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GEOGRAPHICAL AND GEOLOGICAL DATA FROM CAVES AND MINES INFECTED WITH WHITE-NOSE SYNDROME (WNS) BEFORE SEPTEMBER 2009 IN THE EASTERN UNITED STATES

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Abstract: Since 2006, a white fungus named *Geomyces destructans* has been observed on the muzzles, noses, ears, and (or) wings of bats in the eastern United States, and bat colonies that are infected with this fungus have experienced dramatic incidences of mortality. Although it is not exactly certain how and why these bats are dying, this condition has been named white-nose syndrome (WNS). WNS appears to have spread from an initial infection site at a cave that is connected to a commercial cave in New York, and by the end of August 2009 was identified in at least 74 other sites in the eastern United States. Although detailed geographical and geological data are limited, a review of the available data shows that sites infected with WNS before September 2009 include both natural caves and mines. These infected sites extend from New Hampshire to Virginia, and known site elevations range from 84 to 2693 feet above sea level. In terms of geological setting, the infected sites include sedimentary, metamorphic, and igneous rocks of ages ranging from Precambrian to Jurassic. However, by the end of August 2009, no infected sites had been identified in strata of Mississippian, Cretaceous, or Triassic age. Meteorological data are sparse, but most of the recorded air temperatures in the known WNS-infected caves and mines range from 0 to 13.9 °C, and humidity measurements range from 68 to 100 percent. Although it is not certain which environmental parameters are important for WNS, it is hoped that the geographical and geological information presented in this paper will inform and clarify some of the debate about WNS, lead to greater understanding of the environmental parameters associated with WNS, and highlight the paucity of scientific data from caves in the eastern United States.

Introduction

In 2006 and 2007, unusually great numbers of emaciated and dead bats were discovered in several caves in Schoharie County (New York), yet studies of these bats revealed no obvious disease-causing parasites, no viral pathogens, and no unusual bacteriological problems (Blehert et al., 2009). However, a percentage of these bats was characterized by a notable decrease in body fat. In addition, many of these bats exhibited erratic behavior such as a shift in roosting locations closer to cave entrances, out-of-season emergence from hibernation, and flying outside during the daytime. Furthermore, the bats were characterized by the presence of a visually striking white fungus growing on their muzzles, noses, ears, and (or) wings. This condition was named white-nose syndrome (WNS) and all of the sites where this condition has appeared have experienced dramatic incidences of bat mortality. Blehert et al. (2009), for example, have calculated bat population declines in excess of 75 percent at WNS-infected sites. Although exact numbers are difficult to determine, it is estimated that more than 1 million bats may have died from WNS as of December 2009 (Sleeman, 2009). These population declines are likely to have far-reaching ecological consequences because bats play critical roles in insect population control, plant pollination, and seed dissemination (Ransome, 1990; Pierson, 1998; Dumont, 2003; Jones and Rydell, 2003; von Helversen and Winter, 2003).

The white fungus associated with WNS is a newly identified fungus named *Geomyces destructans* (Gargas et al., 2009). *Geomyces* is a genus of terrestrial saprophytes that has been identified in soils in many places throughout the world, usually in colder regions such as northern Europe, Russia, Canada, and the South Orkney Islands of the Antarctic region (e.g., Traaen, 1914; Carmichael, 1962; Sigler and Carmichael, 1976; Van Oorschot, 1980; Marshall, 1998; Rice and Currah, 2006; Kochkina et al., 2007). However, *Geomyces* is a very diverse genus, and it has also been reported from Costa Rica (Sigler and Carmichael, 1976).

The species *Geomyces destructans* has spores with a distinctive and unusual hook shape (Gargas et al., 2009). Until recently, *G. destructans* had been identified only at the WNS-infected sites in the eastern North America (Blehert et al., 2009). However, in March 2009 *G. destructans* was identified on a bat near Périgueux, France (Puechmaille et al., 2010), and subsequently the fungus has been identified at other sites in Europe (Wibbelt et al., 2010). In contrast with the sites in North America, the occurrences of *G. destructans* in Europe do not appear to be associated with dramatic incidences of bat mortality.

In North America, *Geomyces destructans* is seen on sick bats but not on healthy bats. The fungus invades living skin tissue of bats, but does not typically cause inflammation or an immune response (Meteyer et al., 2009; Reichard and Kunz, 2009). Other than attacking skin tissue, it is not yet known if the fungus affects bats in other ways. In fact, it is not yet known whether *G. destructans* is the primary cause of the unusual bat mortality in North America or whether the fungus is simply a secondary infection. However, at the time of this writing, all isolates of *G. destructans* in North America have been genetically identical within the marker genes examined. This observation suggests that the fungus in North America probably disseminated from a point source.

Since it first appeared in New York, *Geomyces destructans* has spread rapidly among bats in the eastern North America. Bats infected with the fungus were first photo-documented on 16 February 2006 in a cave that is connected to Howe Caverns, which are commercial caverns in Schoharie County, New York (Blehert et al., 2009). During early 2007, bats infected with *G. destructans* were discovered in other caves in New York. During January to March 2008, *G. destructans* was identified on hibernating bats at several other locations in New York, as well as locations in Vermont, Massachusetts, and Connecticut. During November 2008, *G. destructans* appeared on bats in Pennsylvania (Mifflin County). During December 2008 to February 2009, the fungus appeared on bats in New Hampshire, New Jersey, and new sites in New York, Vermont, Connecticut, and Pennsylvania. The fungus also appeared in West Virginia (Pendleton County) during January 2009 and in Virginia (Bath County) during February 2009. During March and April 2009, the fungus appeared on bats in southwestern Virginia (Giles County) and at new sites in New York, Connecticut, and Pennsylvania. During May and August 2009, the fungus appeared on bats at new sites in Virginia. After August 2009, very few records of new WNS occurrences are available, other than statements that document the appearance of WNS in previously uninfected counties and states.

According to Blehert et al. (2009) and Turner and Reeder (2009), bat species infected with the fungus include the big brown bat (*Eptesicus fuscus*), the eastern small-footed bat (*Myotis leibii*), the little brown bat (*Myotis lucifugus*), the northern long-eared bat (*Myotis septentrionalis*), the Indiana bat (*Myotis sodalis*), and the tricolored bat (*Perimyotis subflavus*). It is not known if the fungus affects other animals besides bats.

Although studies of *Geomyces destructans* are still in their infancy, there is great interest in how the fungus has spread in the past, and concern about where and how the fungus might spread in the future. Preliminary studies suggest that the fungus may be transmitted from bat to bat, and that the fungus may also be transmitted as an unwanted hitchhiker upon humans, clothing, and caving gear (Sleeman, 2009; Turner and Reeder, 2009). Studies by Blehert et al. (2009) have shown that *G. destructans* prefers cold temperatures for growth, that optimal temperatures for fungus growth are between 5 °C and 10 °C, and that the fungus does not grow at temperatures greater than approximately 20 °C. Anecdotal field evidence suggests that the fungus may prefer relatively high humidity, although no laboratory studies on this topic have been published yet.

At present, it is not certain which environmental parameters are important for predicting the spread of *Geomyces destructans* and WNS. This uncertainty is due, in part, to the lack of a publicly available list of WNS-infected sites and the paucity of detailed scientific data from caves and mines in the United States. In order to improve understanding of the environmental parameters associated with WNS, this paper presents a chronology of where and when WNS appeared in the United States prior to September 2009 (Table 1). This paper then presents (in stratigraphic order from oldest to youngest) a series of short paragraphs that summarize geological and meteorological data from each of the infected sites. These paragraphs are followed by a discussion of observations regarding the distribution of WNS with respect to various geographical, geological, and meteorological parameters. At this early stage of investigation, it is difficult to know which data may or may not be important with regards to WNS. Nevertheless, it is hoped that the information presented in this paper will inform and clarify the debate about WNS, and lead to greater understanding of the environmental parameters associated with WNS.

GEOLOGIC SETTINGS OF CAVES AND MINES INFECTED WITH WNS

By the end of August 2009, 75 sites were known to be infected with WNS, and 42 of these sites were located within the Appalachian Basin (Table 1, Figs. 1 and 2). This basin extends from New York and Ontario in the north to Alabama in the south, and the basin contains strata that range in age from Precambrian to Permian. As shown in Figure 3, the Precambrian rocks (older than ~542 Ma) consist of various igneous, metamorphic, and clastic sedimentary lithologies. The Lower Cambrian strata (~542 to 513 Ma) are predominantly sandstone and mudstone. The Middle Cambrian through Middle Ordovician strata (~513 to 461 Ma) are predominantly carbonate. The Upper Ordovician through lower Silurian strata (~461 to 428 Ma) are predominantly sandstone and mudstone. The upper Silurian through Lower Devonian strata (~428 to 398 Ma) are predominantly carbonate. The Middle Devonian to Upper Devonian strata (~398 to 359 Ma) are predominantly sandstone and mudstone. The Mississippian strata (~359 to 318 Ma) are predominantly carbonate, and the Pennsylvanian and Permian strata (~318 to 251 ma) are predominantly sandstone, mudstone, and coal. Several regional unconformities are present in the Appalachian Basin (Fig. 3). Of particular note for this paper are the Ordovician Owl Creek Unconformity ("Knox Unconformity"), which caps carbonate strata of the Cambrian-Ordovician Knox Group, and the Devonian Wallbridge Unconformity, which caps carbonate strata of the Silurian-Devonian Helderberg Group. Both of these unconformities are overlain in most places by clean, quartz sandstone (Ordovician St. Peter Sandstone, Devonian Oriskany Sandstone).

Thirty-three of the 75 sites that were known to be infected with WNS before September 2009 are located to the north and east of the Appalachian Basin (Fig. 1). This region to the north and east of the Appalachian Basin consists of igneous rocks and various metamorphic rocks that may be correlated with age-equivalent sandstone, mudstone, limestone, and dolomite in the Appalachian Basin. In addition, this region beyond the Appalachian Basin contains numerous small rift basins that formed during the opening of the Atlantic Ocean (e.g., Benson, 1992; Weems and Olsen, 1997). In the United States, these rift basins contain mostly sandstone and mudstone of Triassic and Jurassic age (~226 to 190 Ma).

Geographical and geological data from each of the infected sites are described below in stratigraphic order from oldest to youngest. The descriptions include information on hydrology and meteorology, where such information is available. The descriptions also include any available information on cave sediment/soil, because *Geomyces* are terrestrial saprophytes that are known to reside in soils. Finally, each description provides information on when and who reported the WNS infection at that site.

