflow should significantly help these areas. At a few other sites, the sinkholes drain poorly due to being clogged by debris and trash. After cleaning these out, Class V injection wells could be constructed to allow more rapid drainage. A novel approach is being investigated in one area where a major sinking stream is the cause of numerous sinkholes flooding immediately down-gradient of the sink point. It appears to be possible to construct a narrow dam approximately 10 feet high and 30 feet wide across the sinking stream channel to return the drainage back to surface flow which existed prior to geologically recent, subterranean stream piracy.

GIS Investigation of Potential Karst Impacts Among Proposed I-66 Alignments in Somerset, Kentucky

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The Southern Kentucky Corridor (I-66) is a proposed interstate identified by Congress to be a high priority corridor. The ultimate construction of this interstate along any alignment will have serious consequences to the environment. The project area of this study focuses on three proposed alignments of this interstate from the terminus of the northern bypass of Somerset to Laurel County, Kentucky.

The project area contains portions of the Daniel Boone National Forest along the Cumberland Escarpment. This forest contains undeveloped woodlands and gorges along the Rockcastle River and Buck Creek. The region is highly karstified with tremendous bio-diversity. Regional geology is composed of horizontal bedded units. The lowermost is the Borden Formation of Mississippian age, a non-karstic shale/limestone. Above the Borden are several highly karstified Mississippian limestones. The uppermost Mississippian age rock is the non-karstic Pennington Shale. Numerous sandstones of Pennsylvanian age prevent karstification in the ridges.

We digitized geologic maps and corridor alignments, and used existing digital data and data created during this study to analyze the differences among the three proposed alignments of I-66 within the project area. We calculated impacted areas, lengths, and numbers of features and normalized them to the total within the project area. Criteria and weighting factors afforded a means by which to compute relative impacts of each alignment. Based upon our results, the southernmost of the three proposed alignments has the least potential impact to the environment; however, the Highway 80 alignment would utilize existing roads which have already impacted the environment.

An Overview of Karst Mapping in Virginia

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Karst mapping in Virginia has evolved over the past 40 years with changes in perception of karst both to map makers and map audience. Although the Virginia Cave Survey plotted cave entrances and carbonate boundaries, their focus was caves rather than karst. Some geologic maps used a symbol for sinkholes and hachured groups of sinkholes as representing karst. The first Virginia karst maps were of regional scale and define the extent of karst and relative degree of karstification by plotting carbonate rock boundaries along with sinkhole and cave entrance features. The intended map audience included geologists, government officials, and the public. A major goal was to convey that sinkhole dumping was an important cause of karst groundwater pollution in addition to defining the extent of sinkhole collapse hazards.

The expansion in interest from sinkhole collapse to karst groundwater contamination initiated a shift in focus from features to karst processes. Many individuals inappropriately remain fixated on sinkholes, rather than the less visible karst processes responsible for the array of karst hazards. The misapplication of regional information for site-specific details continues. Digital mapping and GIS have enhanced karst mapping opportunities as well as enabled sinkhole information to be misused at inappropriate scales and purposes.

Detailed geological mapping in the Timberville area contributed to the recognition of geologic and process linked surficial karst units mapable at the 7.5-minute topographic map scale, which include: flood-prone karst, karren karst, ledge karst, pavement karst, pinnacle karst, subsidence karst, travertine-marl deposits, and generalized karst.

U.S. Geological Survey Progress Toward A New National Karst Map

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The U.S. Geological Survey (USGS) Karst Applied Research Studies Through geologic mapping (KARST) Project is compiling a new national karst map as part of geologic mapping and karst hydrogeologic activities for the National Geologic Mapping Program. Support by the Program, National Park Service, and National Cave and Karst Research Institute enabled us to hold workshops, which were attended by representatives from 16 states, the

National Park Service, and other organizations. The outcomes of these meetings include the establishment of personal contacts, offers of data support, suggestions for construction of the map, and regional perspectives on karst-related issues. Initial products of the KARST Project include a GIS version of “The Engineering Aspects of Karst” map by Davies and others (1984). These data are available on the web at the National Map, http://nationalmap.usgs.gov/, as the current national-scale karst GIS layer. In addition, a digital karst map of Puerto Rico is in publication, and will be available on the web soon. Furthermore, as a prototype for the National Karst Map, a 1:1,000,000 scale digital karst map of the Appalachian Highland states has been constructed, and is in an initial review stage. Maps of the individual states are available for public review and comment at: the following website: http://geology.er.usgs.gov/eespteam/EESPT_Projects.html. Data for additional states and territories will be added as they become available.

Implementing the National Cave and Karst Research Institute Vision

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The National Park Service and New Mexico Institute of Mining and Technology convened a two-day Vision Building Workshop in October 2003, culminating a nearly year-long effort to seek diverse cave and karst community input. The 26 invited participants represented six federal agencies, five academic institutes, two state programs, and five non-profit organizations. A professional facilitator led the group through discussions relevant to the development of the National Cave and Karst Research Institute, including its Congressional mandate, the needs and opportunities in the discipline, and the appropriate range of activities. The second day focused on how to most effectively structure the Institute.