Precambrian-Cambrian Igneous and Metamorphic Rocks

Nine of the sites infected with WNS before September 2009 are located in Precambrian and (or) Cambrian igneous and metamorphic rocks (Fig. 3). These sites are present in New York, New Jersey, and Vermont. Seven of these sites are mines, and two of these sites are caves. Three of the sites are located in granite or gneiss (W Mountain Cave, Hibernia Mine, Mount Hope Mine), three of the sites are located in meta-volcanic rocks (Barton Hill Mine, Fisher Hill Mine, Fahnestock State Park Mine), and three of the sites are located in meta-sedimentary rocks (Main Graphite Mine, Williams Cave, Bridgewater Mines).

<u>W Mountain Cave, Franklin County, NY</u> (Site 71 on Fig. 1):

Note: Initial reports erroneously placed this cave in Clinton County (Carroll, 1972b, 1974), but subsequent reports indicate that the cave is located in Franklin County (Cole, 1974; Carroll, 1997, 2009; Porter, 2009c).

Cave Map: Map dated 1973 in Carroll (2009).

Stratigraphy: Precambrian granitic gneiss (Cole, 1974; Carroll, 1997, 2009; Porter, 2009c).

Cave Meteorology: Carroll (2009) reported temperatures of 5.0 to 5.6 °C) 100 feet inside the cave, and temperatures of 2.8 to 3.3 °C 300 feet inside the cave.

WNS Infection Report: Anonymous (2009a) and Porter (2009c). In addition, a WNS infection in Clinton County (NY) was confirmed by the U.S. Geological Survey (USGS) National Wildlife Health Center (NWHC) Quarterly Mortality Reports, 2009, Quarter 1. These USGS reports are available online at http://www.nwhc.usgs.gov/publications/quarterly_reports/.

<u>Hibernia Mine, Morris County, NJ</u> (Site 52 on Fig. 1):

Mine Map: Undated map in Sims (1953).

Stratigraphy: Precambrian granite (Bayley, 1910; Sims, 1953; McManus and Esher, 1971).

Mined Commodity: Iron, mined from approximately 1722 to 1916.

Mine Meteorology: McManus and Escher (1971) reported an air temperature gradient ranging from 0 to 6 °C along a horizontal mine shaft 350 to 650 meters from the entrance. McManus (1974) reported relative humidity of 99 to 100 percent and average air temperature ranging from 1.39 to 4.38 °C.

WNS Infection Report: USGS NWHC (Quarterly Mortality Reports, 2008, Quarter 4).

<u>Mount Hope Mine, Morris County, NJ</u> (Site 53 on Fig. 1):

Mine Map: Undated map in Sims (1953).

Stratigraphy: Precambrian oligoclase-quartz-biotite gneiss enclosed within granite (Bayley, 1910; Sims, 1953; James and Dennen, 1962; Ross, 1982).

Mined Commodity: Iron, mined from approximately 1710 to at least 1959.

WNS Infection Report: USGS NWHC (Quarterly Mortality Reports, 2008, Quarter 4).

<u>Barton Hill Mine, Essex County, NY</u> (Site 43 on Fig. 1):

Mine Map: None published.

Stratigraphy: Magnetite ore in Precambrian meta-volcanic rocks (Kemp, 1898; Newland, 1921; Britzke et al., 2006).

Mined Commodity: Iron, mined during the mid-1800s.

WNS Infection Report: Anonymous (2008), Porter (2008a), and Bat Conservation and Management, Inc. (http://www.batmanagement.com/wns/WNSphotoalbum1/index.html). In addition, a WNS infection in Essex County (NY) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

<u>Fisher Hill Mine, Essex County, NY</u> (Site 44 on Fig. 1):

Mine Map: None published.

Stratigraphy: Magnetite ore in Precambrian meta-volcanic rock (Kemp, 1898; Newland, 1921).

Mined Commodity: Iron, mined periodically from 1845 to 1971

WNS Infection Report: Porter (2008a). In addition, a WNS infection in Essex County (NY) was confirmed by

Table 1. List of sites infected with WNS before September 2009 in the eastern United States.

Site Number on Figures 1 and 2	Cave or Mine Name	Location		Stratigraphic Age	Stratigraphic Name	Elevation		WNS First Identified	
		State	County			m	ft	Month	Year
1	Howe Caverns	N.Y.	Schoharie	Silurian-Devonian	Helderberg Group	319	1047	February	2006
2	Barytes Cave	N.Y.	Schoharie	Silurian-Devonian	Helderberg Group	244	799	March	2006
3	Schoharie Caverns	N.Y.	Schoharie	Silurian-Devonian	Helderberg Group	304	997	January	2007
4	Gage Caverns	N.Y.	Schoharie	Silurian-Devonian	Helderberg Group	387	1271	March	2007
5	Hailes Cave	N.Y.	Albany	Silurian-Devonian	Helderberg Group	356	1167	March	2007
6	Knox Cave	N.Y.	Albany	Silurian-Devonian	Helderberg Group	401	1315	April	2007
7	Merlin's Cave	N.Y.	Columbia	Ordovician	Stockbridge Group	223	731	December	2007
8	Mass Hole	Mass.	Berkshire	Ordovician	Stockbridge Group	33	108	January	2008
9	Williams Preserve Mine	N.Y.	Ulster	Silurian-Devonian	Helderberg Group	65	214	January	2008
10	Williams Hotel Mine	N.Y.	Ulster	Silurian-Devonian	Helderberg Group	77	253	January	2008
11	mine	Vt.	Windham	…	…	…	…	January	2008
12	Morris Cave	Vt.	Rutland	Ordovician	Stockbridge Group	250	820	January	2008
13	Elizabeth Mine	Vt.	Orange	Devonian	Gile Mountain Formation	356	1167	January	2008
14	…	Vt.	Washington	…	…	…	…	January	2008
15	Glen Park Caves	N.Y.	Jefferson	Ordovician	Trenton Limestone	134	439	January	2008
16	Clarksville Cave	N.Y.	Albany	Devonian	Onondaga Limestone	232	761	February	2008
17	Mitchell's Cave	N.Y.	Montgomery	Cambrian	Little Falls Dolomite	215	705	February	2008
18	Williams Lake Mine	N.Y.	Ulster	Silurian-Devonian	Helderberg Group	81	266	February	2008
19	Bat's Den Cave	Mass.	Berkshire	Cambrian-Ordovician	Stockbridge Group	329	1081	February	2008
20	Old Mine	Mass.	Hampden	Ordovician	Chester Amphibolite	206	675	February	2008
21	Bakers Quarry Cave	Mass.	Berkshire	Cambrian-Ordovician	Stockbridge Group	460	1510	February	2008
22	Red Bat Cave	Mass.	Berkshire	Ordovician	Stockbridge Group	457	1500	February	2008
23	mine	Mass.	Franklin	…	…	…	…	February	2008
24	Aeolus Bat Cave	Vt.	Bennington	Ordovician	Stockbridge Group	763	2503	February	2008
25	Benson's Cave	N.Y.	Schoharie	Silurian-Devonian	Helderberg Group	330	1082	March	2008
26	Hell's Wells	N.Y.	Schoharie	Silurian-Devonian	Helderberg Group	298	977	March	2008

Table 1. Continued.

Site Number on Figures 1 and 2	Cave or Mine Name	Location		Stratigraphic Age	Stratigraphic Name	Elevation		WNS First Identified	
		State	County			m	ft	Month	Year
27	Lasell's Hell Hole	N.Y.	Schoharie	Silurian-Devonian	Helderberg Group	367	1203	March	2008
28	Ain't No Catchment Cave	N.Y.	Schoharie	Silurian-Devonian	Helderberg Group	277	910	March	2008
29	South Bethlehem Cave	N.Y.	Albany	Silurian-Devonian	Helderberg Group	66	216	March	2008
30	Martin Mine	N.Y.	Ulster	Silurian-Devonian	Helderberg Group	74	244	March	2008
31	unnamed cave	Conn.	Litchfield	Cambrian-Ordovician	Stockbridge Group	101	331	March	2008
32	…	Conn.	Hartford	…	…	…	…	March	2008
33	Williams Cave	Vt.	Bennington	Precambrian-Cambrian	Nassau Formation	564	1850	March	2008
34	Skinnner Hollow Cave	Vt.	Bennington	Ordovician	Stockbridge Group	585	1920	March	2008
35	Main Graphite Mine	N.Y.	Warren	Precambrian	Metasedimentary rock	486	1596	March	2008
36	Greeley Mine	Vt.	Windsor	Ordovician	Serpentinite	272	892	March	2008
37	McFails Cave	N.Y.	Schoharie	Silurian-Devonian	Helderberg Group	375	1231	April	2008
38	Nature's Way Cave	N.Y.	Albany	Silurian-Devonian	Helderberg Group	261	856	April	2008
39	Shindle Mine	Pa.	Mifflin	Silurian	Tuscarora Sandstone	389	1277	November	2008
40	Hasbrouck Mine	N.Y.	Ulster	Silurian-Devonian	Helderberg Group	26	84	December	2008
41	Indian Oven Cave	N.Y.	Columbia	Cambrian-Ordovician	Stockbridge Group	300	984	December	2008
42	Surprise Cave	N.Y.	Sullivan	Silurian-Devonian	Helderberg Group	221	726	December	2008
43	Barton Hill Mine	N.Y.	Essex	Precambrian	Metavolcanic rock	455	1493	December	2008
44	Fisher Hill Mine	N.Y.	Essex	Precambrian	Metavolcanic rock	499	1638	December	2008
45	cave	N.Y.	Onondaga	…	…	…	…	January	2009
46	…	N.Y.	Hamilton	…	…	…	…	January	2009
47	cave	N.Y.	Washington	…	…	…	…	January	2009
48	Bridgewater Mines	Vt.	Windsor	Cambrian	Pinney Hollow Formation	361	1184	January	2009
49	mine	N.H.	Merrimack	…	…	…	…	January	2009
50	mine	N.H.	Grafton	…	…	…	…	January	2009
51	Fahnestock State Park Mine	N.Y.	Putnam	Precambrian	Amphibolite	305	1000	January	2009

Table 1. Continued.