Efforts in 2004 have concentrated on implementing the prevailing vision provided by the community and its mandate. The National Park Service is moving the National Cave and Karst Research Institute towards a “jointly administered” structure in which New Mexico Institute of Mining and Technology will plan, coordinate, and administer the Institute and its programs while the National Park Service will have ultimate responsibility and retain indirect control. A National Cave and Karst Research Institute corporation with a governing board composed of representatives from partner organizations will likely be established over the next year.

The National Cave and Karst Research Institute’s third primary partner, the City of Carlsbad, plans to begin construction of the Institute headquarters in summer 2004 and complete the project about 18 months later. Over $4 million has been appropriated or pledged towards the building.

GIS Applications in Managing Karst Groundwater and Biological Resources

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Multiple complex factors must be weighed in managing water and biological resources in karst regions. Their relationships are sometimes not apparent. GIS is an effective tool in correlating these factors to identify known or potential problems and delineate zones for effective management. Geologic and hydrologic data must first be considered for their effects on aquifer recharge, development, and transmission of groundwater to wells and springs. Drainage basins for caves are delineated based on surface water flowing into their entrances and groundwater derived from other areas. Caves with rare or endangered species are identified and categorized to determine the species’ distribution relative to potential hydrogeologic barriers. By combining the data, management zones can be established to identify areas best suited for protection or in greatest need of protection, and to map the probable distribution of rare species. Such mapping can be used to redirect urban development away from environmentally vulnerable areas and enhance resource protection efforts. Examples from the central Texas area will be used that include the Edwards and associated aquifers, and cave-dwelling invertebrate species that are federally listed as endangered.

International Exploration

Assessing Cave and Karst Tourism Assets in the Sultanate of Oman

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American caving teams participated in three trips to the Sultanate of Oman to assess the potential use of cave and karst resources to enhance tourism. The Omani Ministry of Information sponsored the first trip in June 2000. The second two trips (August 2001 and January 2002) were sponsored by the Omani Directorate General of Tourism and the National Geographic Society.

The 11.5-kilometer long, 385-meter deep Selma Cave System, in northern Oman, incongruently lies in an ~11 km², arid catchment basin. Large pits in the bottom of normally dry wadis drop between 250 and 300 meters from the four distinctly separated entrance areas. The four entrance rooms constitute the largest (up to ~80 by 200 meters and 70 meters high) chambers in the system. Dramatically more constricted passages depart each entrance chamber at ~1,000 meters msl, following regional dip towards the east. These lower passages merges into a larger trunk passage, which leads to a resurgence cave with an intermittent stream. The entire system carries water during uncommon storms.

Nearby Majlis Al Jinn consists of a huge (3.9x106 m³) chamber. A ubiquitous veneer of calcite coats the smooth walls of the broad, dome-shaped room. The floor is mostly covered with insoluble residue from the clastic-rich, Middle Eocene Seeb Formation bedrock. The cave’s three entrances near the top of a hill provide no evidence that the huge room has ever received significant surface inflow.

The teams also visited Tawi Attair, Al Hota/Al Fallah, Muqal, Al Marnif, and other caves.

Priest Grotto, Western Ukraine

Chris Nicola

In spring 1942, as the Nazis intensified their hold on Eastern Europe, four Jewish families disappeared into the vast underground labyrinths of the western Ukraine. The group included a 75-year-old grandmother and a three-year-old girl, and for almost two years, they lived, worked, ate, and slept directly under the feet of those who would send them to their deaths. 344 days later, on April 12, 1944, every one of the original 38 people who entered the cave that previous spring crawled out from Priest Grotto alive, setting a world record for the longest period of time any human being has survived underground.

In 1963, local cavers, exploring the cave for the first time, discovered several small lanterns and a 150-pound millstone just off the cave’s main tunnel. But by that point there was no one around who could remember what had actually happened there. For 60 years their story was forgotten until a leading American caver came across the remnants of the Jews’ underground sanctuary inside of Ozernaya, the world’s 10th longest cave.

Sino-U.S. expedition to Hunan Province, Peoples Republic of China

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In March and April 2004 a team of cavers sponsored by the Hoffman Environmental Research Institute and the Guilin Institute of Karst and Geology did reconnaissance and karst assessment work in the Xiangzi area, a remote section of the Guizhou Plateau in northwest Hunan Province. The Dalong Cave system, which drains this section of the plateau, resurges into the Xiangzi River via a 300-meter waterfall. Sumped passages at the upstream end of the cave system were explored and mapped. The recharge area for this cave system encompasses 200 km² of tower karst. A number of fault-controlled shafts and caves located on top of the plateau were explored and mapped.

Multiyear Project to Map Caves for the Belize Institute of Archaeology

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In February and March 2004, a group of 13 cavers from the U.S. traveled to Belize to finish mapping Barton Creek Cave and to map several other caves for the Belize Institute of Archeology. The insurgence sump of Barton Creek

Cave was mapped by cave divers. The divers connected St. Hermans Cave to the Blue Hole in Blue Hole National Park and began mapping another cave in the park, Mountain Cow Cave. A 98-foot (30 m) dive was done in Yaxteel Ahauto, a cave in the Roaring River Valley. Thousand-year-old pots filled with calcite were found on a upper level of that cave.