Site Number on Figures 1 and 2	Cave or Mine Name	Location		Stratigraphic Age	Stratigraphic Name	Elevation		WNS First Identified	
		State	County			m	ft	Month	Year
52	Hibernia Mine	N.J.	Morris	Precambrian	Granite	262	861	January	2009
53	Mount Hope Mine	N.J.	Morris	Precambrian	Granite	244	800	January	2009
54	Pahaquarry Copper Mine	N.J.	Warren	Silurian	Bloomsburg Red Beds	168	552	January	2009
55	Dunmore Mine	Pa.	Lackawanna	Pennsylvanian	Llewellyn Formation	316	1036	January	2009
56	Shickshinny mine	Pa.	Luzerne	Pennsylvanian	Llewellyn Formation	260	853	January	2009
57	Hamilton Cave	W.Va.	Pendleton	Silurian-Devonian	Helderberg Group	640	2100	January	2009
58	Trout Cave	W.Va.	Pendleton	Silurian-Devonian	Helderberg Group	622	2040	January	2009
59	Cave Mountain Cave	W.Va.	Pendleton	Silurian-Devonian	Helderberg Group	683	2240	February	2009
60	Breathing Cave	Va.	Bath	Silurian-Devonian	Helderberg Group	716	2350	February	2009
61	Alexander Caverns	Pa.	Mifflin	Ordovician	Trenton Limestone	194	636	February	2009
62	Roxbury Mine	Conn.	Litchfield	Ordovician	Mine Hill Granite Gneiss	215	705	February	2009
63	Brandon Mine	Vt.	Rutland	Cambrian	Winooski Dolomite	125	410	February	2009
64	Single X Cave	N.Y.	Schoharie	Silurian-Devonian	Helderberg Group	180	590	March	2009
65	New-Gate Prison Mine	Conn.	Hartford	Jurassic	Portland Formation	293	960	March	2009
66	Carbondale mine #1	Pa.	Lackawanna	Pennsylvanian	Llewellyn Formation	137	450	March	2009
67	Carbondale mine #2	Pa.	Lackawanna	Pennsylvanian	Llewellyn Formation	342	1123	March	2009
68	Seawra Cave	Pa.	Mifflin	Silurian-Devonian	Helderberg Group	342	1123	March	2009
69	Aitkin Cave	Pa.	Mifflin	Ordovician	Trenton Limestone	220	723	March	2009
70	Clover Hollow Cave	Va.	Giles	Ordovician	Witten Limestone	220	723	March	2009
71	W Mountain Cave	N.Y.	Franklin	Precambrian	Granitic Gneiss	744	2440	April	2009
72	Saltpeter Cave	W.Va.	Pendleton	Silurian-Devonian	Helderberg Group	821	2693	May	2009
73	Newberry-Bane Cave	Va.	Bland	Ordovician	Witten Limestone	527	1729	May	2009
74	Hancock Cave	Va.	Smyth	Ordovician	Witten Limestone	780	2560	May	2009
75	Endless Caverns	Va.	Rockingham	Ordovician	New Market & Lincolnshire Ls.	358	1175	August	2009

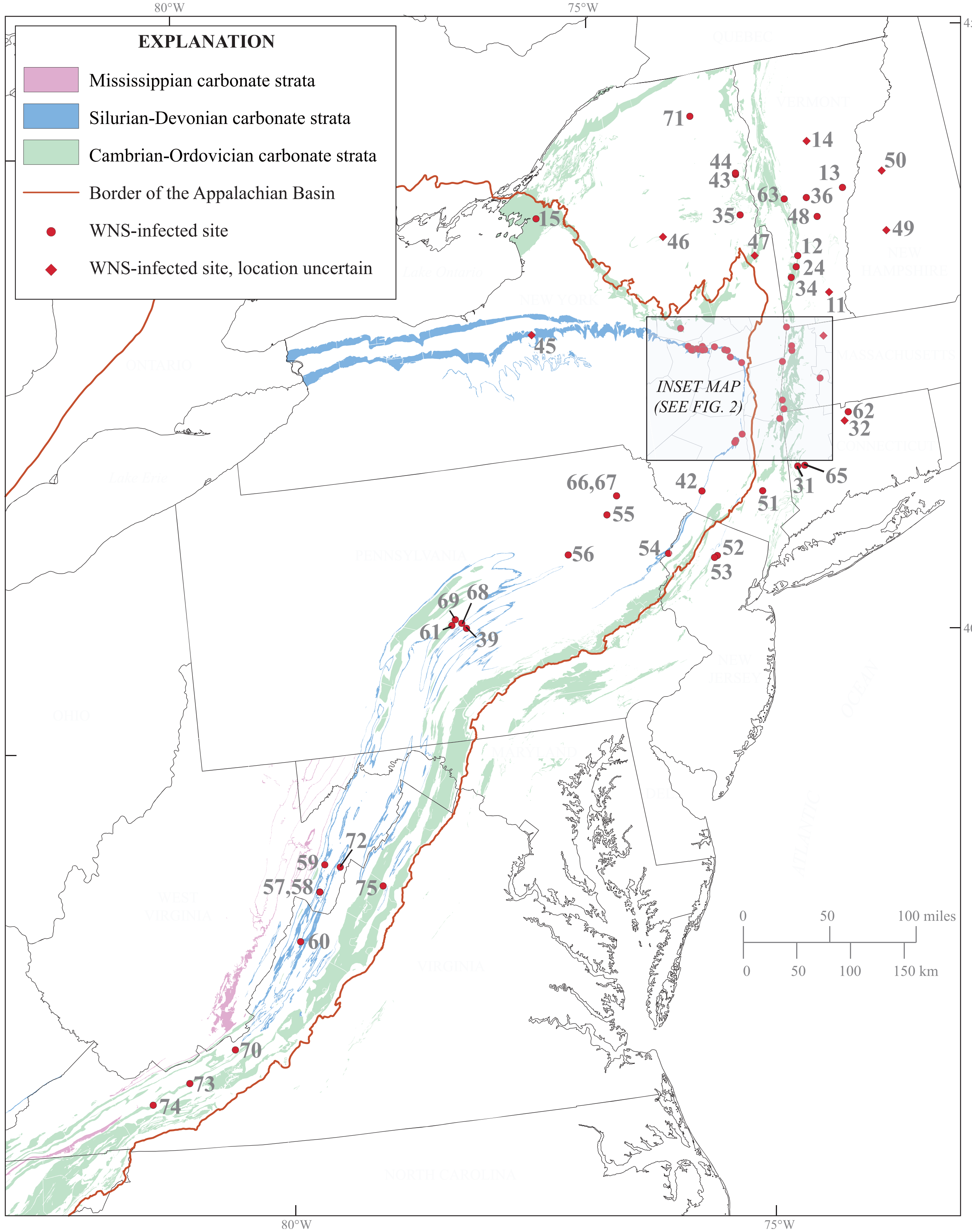

Figure 1. Map showing the locations of sites infected with white-nose syndrome (WNS) before September 2009 in the eastern United States. Sites are numbered in the approximate order in which WNS infection was detected, and the key to location numbers is given in the first column of Table 1. Outline of the Appalachian Basin is from Swezey (2009). Geological data were derived from the U.S. Geological Survey (USGS) Mineral Resources On-Line Spatial Data, which are available online at http://tin.er.usgs.gov/geology/state/ [accessed September 15, 2010].

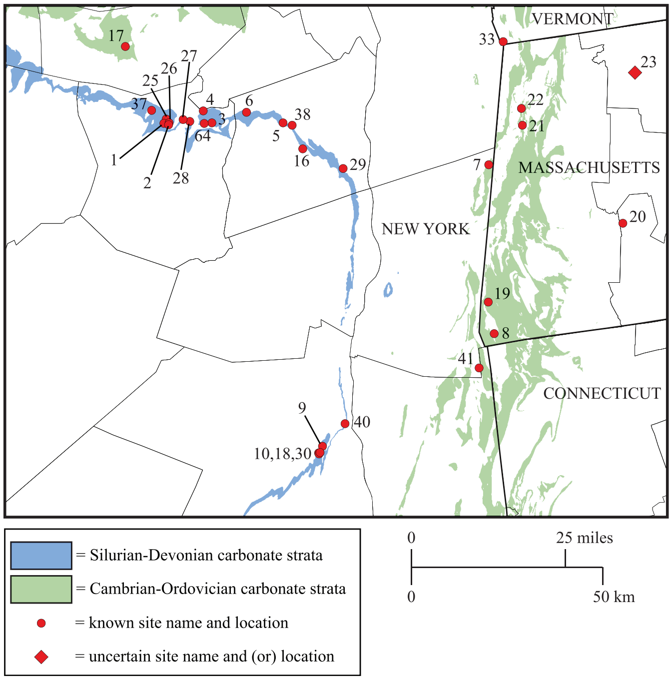

Figure 2. Detailed map showing the locations of sites infected with WNS before September 2009 in part of the northeastern United States (map location is shown on Fig. 1). Sites are numbered in the approximate order in which WNS infection was detected, and the key to location numbers is given in the first column of Table 1. Geological data were derived from the USGS Mineral Resources On-Line Spatial Data, which are available online at http://tin.er.usgs.gov/geology/state/ [accessed September 15, 2010].

the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

<u>Abandoned mine, Fahnestock State Park, Putnam County, NY</u> (Site 51 on Fig. 1):

Mine Map: None published.

Stratigraphy: Precambrian amphibolite.

Mined Commodity: Iron, mined during the 1800s.

WNS Infection Report: Fred Koontz (http://teatown-blog.wordpress.com/2009/04/22/bats-threatened/). In addition, a WNS infection in Putnam County (NY) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

<u>Main Graphite Mine, Warren County, NY</u> (Site 35 on Fig. 1):

Mine Map: None published.

Stratigraphy: Precambrian graphite-rich schist (Kemp and Newland, 1897; Craytor, 1969).

Mined Commodity: Graphite, mined from 1887 to 1921.

Hydrology: Lower levels of the mine are filled with water, and patches of ice are present throughout the year.

Mine Meteorology: Patches of ice are present throughout the year.

WNS Infection Report: Porter (2008a) and Blehert et al. (2009).

<u>Williams Cave, Bennington County, VT</u> (Site 33 on Fig. 2):

Cave Map: Map dated 1999 in Keough (2000).

Stratigraphy: Schist of the Precambrian to Cambrian Nassau Formation (Porter, 1968; Keough, 2000; Ratcliffe et al., 2010, in prep.). According to Ratcliffe (1974), the Nassau Formation is stratigraphically equivalent to the Cambrian Everett Formation (depicted in Fig. 5).

WNS Infection Report: Porter (2008a).

<u>Bridgewater Mines, Windsor County, VT</u> (Site 48 on Fig. 1):

Mine Map: None published.

Stratigraphy: Schist of the Cambrian Pinney Hollow Formation (Hitchcock et al., 1861; Perry, 1929; Ratcliffe, 1994).

Mined Commodity: Gold, mined from 1851 to 1855.

WNS Infection Report: Anonymous (2009a,b). In addition, a WNS infection in Windsor County (VT) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

Cambrian-Ordovician Carbonate Strata Below the Knox Unconformity

Twelve of the sites infected with WNS before September 2009 are located in Cambrian-Ordovician carbonate strata below the Knox Unconformity (Figs. 3 and 4). These sites are present in New York, Vermont, Massachusetts, and Connecticut. One of these sites is a mine, and 11 of these sites are caves. All of these sites are located in limestone, dolomite, or marble of the Middle Cambrian-Middle Ordovician Stockbridge Group (Fig. 4) or equivalent strata (Bat's Den Cave, Mass Hole, Bakers Quarry, Red Bat, Indian Oven Cave, Merlin's Cave, Mitchell's Cave, Brandon Mine, Morris Cave, Aeolus Bat Cave, Skinner Hollow Cave, and an unnamed cave in Litchfield County). Although these Middle Cambrian-Middle Ordovician carbonate rocks occupy a stratigraphic position immediately below the Knox Unconformity, the WNS-infected caves are located in an area where schist has been thrust over the carbonate rocks (Fig. 5), and the carbonate rocks have experienced some metamorphism. Estimates for the age of the schist range from Precambrian to Ordovician.

<u>Bat's Den Cave, Berkshire County, MA</u> (Site 19 on Fig. 2):

Cave Map: Map dated 1991 in Plante (1991).

Stratigraphy: Cambrian-Ordovician Stockbridge Formation (Hauer, 1969; Plante, 1991, 1992), as shown in Figure 5.

Cave Meteorology: Veilleux (2007) reported air temperatures ranging from 4.5 to 8.3 °C.

WNS Infection Report: Porter (2008a) and supporting online material for Blehert et al. (2009).

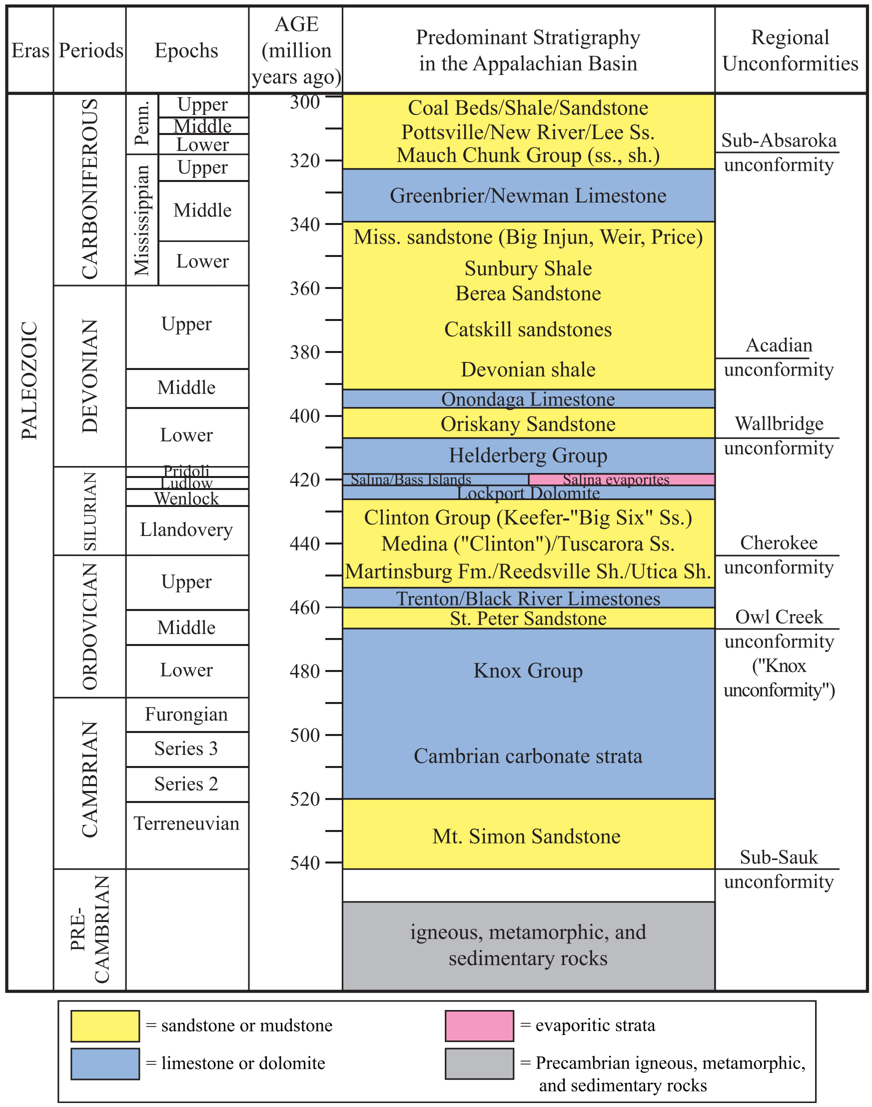

Figure 3. Schematic stratigraphy of the Appalachian Basin in the eastern United States, and some common stratigraphic names used in the basin (modified from Swezey, 2002). Time scale is from Gradstein et al. (2004). Penn. = Pennsylvanian; Sh. = Shale; Ss. = Sandstone; Miss. = Mississippian.

Mass Hole, Berkshire County, MA (Site 8 on Fig. 2):

Cave Map: Map dated 2008 in Goodman (2009).

Stratigraphy: Cambrian-Ordovician Stockbridge Formation (Berkshire Diggers and the Rockeaters, 2008; Goodman, 2009; Hackley, 2009).

Hydrology: The cave contains a stream and waterfalls.

Cave Sediments: Breakdown blocks in all of the major passages, and one room contains a lot of mud.

WNS Infection Report: Berkshire Diggers and the Rockeaters (2008) and Anonymous (2009a).

Bakers Quarry Cave, Berkshire County, MA (Site 21 on Fig. 2):

Cave Map: Map dated 1990 in Plante (1992).

Stratigraphy: Ordovician Shelburne Marble (Fig. 4) of the Cambrian-Ordovician Stockbridge Group (Barr, 1958; Anonymous, 1960; Hauer, 1969; Plante, 1992).

Hydrology: A stream flows in the cave entrance and along the most of the main passage.

WNS Infection Report: Porter (2008a).

Red Bat Cave, Berkshire County, MA (Site 22 on Fig. 2):

Cave Map: Undated map in Hauer (1969).

Stratigraphy: Cambrian-Ordovician Stockbridge Group (Davis and Palmer, 1959; Hauer, 1969).

WNS Infection Report: Porter (2008a).

Indian Oven Cave, Columbia County, NY (Site 41 on Fig. 2):

Cave Map: Undated map in van Beynen and Febbroriello (2006).

Stratigraphy: Cambrian-Ordovician Stockbridge Formation (Fisher, 1954; Seigel, 1957; van Beynen and Febbroriello, 2006). At this site, the Stockbridge Formation is

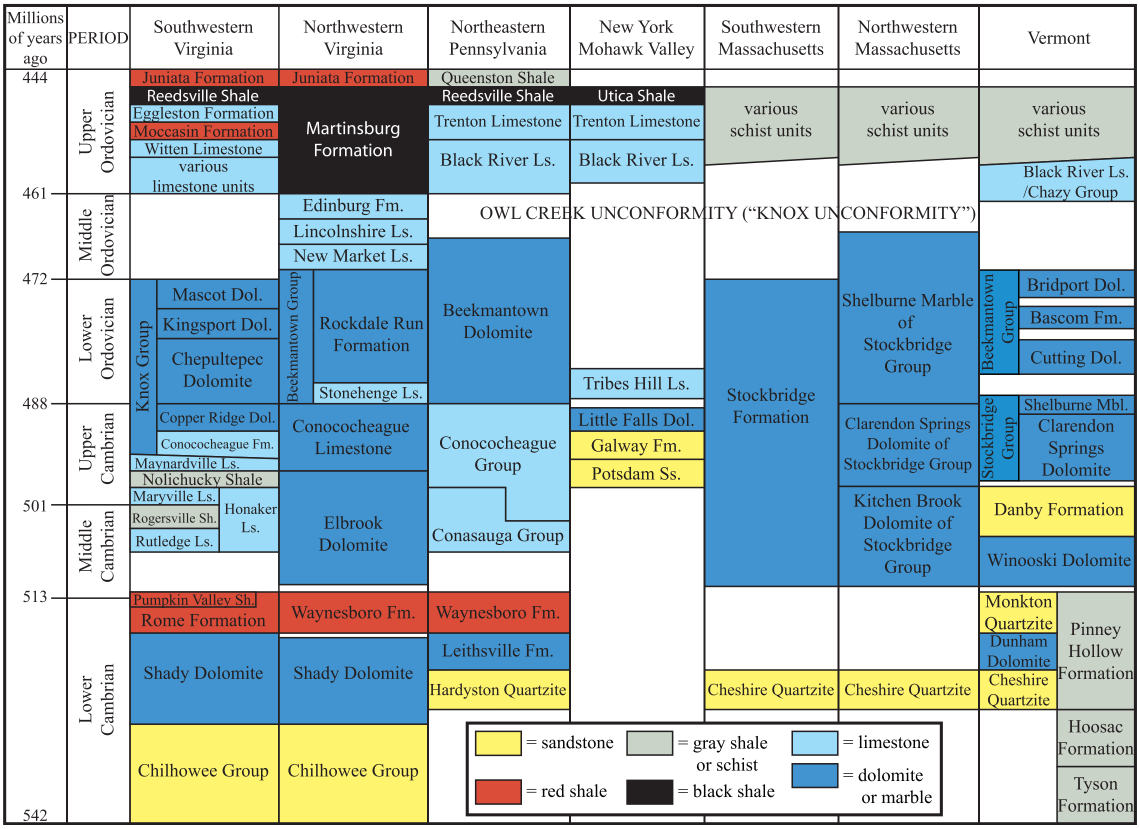

Figure 4. Cambrian through Ordovician strata in selected regions of the eastern United States (modified from Rader and Biggs, 1976, p. 6–25; Le Van and Rader, 1983; Read, 1989; Ratcliffe, 1994; Swezey, 2002; Landing, 2007; Ryder et al., 2008, 2009). Time scale is from Gradstein et al. (2004). Dol. = Dolomite; Fm. = Formation; Ls. = Limestone; Mbl. = Marble; Sh. = Shale; Ss. = Sandstone.