Exploration of the Roraima Sur Cave, Bolivar State, Venezuela, The Longest Quartzite Cave in the World

(Exploración de la Cueva Roraima Sur, estado Bolívar, Venezuela, la mayor caverna del mundo en cuarcitas)

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The Roraima Sur Cave is located at the summit of Roraima tepuy, a Venezuelan table mountain, near the border with Brazil and Guyana. The cavern is composed of a complex framework of horizontal galleries with numerous low ceiling passages. This system was formed in the weaker strata of the Roraima Group sandstone. With more than 5 kilometers of development, Roraima Sur Cave surpasses the documented 4.7-kilometer length of Brazil's Gruta do Centenario, which was, until now, the world's longest cave in quartzite rock.

The recent Venezuelan Speleological Society (SVE) expedition surveyed approximately 5.5 kilometers of galleries, with a depth of 50 meters. The Society also connected a previously explored passage to a neighboring cave, doubling the total cave length measured by a previous Czech and Slovak caving team.

Roraima Sur Cave exhibits several peculiar geomorphologic characteristics. With its extensive system of horizontal galleries, it defies the typical vertical profile of most caves in the Venezuelan Guiana Shield karst. The abundance of highly developed opal stalactites, found deep in the cave, is a unique phenomenon that had only been previously reported in Sarisariñama's Sima de la Lluvia, but as much less abundant and smaller. These stalactites are also peculiarly slanted, evidence of the presence of a consistent air current through the cave system.

Photography

Extending Your Dynamic Range: Getting the Most from Your Highlights and Shadows in Post Processing

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Dynamic range refers to the range of detail we can capture in an image from the brightest to darkest. In cave photography, we are constantly dealing with this issue. Ideally, all of our flashes would be placed perfectly to give uniform exposure throughout. Because caves contain subjects ranging from near black to white or clear, we inevitably end up with photos with burnt-out highlights or shadow areas that are too dark. Even more problematic are photos incorporating natural light in which we want to light the cave within as well. This is an even greater problem with digital, which has less dynamic range than film. This talk focuses on techniques in Photoshop to eke more detail from highlights and shadows from individual photos, and on approaches where combining two or more photos at different exposures can solve problems not possible in a single exposure. A typical sequence involves adjustment of color balance (many digitals, especially when using the onboard flash, are cyan-heavy), global shifts in tonal range, sharpening, then localized adjustment of highlight and/or shadow. Advantages of working in CMYK color space include having an extra color channel to adjust that is basically grayscale information, and ability to sharpen just the black channel, which enhances detail without giving an oversharpened look. Finally, the processed files are saved as originalname_r.jpg and the originals preserved. If you typically rename files, it is better to do that before processing if you use such a naming convention, so you can easily reference your originals. Files that will require several saves are first converted to the lossless Tiff format. Photoshop 7 even allows adjustments to be saved in a reversible manner with adjustment layers, especially nice when preparing digital images for any type of output (print, slide) where subsequent corrections might be needed to get optimal saturation and brightness.

Envisioning "The Cave" in Central Park, New York City, Through Archival Photography

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Sadly, many caves have been destroyed in whole or in part through landscape modification, construction, or quarrying. As a result, the only way most of these caves may be documented is through contemporary written descriptions, primitive sketches, or vintage photographs.

"The Cave" in Central Park, on Manhattan Island in the New York City is an excellent example of how archival materials can lead to a fairly accurate depiction, even though a map of the cave is not known to exist. The Cave was a "fanciful creation" of the two principle designers and architects of Central Park, Frederick Law Olmstead and Calvert Vaux. During the construction of the park in the 1850s and 1860s, they had a natural cleft in outcrops of bedrock roofed over with boulders, creating a short, tunnel-like cave. In the 1920s the Park administration had The Cave sealed with stone and concrete, as it had become the "haunt of tramps and vagrants" and was considered dangerous. Several postcards and over a dozen stereopticon views were published during the interval that The Cave was open to visitors. These are indispensable for describing the features in some detail. A composite map may be constructed from these archival photographs.

Spelean History

Cave Hoaxes and Nineteenth Century Archaeological Theory

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American archaeology in the 19th century was dominated by the Mound Builder myth, which held that the tens of thousands of earthen mounds in North America were constructed by a superior vanished race unrelated to the Indians. Several distinctive Mound Builder motifs appear in the nationally propagated Nesmith Cave hoax of 1866–67, which was based on an actual cave, Chutes Cave, in Minneapolis, Minnesota. Specifically, there are close parallels between details in the cave hoax and Ancient Monuments of the Mississippi Valley, a classic of American archaeology and the first publication (1848) of the newly founded Smithsonian Institution. The authors, Ephraim Squier and Edwin Davis, were squarely in the Mound Builder tradition. In excavating mounds they found stone coffins, skeletons that crumbled to powder, and sacrificial altars with calcined bones, all of which were also supposedly found in the hoax cave by the fictitious Mr. Nesmith. The latter concludes, as Squier and Davis had earlier, that "the relics found are not at all aboriginal in character, and may have been the work of a people existing long before even these prairies were the hunting grounds of the Indians."

The Application of Back's Principle to Cave History

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William Back, in his 1981 article, "Hydromythology and Ethnohydrology in the New World," wrote "[i]f used with caution, mythology can sometimes extend historical and archeological interpretation further back in time." This paper applies the principle to Minnesota cave history. According to early missionaries, the indigenous Dakota people believed that the junction of the Minnesota and Mississippi Rivers was the center of the Earth, positioned directly under the center of the heavens. Nearby was the dwelling place of Unktahe, Dakota god of waters and of the underworld, who was often depicted as a serpent. Mary Eastman, in her 1849 book, Dahcotah, or Life and Legends of the Sioux around Fort Snelling, wrote that "Unktahe, the god of the waters, is much reverenced by the Dahcotahs. Morgan's Bluff, near Fort Snelling, is called 'God's House' by the Dahcotahs; they say it is the residence of Unktahe, and under the hill is a subterranean passage, through which they say the water-god passes when he enters the St. Peter's [Minnesota River]. He is said to be as large as a white man's house." Taken at face value, the myth of the subterranean god, Unktahe, constitutes the oldest cave reference for Minnesota, antedating the accounts of explorers such as LeSueur (1700) and Carver (1778).

HISTORY OF THE GEORGE WASHINGTON UNIVERSITY STUDENT GROTTO

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The George Washington Student Grotto (GWU Grotto), NSS grotto #134, existed from 1966 to 1974. The first grotto Constitution had five elected officers, including a "Publicity Director." The second Constitution (1969) changed elections to April so that the now three officers could plan the upcoming school year. The GWU Grotto primarily caved in Virginia and West Virginia. From 1966 through 1968, the club mapped caves for "Descriptions of Virginia Caves." The first Chairman, Hugh H. Howard, was the most dynamic. He tried to start the GWU grotto in 1965, but had to first overcome a rule that any on-campus club could not be affiliated with a national organization. The grotto had 54 members in its first year and published The Colonial Caver. In the fall of 1967, Warren Broughton was elected Chairman. The club published professional-looking issues of The Colonial Caver. Charles Pfuntner was elected Chairman for the 1969–70 school year and Leonard LeRoy was elected grotto Chairman for the 1970–71 school year. The Vietnam War affected grotto membership. Paul Stevens was elected Chairman for the 1971–72 and 1972–73 school years. Paul took the grotto by storm, and "The Foggy Bottom Caver" was started. Grotto membership expanded to 35. Steve Stokowski was elected Chairman for the 1973–74 school year. By 1974, all the GWU student members had either graduated or left the university. After considering that advertising for new cavers might result in a cave conservation disaster, Stokowski dissolved the grotto.

THE ROQUEFORT CAVES OF ST. PAUL, MINNESOTA

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The Roquefort caves of France have a history dating back to Classical antiquity. In 1933, Professor Willis Barnes Combs of the University of Minnesota began experimental ripening of a domestic Roquefort cheese in artificial sandstone caves at St. Paul, Minnesota, which he determined had the proper combination of low temperature and high humidity. Combs stated that there was no commercial production of Roquefort in the United States at this time. After spectacular success at the University Cave, he boasted that St. Paul's caves could supply the entire world demand for Roquefort. Made from the more plentiful cow's milk, rather than from sheep's milk as in France, the Minnesota cheese was initially called Roquefort but after complaints by the French Foreign Trade Commission was relabeled Blue Cheese. The production of Minnesota Blue did not really take off until 1940, however, when World War II cut off Roquefort imports from France. Kraft Cheese and Land O'Lakes then rented caves in St. Paul and ripened millions of pounds of blue cheese. For a brief moment, St. Paul was acclaimed the Blue Cheese Capital of the World. The University Cave, which ceased operations in the 1950s, was recently dug open by the author. Filled with debris that was pushed into it with a bulldozer years ago, the cave contains no obvious artifacts from the cheese-making era.

SURVEY AND CARTOGRAPHY

TIPS FOR EFFICIENT CAVE SURVEYING

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This presentation describes some ways that a survey team can improve their productivity and efficiency by "working smart, not hard." Among the techniques described are allocating tasks so that no team member is overloaded or under utilized, defining the responsibilities of each team member, placing stations to facilitate easy shots, taking readings in a consistent order, taking advantage of geometry to make shots easier to read, avoiding reading and recording errors, testing instruments before each trip, agreeing in advance on how dimension data is to be recorded, carrying instruments to facilitate quick use, using a small flashlight to light stations for backshots, and knowing when to quit and head out of the cave.

AN ANALYSIS OF RANDOM AND SYSTEMATIC SURVEYING ERRORS

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An analysis was performed of various types of surveying errors, with the errors falling into two categories, random and systematic. Random errors are errors that are as likely to be off in one direction as the other, and may be large or small in magnitude. Random errors come from instrument readability (usually on the order of 1–2 degrees) and "blunders" which can be small or large. Systematic errors are errors that are consistently off in one direction. Systematic errors generally come from instrument offset. This analysis concentrated on compass and inclinometer readings in longer passages.

Analysis was performed using statistical methods and by numerical experimentation where 50 shots of actual survey data were taken and errors were assigned to the data. The differences between the data with errors and the data without errors were calculated.

The conclusions were as follows: Random errors caused by instrument readability consistently cancel out in longer passages. Therefore, meticulous matching of the foresight and backsight readings beyond that which serves to catch large blunders is not helpful. Instrument offsets of even half a degree give much larger final errors, even if the instrument offset is smaller than the readability of the instrument. This is because systematic errors accumulate rather than cancel. Fairly frequent blunders of 10 degrees make less difference in the final answer than instrument offset. Aside from preventing major blunders, the best way to improve survey data is to carefully take into account the differences between survey instruments.