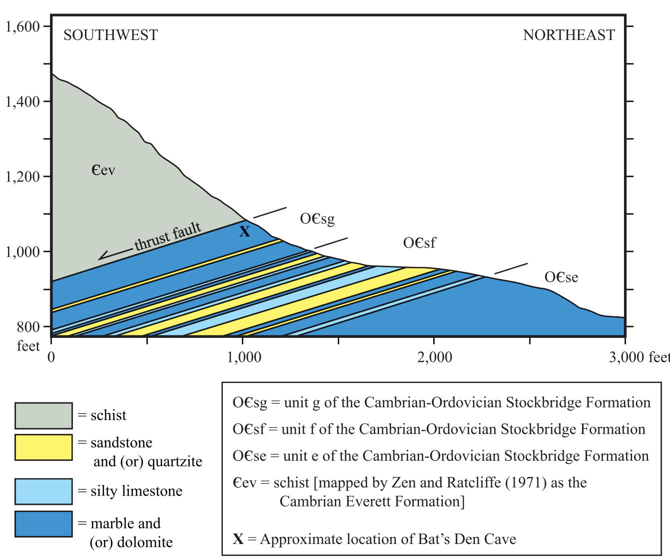

Figure 5. Geologic cross-section in the vicinity of Bat’s Den Cave, Berkshire County, Massachusetts (modified from Plante, 1991; additional data from Zen and Hartshorn, 1966; Zen and Ratcliffe, 1971; Stanley and Ratcliffe, 1985). The vertical scale is in feet relative to sea level.

overlain by the Berkshire Schist, which is thought by Weaver (1957) to be stratigraphically equivalent to the black shale above the Upper Ordovician Trenton Limestone (Fig. 4).

Hydrology: A stream flows along the length of the cave.

Cave Meteorology: Air is reported to have relative humidity >95 percent (van Beynen and Febbroriello, 2006).

WNS Infection Report: Porter (2008a).

<u>Merlin’s Cave (XTC Cave), Columbia County, NY</u> (Site 7 on Fig. 2):

Cave Map: Map dated 2008 in Porter (2009a).

Stratigraphy: Cambrian-Ordovician Stockbridge Formation (Botto, 2007; Dunham, 2007, 2009; Porter, 2009a).

Hydrology: The cave contains streams and waterfalls.

Cave Sediments: Mud is present throughout much of the cave (Dunham, 2010).

Cave Meteorology: Botto (2007) reported air temperature of 8.9 °C in one room.

WNS Infection Report: Porter (2008a).

<u>Mitchell’s Cave, Montgomery County, NY</u> (Site 17 on Fig. 2):

Cave Map: Map dated 1954 in Curl and Peters (1954) and Evans et al. (1979).

Stratigraphy: Upper Cambrian Little Falls Dolomite (Curl and Peters, 1954; Jurgens, 1960; Anonymous, 1965; Porter, 1972), which is equivalent stratigraphically to the middle part of the Stockbridge Group (Fig. 4).

Hydrology: Water is present in some parts of the cave.

WNS Infection Report: Porter (2008a) and Armstrong (2009).

Brandon Mine, Rutland County, VT (Site 63 on Fig. 1):

Mine Map: None published.

Stratigraphy: Middle Cambrian Winooski Dolomite (Clark, 1990), which is equivalent stratigraphically to the lower part of the Stockbridge Group (Fig. 4).

Mined Commodity: Iron, mined during the 1870s, the 1950s, and possible other times.

Mine Meteorology: A data logger recorded nearly constant air temperature of 6.5 °C for four months (Kennedy, 2002).

WNS Infection Report: Dave McDevitt (http://www.nature.org/wherewework/northamerica/states/vermont/science/art27325.html#Feb_11). In addition, a WNS infection in Rutland County (VT) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

Morris Cave, Rutland County, VT (Site 12 on Fig. 1):

Cave Map: Map dated 1978 in Schweyen (1987) and Quick (1994).

Stratigraphy: Cambrian-Ordovician carbonate strata below the Knox Unconformity (Thayer, 1967; Schweyen, 1987; Higham, 1992, 1996; Quick, 1994; Porter, 2009b). The cave is located either in the Upper Cambrian-Lower Ordovician Shelburne Marble of the Stockbridge Group near the contact between the Stockbridge Group and schist that has been thrust over the Stockbridge Group (Thayer, 1967; Schweyen, 1987; Higham, 1992), or in the Upper Cambrian Clarendon Springs Dolomite (Fig. 4), which lies directly below the Shelburne Marble in Vermont (Quick, 1994).

Hydrology: Streams and waterfalls are present within parts of the cave.

Cave Meteorology: Thayer (1967) reported an air temperature of 6.1 °C.

WNS Infection Report: Porter (2008a,b). In addition, a WNS infection in Rutland County (VT) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

Aeolus Bat Cave (Dorset Bat Cave), Bennington County, VT (Site 24 on Fig. 1):

Cave Map: Map dated 1980 in Quick (1994).

Stratigraphy: Cambrian-Ordovician Shelburne Marble of the Stockbridge Group (Scott, 1959; Carroll, 1969; Quick, 1994; Porter, 2009b).

Cave Meteorology: Kennedy (2002) reported the air temperature to be approximately 6.1 °C, although Griffin (1945) mentions one instance when sub-freezing temperatures occurred during the winter.

WNS Infection Report: Porter (2008a,b), the USGS NWHC (Quarterly Mortality Reports, 2008, Quarter 4), and supporting online material for Blehert et al. (2009).

Skinner Hollow Cave, Bennington County, VT (Site 34 on Fig. 1):

Cave Map: Map dated 2000 in Quick (2001).

Stratigraphy: Marble of the Lower Ordovician Bascom Formation of the Beekmantown Group (Fig. 4), a few hundred feet below the contact between the marble and schist that has been thrust over the marble (Perry, 1942; Scott, 1959; Carroll, 1988; Quick, 1994, 2001).

Hydrology: A stream flows through parts of the cave.

Cave Meteorology: The entrance of the cave gets little direct sunlight, and snow and ice may persist in the cave well into the summer (Perry, 1942; Quick, 2001). Cave air temperatures as low as 1.7 °C have been measured in August (Quick, 2001).

WNS Infection Report: Porter (2008a) and Anonymous (2009a).

Unnamed cave near New Milford, Litchfield County, CT (Site 31 on Fig. 1):

WNS infection at this site was suggested by Kocer (2009) and reported in supporting online material for Blehert et al. (2009). Additional information has not been reported, but all known caves in Litchfield County are located within the Cambrian-Ordovician Stockbridge Formation (Huntington, 1963).

Ordovician Carbonate Strata Above the Knox Unconformity

Seven of the sites infected with WNS before September 2009 are located in Ordovician carbonate strata above the Knox Unconformity (Figs. 3 and 4). These sites include a group of caves in New York (Glen Park Caves), two caves in Pennsylvania (Aitkin Cave, Alexander Caverns), and four caves in Virginia (Endless Caverns, Clover Hollow Cave, Newberry-Bane Cave, Hancock Cave). The Glen Park Caves, Aitkin Cave, and Alexander Caverns have developed mainly in the Upper Ordovician Trenton Limestone (Fig. 4). Endless Caverns in Virginia are located in Middle Ordovician limestone beneath the Upper Ordovician Martinsburg Formation. The three other caves in Virginia (Clover Hollow Cave, Newberry-Bane Cave, Hancock Cave) are located in Upper Ordovician limestone, immediately below shale of the Upper Ordovician Moccasin Formation (Fig. 4).

Glen Park Caves, Jefferson County, NY (Site 15 on Fig. 1):

Cave Maps: Map dated 1979 of Glen Park Commercial Cave (Nekvasil-Coraor, 1979); Map dated 1972 of Glen Park Labyrinth System (Nekvasil-Coraor, 1979); Undated map of Glen Park Labyrinth System (Engel, 2009); Maps of other Glen Park caves (Fisher, 1958; Carroll, 1972a; Evans et al., 1979).

Stratigraphy: Upper Ordovician Black River Limestone and the overlying Upper Ordovician Trenton Limestone (Fisher, 1958; Carroll, 1970, 1972a; Nekvasil-Coraor, 1979; Engel, 1987, 2009).

Hydrology: Many of the Glen Park Caves are wet and (or) contain ice.

Cave Sediments: Mud is present in many of the Glen Park Caves.

WNS Infection Report: Porter (2008a,b).

<u>Aitkin Cave, Mifflin County, PA</u> (Site 69 on Fig. 1):

Cave Map: Map dated 1980 in Dayton et al. (1981).

Stratigraphy: Upper Ordovician Trenton Limestone (Stone, 1932, 1953; Dayton et al., 1981).

Hydrology: A canyon-like water course traverses the cave passage 20 feet inside the entrance, and a stream flows along the length of the cave during the winter. The ground water level in this area fluctuates greatly, and at times the entire cave is filled with water.

WNS Infection Report: Bat Conservation and Management, Inc. (http://www.batmanagement.com/wns/WNS photoalbum1/index.html) and the Pennsylvania Department of Conservation and Natural Resources (http://www.dcnr.state.pa.us/news/resource/res2009/09-0311-resource.aspx#blurb2).

<u>Alexander Caverns, Mifflin County, PA</u> (Site 61 on Fig. 1):

Cave Map: Map dated 1951 in Dayton et al. (1981).

Stratigraphy: Upper Ordovician Trenton Limestone (Stone, 1932; Dayton et al., 1981; Ibberson, 1988).

Hydrology: The caverns are essentially a master trunk drainage system that receives water from many tributary streams that sink in the area. One part of the caverns is dry, whereas another part is wet. The caverns have three entrances, one of which is a spring mouth.

Cave Sediments: Mud and gravel are present at various locations within the caverns.

Cave Meteorology: Air temperature is 11.1 °C throughout the year (Stone, 1932).

WNS Infection Report: Danielle Moxley (http://thesnapper.com/2009/11/12/bye-bye-bats-white-nose-syndrome-waking-bats-from-their-sleep/) and Kiernam Schalk (http://mobile.lewistownsentinel.com/page/wap.home/?id=512320).

<u>Endless Caverns, Rockingham County, VA</u> (Site 75 on Fig. 1):

Cave Map: Map dated 1966 in Holsinger (1975).