ENHANCING WORKFLOW IN DIGITAL CARTOGRAPHY

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While the advent of computer mapping has greatly improved the potential of the cave map, digital maps often sacrifice that timeless humanistic fluidity of a hand-drawn map for machine-like repetitions that make us say, "that's definitely digital." This presentation will focus on various features in Adobe Illustrator that allow you to speed up the cartographic process while creating maps that allow a digital cartographer to keep that timeless hand-drawn appearance. We will use layers to make global changes to specific features, generate brushes to cut time from drawing the minute details, and copy and manipulate forms to create repeating shapes that don't resemble computerized duplicates.

AURIGA, OR TRADING YOUR SURVEY NOTEBOOK FOR A PDA

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The Auriga cave survey software for Palm OS was originally written to assist in the development of an electronic sensor box designed to automatically acquire azimuth and slope measurements, but has now evolved into a smart survey notebook replacement for in-cave use and a lighter weight laptop replacement while at camp. Surveyors can see the cave map on screen while doing their survey, and data does not need to be transcribed later, thus preventing many blunders throughout the process. Despite the smaller screen and slower CPU of Palm devices (vs PCs), Auriga offers graphical and spreadsheet rendition of cave passages, survey stations, and survey shots between them. Thanks to sessions, a concept already present in most cave survey software, surveyors can free their mind of instrument calibration, varying magnetic declination, and mixed measurement units. This allows Auriga to faithfully store survey data exactly as input, only applying corrections and conversions when computing coordinates. Several efficient design aspects provide the cave surveyor with a highly configurable and ergonomic interface, even when operating through a windowed protection box. Once back on the surface, survey data can be sent to other Palm devices through an IR beam or uploaded onto a computer and converted into common cave survey file formats via a software "conduit." The Auriga freeware is under intensive and constant evolution; support for networks of several caves and loop closure are currently in the works, while on-screen freehand sketching of cave walls and details remains the ultimate goal.

UNITED STATES EXPLORATION

NON-TRADITIONAL CAVING IN COLORADO

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In addition to its many fine limestone caves, the state of Colorado contains a substantial variety of caves in other media. These include dolomite, tufa, granite, rhyolite, basalt, welded tuff, sandstone, claystone, and gypsum. Many of these caves have only been found in the past few years and include a cave/crevice complex in sandstone, previously unreported lava tubes, and caves in gypsum.

Pautler Cave System, Illinois

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Pautler Cave, located in Monroe County, Illinois, had some history of visitation but was lost to organized caving after the entrance was bulldozed in 1968. By the 1980s no cavers seemed to remember exactly where the entrance had been. No map of the cave was known to exist, but there were biological records and a brief description in the Bretz and Harris 1961 publication, *Caves of Illinois*. In 1996 the entrance was re-discovered and exploration and survey began in earnest. Currently over five miles have passages have been mapped with almost another mile has been documented in disjunct caves within the system.

North Coast Karst, Puerto Rico

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Puerto Rico is a carbonate island with a volcanic core. The north side of the island contains a belt of carbonate rocks that take the drainage that flows off the volcanic core forming the island's most significant cave systems. The area consists of a variety of karst landforms that include cone and tower karst, alluviated valleys, deep limestone gorges, zanjones (vertical-walled trenches), and active river caves. In addition to the active caves there are many dry segments, which are developed at higher elevations. These are paleo-segments of conduits that drained the basin in the past and are indicative of tectonic uplift of the island and sea level fluctuations. Over the past several years, exploration and survey efforts have concentrated on locating and mapping the dry upper segments, on extending the known cave systems, and in doing reconnaissance in carbonate areas where caves are currently not known.

Coldwater Cave–Past, Present, and Future

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Coldwater Cave(Winneshiek County, Iowa) is the upper Midwest's longest known cave. Since its discovery in 1967 by Iowa Grotto cave divers Dave Jagnow and Steve Barnett, several generations of cavers have pushed the cave's mapped extent to nearly 17 miles (27.2 km). Coldwater Cave is a dynamic, hydrologically active system that responds rapidly to surface drainage. Many remote areas of the cave are accessible only during periods of low groundwater levels. Because of lower than average rainfall in recent years, extensive survey, exploration and study has taken place in the furthest upstream and downstream reaches of the cave, including some areas that have been inaccessable since the cave's initial exploration.

Cumberland Gap Cave—Cumberland Gap National Historical Park

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The Cave Research Foundation manages a multidisciplinary karst study at Cumberland Gap in the political jurisdictions of Virginia, Tennessee, and Kentucky within Cumberland Gap National Historical Park. The southern edge of the Pine Mountain Thrust Sheet rises 600 meters above Powell Valley, exposing 150 meters of Newman (Greenbriar) Limestone dipped 40 degrees northwest. Cudjos Cave Underthrust Fault affects the limestone members from the Gap beyond Lewis Hollow two miles to the northeast. The Gap lies south of the Middlesboro Impact Structure, with a 20-kilometer circumference, and north of several exposed members of tilted Ordovician limestone exhibiting a 120-square-kilometer karst plain. Gap Cave is formed within this complex geologic structure trending along the Newman Limestone strike. The cave has an extensive modern culture related to human use and unique hydrology, geology, and biology. Cartography of Gap Cave has been the major project activity since research began April 2003. The working map exceeds 7 kilometers. Gap Cave exhibits the potential to exceed the 11.25-kilometer known length. While research continues, efforts will be made to connect passage northeast beyond Lewis Hollow where the exposed limestone along Cumberland Mountain continues for more than 25 kilometers.

Lechuguilla Cave Expedition, October 2003

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Most of the recent efforts in Lechugilla Cave, New Mexico, have focused on validating and correcting earlier surveys. In October 2003, one team of four cavers spent five days resurveying in the Southwest Branch in an effort to correct several loop closure failures. In the course of resurveying over 600 meters of passage, they identified azimuth errors ranging from 4° to 20°. It is likely that these errors were introduced by the use of a metallic flashlight to illuminate the survey instruments. The team also produced slightly over 130 meters of new survey.

Wisconsin Caves: A Historical Timeline From Early Native American Use to Modern Day Exploration

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Wisconsin has hundreds of documented limestone and sandstone caves. Many small sandstone caves and rockshelters are very significant and contain prehistoric rock art. Southwestern Wisconsin is home to one of eastern North America's premier rock art sites, in a cave located in the Lower Wisconsin River watershed. This site was used by Ioway and Ho-Chunk Indians as a religious shrine, beginning at about 300 A.D. through the early 19th century. The lead and zinc mining district of southwestern Wisconsin, located in the unglaciated "Driftless Area," produced about one half of the world's lead consumption in the 19th century. Scientific exploration of Wisconsin's caves began in the late 1800s. Wisconsin's longest natural cave is over 3,000 feet (914 m) long and several caves have over 90 feet (27 m) of vertical relief. The Niagara Escarpment of eastern Wisconsin harbors some of the state's deepest and longest caves. Commercial caves first appeared in Wisconsin in the 1800s. The Wisconsin Speleological Society has been active for over 40 years exploring, surveying, and working to protect these great resources.

The Chain of Pukas System, Hawai`i

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The Chain of Pukas System began with the mapping of A'a Surprise Cave in 1998, an unusual find in an a'a lava flow, following-up on a Doug Medville lead from an aerial photograph showing a distinct line of pukas in an historic flow. The exploration of the chain of pukas commenced in 2003, with a concerted effort to document and tie in all the pukas in this part of the flow. This yielded several new finds, including Beer Barrel Puka, Cave `Til You Puka, and the best find of the trip: Once A Puka Twice A Cave. In January 2004, the uppermost pukas in the nine-puka chain were explored, yielding Pukas Interuptus, and A'a Demise.

Caves of Playa Pajaros, Isla de Mona, Puerto Rico

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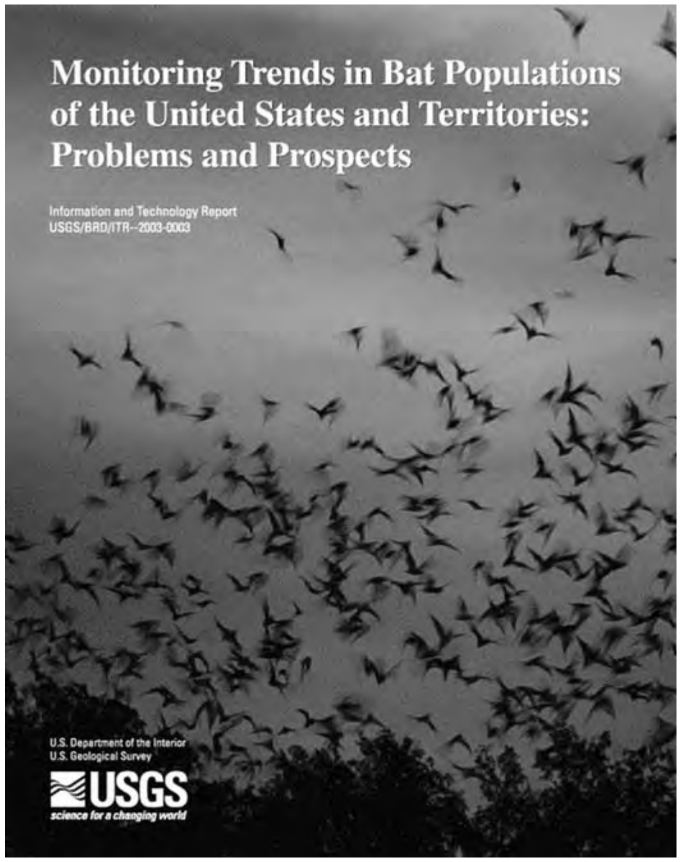
Since 1998, the Isla de Mona Project has been exploring and mapping caves, cave systems, and pits on Playa Pajaros, located on the southeast side of the island. The karst on Mona is a world-class example of flank margin cave development. As of June, 2004, all of the caves on Playa Pajaros have been located and mapped. Work will continue on the meseta where more than 30 small pits have been documented to date. A reconnaissance of the northwest side of the island revealed many more large flank-margin caves that need to be mapped.

Monitoring Trends in Bat Populations of the United States and Territories: Problems and Prospects

O'Shea, T.J., and Bogan, M.A., eds., U.S. Geological Survey, Biological Resources Discipline, Information and Technology Report, USGS/BRD/ITR-2003-003, 274 p. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 (1-800-553-6847) or on the internet at http://www.fort.usgs.gov/products/publications/21329/21329.asp. No cost.