Stratigraphy: Middle Ordovician limestone. The commercial part of the caverns is located in the Middle Ordovician New Market Limestone (Douglas, 1964; Holsinger, 1975; Hubbard, 1995; Jones, 1999, 2009). Beyond the commercial part, the main passages have developed along the contact of the New Market Limestone and the overlying Middle Ordovician Lincolnshire Limestone (Fig. 4). In a

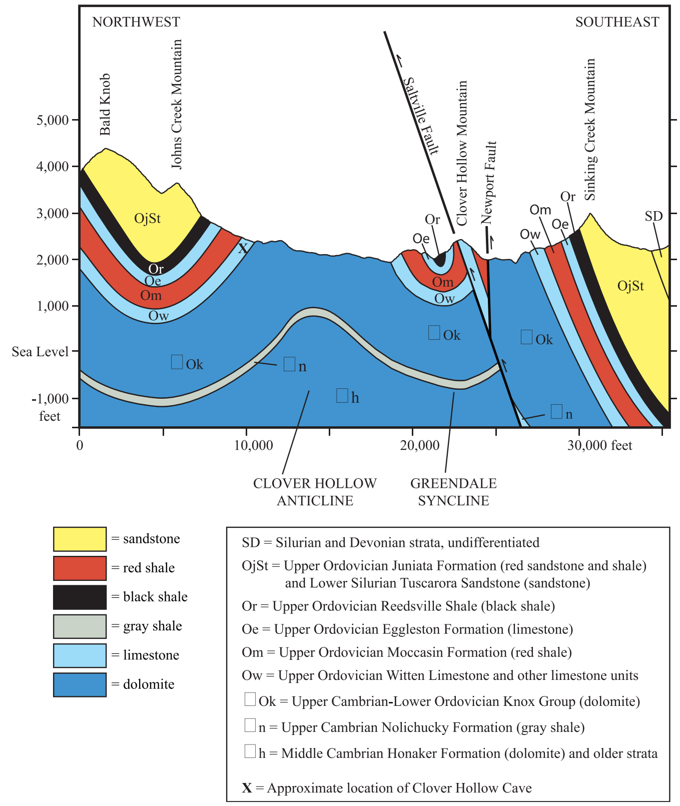

Figure 6. Geologic cross-section in the vicinity of Clover Hollow Cave, Giles County, Virginia (modified from Le Van and Rader, 1983; Schultz et al., 1986; Orndorff, 1995). The Knox Unconformity is present at the top of unit □Ok (Upper Cambrian-Lower Ordovician Knox Group). The vertical scale is in feet relative to sea level.

few areas, the caverns extend above the Lincolnshire Limestone and into the overlying Middle Ordovician Edinburg Formation, which lies immediately below the Upper Ordovician Martinsburg Formation (Fig. 4).

Hydrology: A stream flows north and west through the non-commercial lower level of the caverns. This stream water arises from colluvium on the western slope of Massanutten Mountain, sinks underground and flows through the caverns, and then rises to the surface as a spring in the Edinburg Formation below the Endless Caverns gift shop.

Cave Sediments: Large clasts of Silurian sandstone fill many of the western passages of the caverns (Hubbard and Grady, 1999).

Cave Meteorology: Reeds (1925) states that the air temperature is 13.3 °C.

WNS Infection Report: Dasher (2009b) and the Virginia Department of Conservation and Recreation (DCR) Natural Heritage Program (http://www.dgif.virginia.gov/wildlife/bats/white-nose-syndrome/white-nose-syndrome-recommendations.pdf).

<u>Clover Hollow Cave, Giles County, VA</u> (Site 70 on Fig. 1):

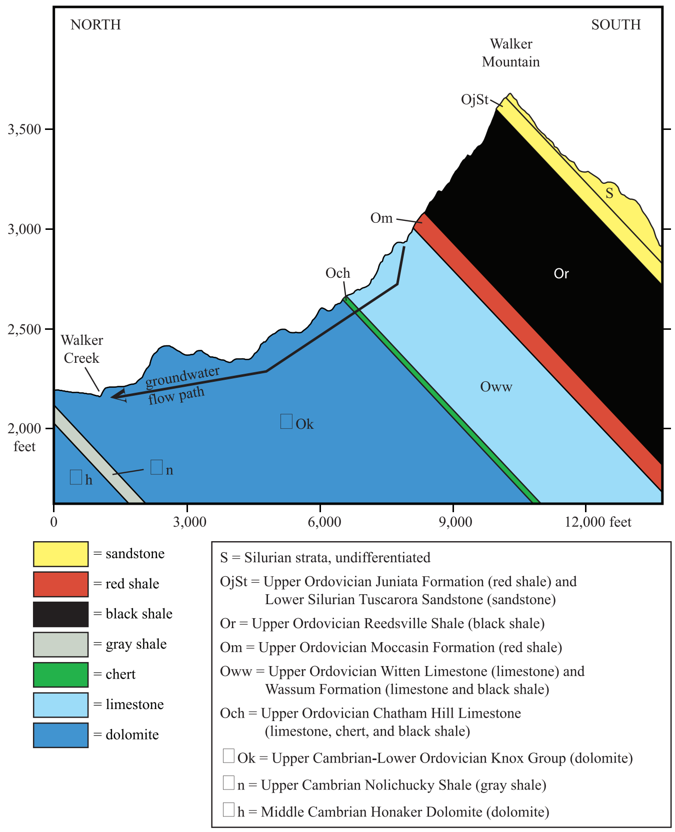

Figure 7. Geological cross-section in the vicinity of Newberry-Bane Cave, Bland County, Virginia (modified from Le Van and Rader, 1983; Wright, 1995). Newberry-Bane Cave is located along the extent of the ground water flow path shown. The Knox Unconformity is present at the top of unit □Ok (Upper Cambrian–Lower Ordovician Knox Group). The vertical scale is in feet relative to sea level.

Cave Map: Map dated 1978 in Zokaites (1995b).

Stratigraphy: Upper Ordovician limestone (Douglas, 1964; Sluzarski, 1972; Saunders, 1974; Holsinger, 1975; Saunders et al., 1981; Orndorff, 1995). The cave entrance is located near the contact between the Upper Ordovician Witten Limestone and the overlying Upper Ordovician Moccasin Formation (Figs. 4 and 6).

Hydrology: Surface water flows down Johns Creek Mountain across relatively impermeable Silurian and Ordovician strata (Fig. 6). Upon encountering the Upper Ordovician Witten Limestone, water flows into the cave near the entrance and flows through the rest of the cave. Dye tracing has shown that this water resurges about 8 km southwest of the cave at Tawney Spring and Smokehole Spring along Sinking Creek.

WNS Infection Report: Dasher (2009b), Youngbaer (2009b), the Virginia Department of Conservation and Recreation (DCR) Natural Heritage Program (http://www.dgif.virginia.gov/wildlife/bats/white-nose-syndrome/white-nose-syndrome-recommendations.pdf), and the Virginia Department of Game and Inland Fisheries (http://www.dgif.virginia.gov/news/release.asp?id=214). In addition, a WNS infection in Giles County (VA) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

Newberry-Bane Cave, Bland County, VA (Site 73 on Fig. 1):

Cave Map: Map dated 1995 in Zokaites (1995b).

Stratigraphy: Limestone of the Upper Ordovician Wassum Formation (Figs. 4 and 7) and the overlying Upper Ordovician Witten Limestone (Douglas, 1964; Holsinger, 1975; Wright, 1982, 1995; Zokaites, 1995a; Schwartz et al., 2009).

Hydrology: Surface water flows down the north slope of Walker Mountain across relatively impermeable Silurian and Ordovician strata (Fig. 7). Upon encountering the Upper Ordovician Witten Limestone, water flows into pits and sinkholes and eventually reaches Newberry-Bane Cave. In the cave, chert and black shale of the Upper Ordovician Chatham Hill Limestone (which underlies the Wassum Formation) act as a hydrological barrier that inhibits cave development in older strata. At one location, however, water in the cave penetrates the Chatham Hill Limestone, flows north through the underlying Cambrian-Ordovician Knox Group, and resurges at Burnt House Spring, which flows north into Walker Creek (Fig. 7).

Cave Meteorology: Air temperatures range from 7.0 to 11 °C (Brack et al., 2005).

WNS Infection Report: Dasher (2009a,b), Youngbaer (2010), and the Virginia Department of Conservation and Recreation (DCR) Natural Heritage Program (http://www.dgif.virginia.gov/wildlife/bats/white-nose-syndrome/white-nose-syndrome-recommendations.pdf).

Hancock Cave, Smyth County, VA (Site 74 on Fig. 1):

Cave Map: None published.

Stratigraphy: Upper Ordovician limestone on the northwest flank of Walker Mountain.

WNS Infection Report: Dasher (2009b), the Virginia Department of Conservation and Recreation (DCR) Natural Heritage Program (http://www.dgif.virginia.gov/wildlife/bats/white-nose-syndrome/white-nose-syndrome-recommendations.pdf), and the U.S. Fish and Wildlife Service (http://www.fws.gov/northeast/whitenose/PDF/WNSBulletinJune2009-Final.pdf).

Ordovician-Silurian Non-Carbonate Strata

Five of the sites infected with WNS before September 2009 are located in Ordovician-Silurian non-carbonate rock (Fig. 3). These sites are mines in Connecticut, Massachusetts, Vermont, New Jersey, and Pennsylvania. One site is located in Ordovician granite gneiss (Roxbury Mine), two sites are associated with Ordovician schist (The Old Mine, Greeley Mine), and two sites are located in Silurian sandstone and (or) mudstone (Pahaquarry Copper Mine, Shindle Mine).

Roxbury Mine, Litchfield County, CT (Site 62 on Fig. 1):

Mine Map: Map dated 2005 in Jacobs (2006).

Stratigraphy: Ordovician Mine Hill Granite Gneiss (Gates, 1959; Echols, 1961; Jacobs, 2006).

Mined Commodity: Iron (siderite), mined from 1760 to 1872.

Hydrology: Parts of the lower level of the mine contain standing water.

WNS Infection Report: Suggested by Kocer (2009) and in the Helderberg-Hudson Grotto newsletter "Mudslinger" (February 2009, v. 24, no. 2), and subsequently reported in "The Northeastern Caver" (June 2009, v. 40, p. 44–45). In addition, a WNS infection near the town of Roxbury in Litchfield County (CT) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2008, Quarter 4).

The Old Mine (Upper Chester Mine), Hampden County, MA (Site 20 on Fig. 2):

Mine Map: None published.

Stratigraphy: Ordovician Chester Amphibolite, near the contact of the Chester Amphibolite with the Ordovician Savoy Schist (Hartline, 1965; Lincks, 1978). The Savoy Schist is approximately equivalent stratigraphically to the Upper Ordovician siliciclastic strata shown in Figure 3.

Mined Commodity: Emery, mined from approximately 1856 to 1950.

Hydrology: Water flows through some parts of the mine.

WNS Infection Report: Porter (2008a,b), and supporting online material for Blehert et al. (2009). In addition, a WNS infection in Hampden County (MA) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

Greeley Mine, Windsor County, VT (Site 36 on Fig. 1):

Mine Map: None published.

Stratigraphy: Ordovician serpentinite (Gillson, 1927; Trombulak et al., 2001).

Mined Commodity: Talc, mined prior to 1930.

WNS Infection Report: Porter (2009d) and the U.S. Fish and Wildlife Service (http://www.fws.gov/northeast/wnspics.html).

Pahaquarry Copper Mine, Delaware Water Gap National Recreation Area, Warren County, NJ (Site 54 on Fig. 1):

Mine Map: None published.

Stratigraphy: Red and gray sandstone of the Upper Silurian Bloomsburg Red Beds (Weed, 1911; Woodward, 1944; Burns Chavez and Clemensen, 1995; Monteverde, 2001). The Bloomsburg Red Beds overlie the Silurian Shawangunk Conglomerate, which in turn overlies the Upper Ordovician Martinsburg Formation (Fig. 4).

Mined Commodity: Copper, mined at various times from approximately 1750 to 1912.

WNS Infection Report: USGS NWHC (Quarterly Mortality Reports, 2008, Quarter 4).

Shindle Mine, Mifflin County, PA (Site 39 on Fig. 1):

Mine Map: None published.

Stratigraphy: Lower Silurian Tuscarora Sandstone (Fig. 3).

Mined Commodity: Iron, although dates of operation are not known.

WNS Infection Report: USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

Carbonate Strata Of The Lower Part Of The Silurian-Devonian Helderberg Group

Twenty of the sites infected with WNS before September 2009 are located in carbonate strata of the lower part of the Silurian-Devonian Helderberg Group, specifically within the Coeymans Limestone, Manlius Limestone, and Keyser Limestone (Figs. 3 and 8). Fourteen of these sites are caves in New York (Howe Caverns, McFail's Cave, Benson's Cave, Hell's Wells, Barytes Cave, Ain't No Catchment Cave, Gage Caverns, Schoharie Caverns, Single X Cave, Knox Cave, Hailes Cave, Nature's Way Cave, South Bethlehem Cave, Surprise Cave), and five of these sites are mines in New York (Hasbrouck Mine, Williams Preserve Mine, Williams Hotel Mine, Williams Lake Mine, Martin Mine). One site is a cave in Virginia that has formed in limestone confined between two beds of low-permeability sandstone (Breathing Cave).

Howe Caverns, Schoharie County, NY (Site 1 on Fig. 2):

Note: Howe Caverns is the name of a large cave system, part of which is commercial. In some publications, the name "Howe Caverns" is restricted to only the commercial section of the cave system, and the name "Howe Cave" is given to the non-commercial sections of the cave system (Davis et al., 1966).

Cave Map: Map dated 1977 in Mylroie (1977).

Stratigraphy: Upper Silurian-Lower Devonian Manlius Limestone and the overlying Lower Devonian Coeymans Limestone (Fig. 9) of the Helderberg Group (Schweiker et al., 1958; Olesen, 1961; Davis et al., 1966; Addis, 1969; Egemeier, 1969; Mylroie, 1972, 1977; Gregg, 1974; Kastning, 1975; Cullen et al., 1979).

Hydrology: Howe Caverns are wet, and a river flows southeast through part of the cave system. Dye tracing indicates that at least some of the water comes from McFail's Cave (Site 37 on Fig. 2), approximately 3 miles northwest of Howe Caverns (Baker, 1976). Water from the caverns resurges on the banks of Cobleskill Creek (Mylroie, 1977).

Cave Sediments: Brown clay, gray laminated clay and sandy gravel containing chert pebbles are present in the caverns (Engel, 2009; Rubin, 2009). At one location (the "Lake of Venus"), a bed of sandy gravel is overlain by a bed of brown clay, which is overlain by bed of gray laminated clay (Rubin, 2009).

Cave Meteorology: Meteorological measurements taken February 26 to April 30, 1971 from the commercial part of Howe Caverns revealed air temperatures ranging from 9.4

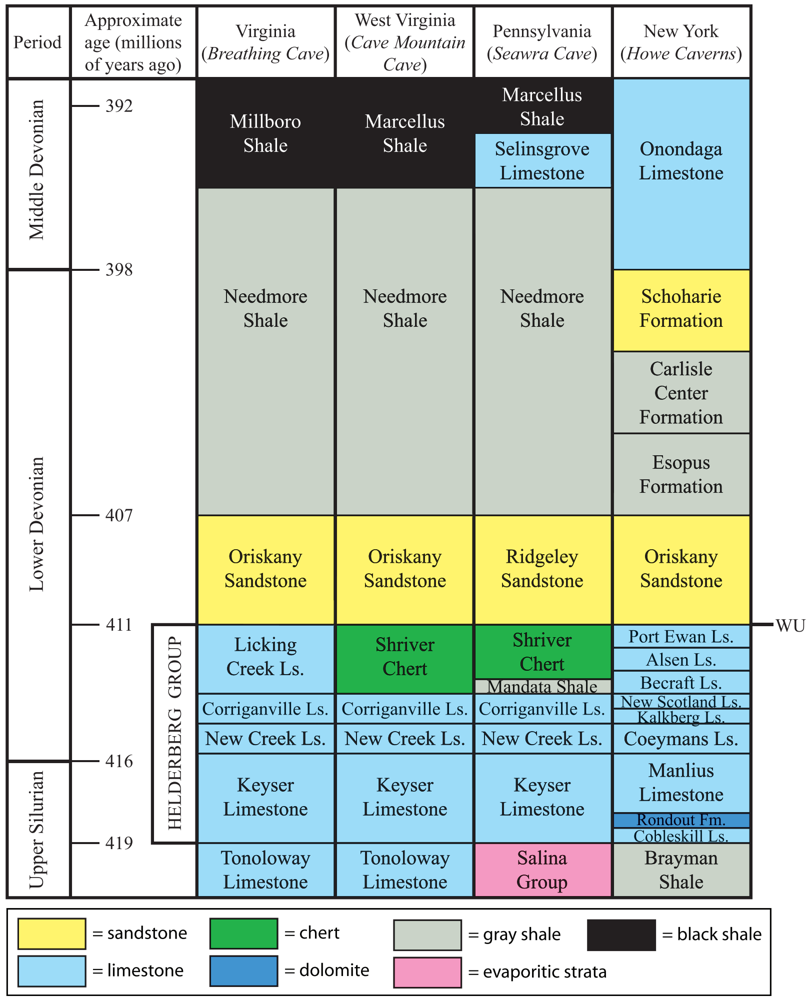

Figure 8. Selected Upper Silurian through Middle Devonian stratigraphic units in the Appalachian Basin (from Head, 1974; Kastning, 1975; Dennison and Hasson, 1979; Dorobek and Read, 1986; Fisher, 1987; Smosna, 1988; Harris et al., 1994; Van Tyne, 1996; Swezey, 2002). Time scale is from Gradstein et al. (2004). Fm. = Formation; Ls. = Limestone. In many places, a regional unconformity is present below the Devonian Oriskany Sandstone and Ridgeley Sandstone (WU: Wallbridge Unconformity). Unconformities are also present in New York on top of the Silurian Brayman Shale and on top of the Devonian Schoharie Formation. Example caves are listed in italics at the tops of columns.

to 10.6 °C and relative humidity ranging from 68 to 72 percent (Mylroie, 1972).

WNS Infection Report: Porter (2008a,b), Armstrong (2009), and Blehert et al. (2009).

McFail's Cave, Schoharie County, NY (Site 37 on Fig. 2):

Cave Map: Map dated 1991 in Haberland (1991).

Stratigraphy: The two active entrances to McFail's Cave are located in the Lower Devonian Kalkberg Limestone (Figs. 8, 9, and 10), but most of the cave has formed in the Upper Silurian-Lower Devonian Manlius Limestone and the overlying Lower Devonian Coeymans Limestone of the Helderberg Group (Olesen, 1961; Egemeier, 1969; Kastning, 1975; Baker, 1976; Mylroie, 1977; Palmer, 2002). In addition, the southernmost portion of the cave has formed partially in the Upper Silurian Rondout Formation.

Hydrology: Water flows through much of the cave and dye tracing has revealed that this water flows to Doc Shaul's Spring (Fig. 10), to Howe Caverns, and to some other springs in the vicinity (Baker, 1970, 1973, 1976).

Cave Sediments: Breakdown blocks, gravel, and mud are present in the cave (Olesen, 1961; Baker, 1973; Kastning, 1975). In addition, Porter (1985) mentioned sediments that are interpreted as glacial varves, and Rubin (1985) described a stream channel incised into a clay bank.

Cave Meteorology: The annual average air temperature is 7.3 °C (van Beynen et al., 2004).

WNS Infection Report: Porter (2008a) and Armstrong (2009).

Benson's Cave, Schoharie County, NY (Site 25 on Fig. 2):

Cave Map: Map dated 1976 in Mylroie (1977).

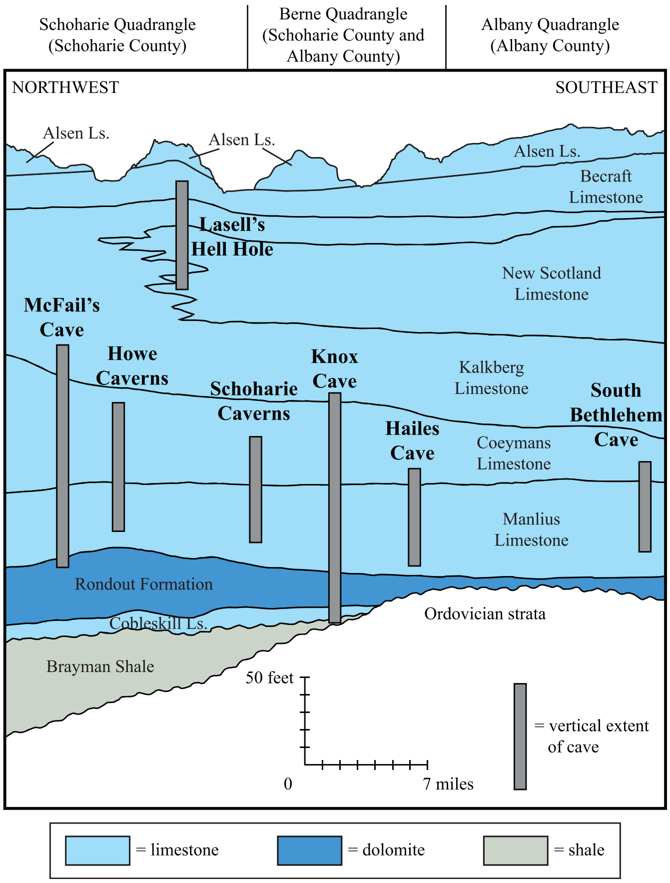

Figure 9. Geologic cross-section through Schoharie, Berne, and Albany 15-minute topographic quadrangles (Schoharie County and Albany County, New York) showing the distribution of selected caves in the Silurian-Devonian Helderberg Group (modified from Kastning, 1975; data on Knox Cave from Palmer, 2000, 2001).