Bats are notoriously difficult to census because of their behavioral patterns and nocturnal habits. Many bat species are also widely perceived to be declining in numbers, generally as a result of direct or indirect human impacts. The U.S. Fish and Wildlife Service lists four bat species and five subspecies as endangered, and others are candidates for threatened or endangered status (before USFWS dropped the candidate categories). Most bat species have low reproductive rates, and many tend to congregate in large numbers in relatively few locations, making them vulnerable to decline. For these reasons there is a need for techniques to monitor bat populations reliably and consistently. This collection of papers from the Biological Resources Discipline of USGS provides an excellent review of the historical problems related to monitoring bat populations, the present state of the art, and promising new directions in this field.

This book includes a brief introduction and two major sections. Part I is a collection of papers by recognized experts in the fields of bat ecology and wildlife monitoring techniques. In the first paper, Thomas Kunz provides an excellent review of historical techniques used for censusing bats and discusses many of the problems and biases associated with these techniques. He also describes some of the recent advances in counting techniques, including ultrasonic detection and identification systems and computerized thermal imaging procedures.

The next few papers describe techniques and potential difficulties in counting specific groups of bats in a wide variety of conditions. Brazilian free-tailed bats (*Tadarida brasiliensis*) are generally found in very large colonies in relatively few sites, and Gary McCracken describes several methods for counting this species. Merlin Tuttle describes possible ways of monitoring bat species that hibernate in caves and mines, and he cautions about the various problems and biases that can affect these counts. Foliage-roosting, solitary bats in the genus *Lasiurus* present a different set of monitoring problems and responses to habitat change that are discussed by Timothy Carter, Michael Menzel, and David Saugey. Ruth Utzurrum and three co-authors describe counting methods that have been used with flying foxes in the genus *Pteropus* in U.S. territories in the Mariana Islands and Samoa in the South Pacific, and they report current population trends of these species. Population trends and the current status of the three species of pollinating bats in the southwestern U.S. are the subject of the paper by Theodore Fleming and co-authors. Michael Bogan and co-authors present data on the western bats that use crevices or cavities for roost sites. This group of 25 species is generally underrepresented in counts because of difficulties in locating roosts or observing bats within roosts. Rare bats in the bottomland hardwood forests of the southeast, discussed by Mary Kay Clark, present similar censusing problems. Bat species that use buildings as roost sites pose unusual monitoring conditions, as described by Thomas Kunz and R. Scott Reynolds. The longest paper (109 pages) in Part 1 is a summary and analysis of the USGS bat population database by Laura Ellison and co-authors. This paper provides a basic description of the data base that is accessible on the internet at http://www.fort.usgs.gov/products/data/bpd/bpd.asp. Bat population trend analyses are provided in 66 pages of tables for all species with adequate counts.

Although the title of the publication specifically refers to bat populations of the U.S. and its territories, Allyson Walsh and co-authors describe the United Kingdom National Bat Monitoring Programme. However, this paper is valuable as a reminder that issues of declining bat populations are not restricted to the United States, and it describes the use of transect and point-count techniques for counting dispersed bats. John Sauer reviews national monitoring programs for other wildlife groups, particularly birds. Although the list of key words for this paper includes "bats," bats are never mentioned elsewhere in the text or abstract of this paper. While Sauer provides a valuable, critical review of the difficulties of monitoring other wildlife groups, he missed the opportunity to relate these observations to the problems presented in monitoring bats.

Part II is a series of reports from a workshop on monitoring bat populations. The major topic areas include: (a) analytical and methodological problems in assessing bat numbers and trends; (b) categorizing bat species, species groups, and regions for priorities in establishing monitoring programs; and (c) a review of existing information and monitoring programs. Each report includes an issue description and rationale, and means to resolve the critical uncertainties surrounding the issue.

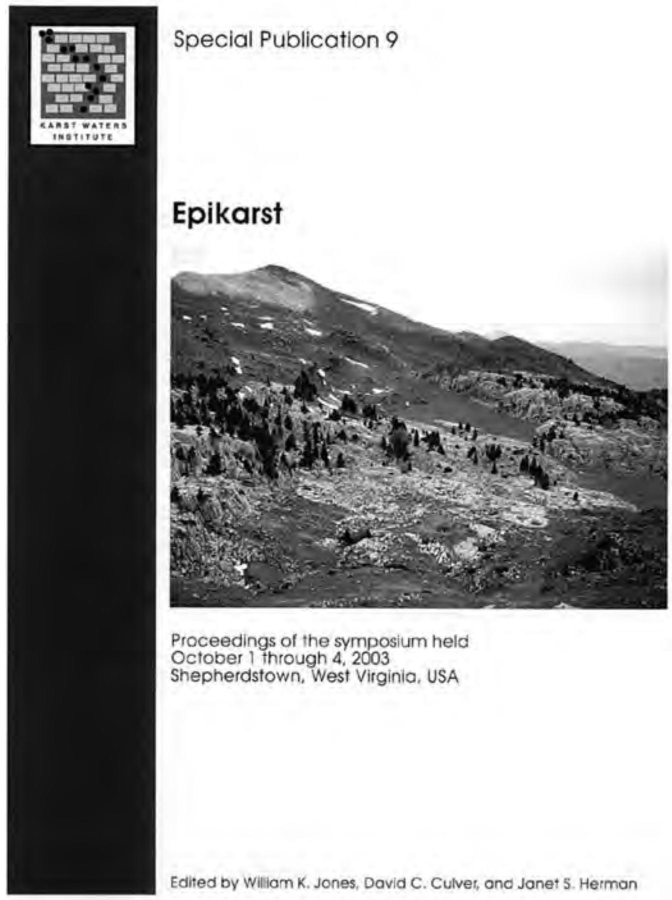
Five major conclusions and recommendations are drawn from the workshop reports: (1) the natural history of bats poses many challenges to population monitoring; (2) major improvements are needed in methods of estimating numbers of bats; (3) objectives and priorities of bat population monitoring need careful consideration; (4) monitoring bat populations on a broad scale will require strong commitment and well-planned sampling designs; and (5) information exchange among bat specialists should be enhanced.

In conclusion, this book provides a valuable resource covering a wide range of bat species and monitoring issues. I recommend it highly for anyone engaged in bat monitoring or having an interest in this field.

Book reviewed by: Thomas R. Strong, Visiting Chief Scientist, National Cave and Karst Research Institute, 1400 University Drive, Carlsbad, NM 88220, (tstrong@cemrc.org) November, 2004.

EPIKARST

William Jones, David Culver, and Janet Herman, eds., Karst Waters Institute Special Publication 9 (2004). Charles Town, WV, 160 p. softbound. ISBN 0-9640258-8-4. $32 (US) plus shipping. Order on-line at http://www.karstwaters.org. or from Publication Sales, c/o E.L. White, 4538 Miller Rd., Petersburg, PA 16669-9211, publications@karstwaters.org.



Epikarst: Special Publication 9 of the Karst Waters Institute includes the proceedings of a four-day meeting held in Shepherdstown, WV, in October 2003. The meeting brought together an interdisciplinary group of hydrologists, biologists, and geoscientists in an effort to better understand and define epikarst. In any other terrain the "epikarst" might simply be described as the regolith: the weathered top of the rock zone. However, in karst this weathered bedrock zone takes on a special meaning. Hydrologically, the epikarst often represents an upper water-bearing zone (the subcutaneous zone), which may be linked to solutionally enlarged fissures and conduits below. Its boundaries were not well defined or agreed upon either before or after the meeting. The result is a publication unlike any of its kind: a collection of papers that addresses the unique hydrologic, geomorphic, and ecologic characteristics of the epikarst. Applied hydrogeologists and ecologists who are interested in karst systems will find this collection of papers to be an invaluable resource.

The meeting proceedings include 21 technical papers, bounded by an editor's introduction and conclusion, and tied together by a common theme: describing the epikarst in the hope of better defining it. The authors represent eight countries, and include some of the world authorities on the topic. Papers describe a number of field sites across the globe, while others are strictly process-based. The text is well organized, beginning with two papers that define the nature of the epikarst zone. Interestingly, several of the papers begin with their own description of the epikarstic zone, all of which are slightly different! Topics address the geochemical evolution and characterization of epikarstic waters, application of stable isotopes, role of contaminant storage and transport, on-site wastewater technologies, and the geomorphic evolution of epikarst. Several papers consider the biota and ecology of the epikarst, with special emphasis on cave drip-water pools supplied by epikarst drainage. All papers are in English, are concise, and appear to be well written and edited. The many photos and diagrams are clear, though some show the fuzziness of being scanned. All photos and graphics are in black and white, with the exception of a series of color graphs linked to one paper.

The editors, who also served as the meeting organizers, hoped to revise the definition of epikarst, stressing that a "common vocabulary, starting with a common definition, is a strong starting point for improved communication across disciplines." An initial working definition presented before the meeting takes on a longer, more complex character after four days. Clearly this is the result of the many specialists and their unique perspectives from diverse fields. An interesting addition to these proceedings is an informal round-table discussion that seeks a refined definition of the epikarst taken after all of the paper presentations. For those who know little about the epikarst, this may be a good starting point.

Reviewed by: Thomas P. Feeney, Department of Geography and Earth Science, Shippensburg University, Shippensburg, PA 17257 (tpfeen@ship.edu), October 2004.

INDEX TO VOLUME 66 OF THE JOURNAL OF CAVE AND KARST STUDIES

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This index covers all articles and abstracts published in volume 66 parts 1, 2, and 3. Selected abstracts from the 2004 Society convention in Marquette, Michigan are included.

The index has three sections. The first is a Keyword index, containing general and specific terms from the title and body of an article. This includes cave names, geographic names, etc. Numerical keywords (such as 1814) are indexed according to alphabetic spelling (Eighteen fourteen). The second section is a Biologic names index. These terms are Latin names of organisms discussed in articles. For articles containing extensive lists of organisms indexing was conducted at least to the level of Order. The third section is an alphabetical Author index. Articles with multiple authors are indexed for each author, and each author's name was cited as given.

Citations include only the name of the author, followed by the page numbers. Within an index listing, such as "Bats", the earliest article is cited first.

KEYWORD INDEX

BIOLOGIC NAMES INDEX

AUTHOR INDEX

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