Stratigraphy: Upper Silurian-Lower Devonian Manlius Limestone and the overlying Lower Devonian Coeymans Limestone of the Helderberg Group (Schweiker et al., 1958; Davis et al., 1966; Egemeier, 1969; Kastning, 1975; Dimbirs and Wood, 1977; Mylroie, 1977).

Hydrology: Water enters the cave at several locations, eventually joins a stream from nearby Secret Caverns, and then flows south and east to Barytes Cave.

WNS Infection Report: Porter (2008a).

Hell's Wells, Schoharie County, NY (Site 26 on Fig. 2):

Cave Map: Map dated 1976 in Mylroie (1977).

Stratigraphy: Lower Devonian Coeymans Limestone of the Helderberg Group (Schweiker et al., 1958; Davis et al., 1966; Mylroie, 1977).

Hydrology: The cave is described as "semi-abandoned pit insurgences" (Mylroie, 1977).

WNS Infection Report: Alan Hicks of the New York State Department of Environmental Conservation (http://www.necaveconservancy.org/files/wns_3-30-08.pdf) and Armstrong (2009).

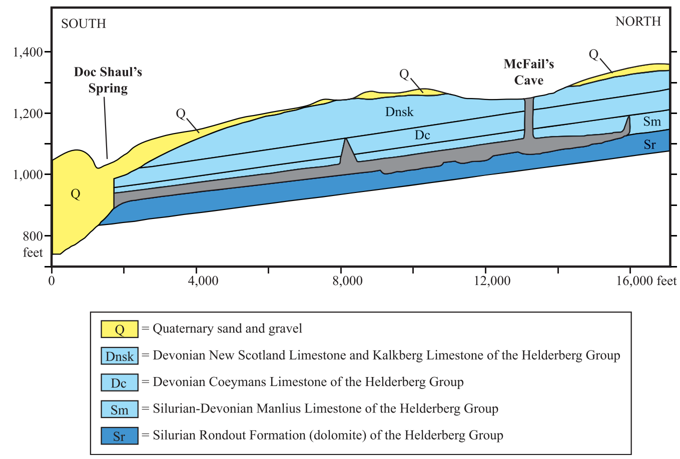

Figure 10. Geologic cross-section through McFail's Cave, Schoharie County, New York (modified from Baker, 1976). The vertical scale is in feet relative to sea level.

Barytes Cave, Schoharie County, NY (Site 2 on Fig. 2):

Cave Map: Map dated 1978 in Middleton (1979).

Stratigraphy: Upper Silurian Rondout Formation and the overlying Upper Silurian-Lower Devonian Manlius Limestone of the Helderberg Group (Schweiker et al., 1958; Davis et al., 1966; Dimbirs and Wood, 1977; Mylroie, 1977; Middleton, 1979).

Hydrology: The cave is connected hydrologically with the nearby Secret-Bensons Cave System (Dimbirs and Wood, 1977; Mylroie, 1977; Siemion et al., 2003; Siemion, 2005). Water in Secret Caverns flows into Bensons Cave, and then flows south and east to Barytes Cave. Dimbirs and Wood (1977) stated that water in Barytes Cave resurges further south at No Admittance Spring, whereas Mylroie (1977) stated that water in Barytes Cave resurges at an occluded bluff spring named Corners Spring.

WNS Infection Report: Alan Hicks of the New York State Department of Environmental Conservation (http://www.necaveconservancy.org/files/wns_3-30-08.pdf).

Ain't No Catchment (ANC) Cave, Schoharie County, NY (Site 28 on Fig. 2):

Cave Map: Map dated 2005 in Armstrong et al. (2005).

Stratigraphy: Upper Silurian Cobleskill Formation and the overlying Upper Silurian Rondout Formation of the Helderberg Group (Hopkins, 1996b; Rubinstein, 1998; Armstrong et al., 2005).

Hydrology: A perennial spring flows from the cave, and at times the entrance is completely flooded.

WNS Infection Report: Porter (2008a) and Armstrong (2009).

Gage Caverns, Schoharie County, NY (Site 4 on Fig. 2):

Cave Map: Map dated 1976 in Mylroie (1977).

Stratigraphy: Upper Silurian-Lower Devonian Manlius Limestone and the overlying Lower Devonian Coeymans

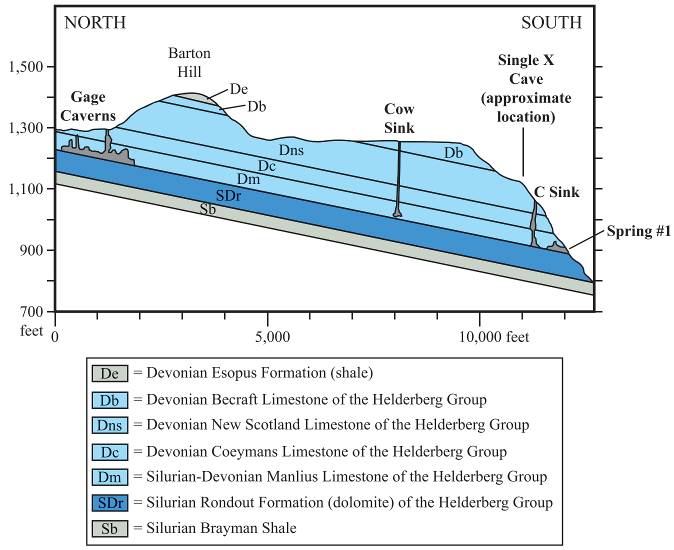

Figure 11. Geologic cross-section through Barton Hill (Schoharie County, New York), showing the location of Gage Caverns and other nearby karst features (modified from Anderson, 1961). The vertical scale is in feet relative to sea level.

Limestone (Fig. 11) of the Helderberg Group (Gurnee, 1957; Schweiker et al., 1958; Anderson, 1961; Baker, 1976; Mylroie, 1977; Engle, 1988).

Hydrology: The caverns are wet, and contain a stream and lakes. Anderson (1961) stated that water in the caverns resurges at Spring #1 (Fig. 11), located approximately 10,800 feet south of the caverns. However, dye tracing has shown that water in Gage Caverns exits at Young's Spring, which is 4,200 feet southwest of the dye injection site (Baker, 1970).

Cave Meteorology: Gurnee (1957) reported air temperature measurements ranging from 8.9 to 12.2 °C from seven locations in the caverns, whereas Moore (1958) stated that the air temperature is approximately 7.8 °C throughout the year.

WNS Infection Report: Folsom (2008), Porter (2008a,b), and Armstrong (2009).

Schoharie Caverns, Schoharie County, NY (Site 3 on Fig. 2):

Cave Map: Map dated 1989 in Schweyen (1989).

Stratigraphy: Upper Silurian-Lower Devonian Manlius Limestone and the overlying Lower Devonian Coeymans Limestone (Fig. 9) of the Helderberg Group (Schweiker et al., 1958; Davis et al., 1966; Kastning, 1975; Dimbirs and Wood, 1977; Mylroie, 1977; Cullen et al., 1979; Schweyen, 1989).

Hydrology: At the back end of the caverns, a perennial stream emerges at the contact between the Manlius Limestone and the overlying Coeymans Limestone (Mylroie, 1977). This stream flows along the entire length of the caverns, and exits at the cavern entrance. Dimbirs and Wood (1977) claimed that water in the caverns overflows into another cave system named the Spider Cave System, whereas Cullen et al. (1979) claimed that water in the caverns overflows into a nearby cave named Tufa Cave.

WNS Infection Report: Folsom (2008), Porter (2008a,b), the USGS NWHC (Quarterly Mortality Reports, 2008, Quarter 4), and supporting online material for Blehert et al. (2009).

Single X Cave, Schoharie County, NY (Site 64 on Fig. 2):

Cave Map: Map dated 1975 in Mylroie (1977).

Stratigraphy: Silurian-Devonian Helderberg Group (Fig. 11). From the cave entrance, a passage trends northwest along strike in the Upper Silurian Cobleskill Limestone and the overlying Upper Silurian Rondout Formation (Middleton, 1977; Mylroie, 1977, 1980). After 715 feet, this entrance passage intersects the main cave passage, which trends north-northeast and is located primarily in the Upper Silurian-Lower Devonian Manlius Limestone and the overlying Lower Devonian Coeymans Limestone. Some high dome pits along this passage may extend up into the Lower Devonian Kalkberg Limestone.

Hydrology: The cave contains a stream, which is incised into mud banks in places. This stream flows south-southwest along the main passage and then flows southeast along the entrance passage and out the cave entrance (a location named Traux Spring).

Cave Sediments: Breakdown blocks, cobbles, and mud (including mud spatter cones) are present within the cave. In some places, cobbles are cemented to the passage walls by flowstone up to 20 feet above the modern stream level.

WNS Infection Report: Armstrong (2009).

Knox Cave, Albany County, NY (Site 6 on Fig. 2):

Cave Map: Map dated 2000 in Palmer (2000).

Stratigraphy: Most of the cave has developed within the Upper Silurian-Lower Devonian Manlius Limestone and the overlying Lower Devonian Coeymans Limestone (Figs. 9 and 12) of the Helderberg Group (Hornung, 1953; Schweiker, 1958; Palmer, 1963, 2000, 2001; Kastning, 1975; Rubin, 1986). At a few locations, passages extend below the Manlius Limestone and into the underlying Upper Silurian Rondout Formation, Cobleskill Formation, and the Brayman Shale (Fig. 12).

Hydrology: A stream flows through much of the cave (Palmer, 1963). Dye traces indicate that the stream in Knox Cave and a stream in nearby Skull Cave both resurge at the same spring south of the two caves (Egemeier, 1969).

Cave Meteorology: Measurements taken at multiple locations in the cave on October 20, 1962 revealed dry bulb air temperatures ranging from 6.0 to 10.0 °C, wet bulb air temperatures ranging from 5.8 to 9.7 °C, and relative humidity ranging from 93 to 100 percent (Kreider, 1963).

WNS Infection Report: Folsom (2008), Porter (2008a,b), and Armstrong (2009).

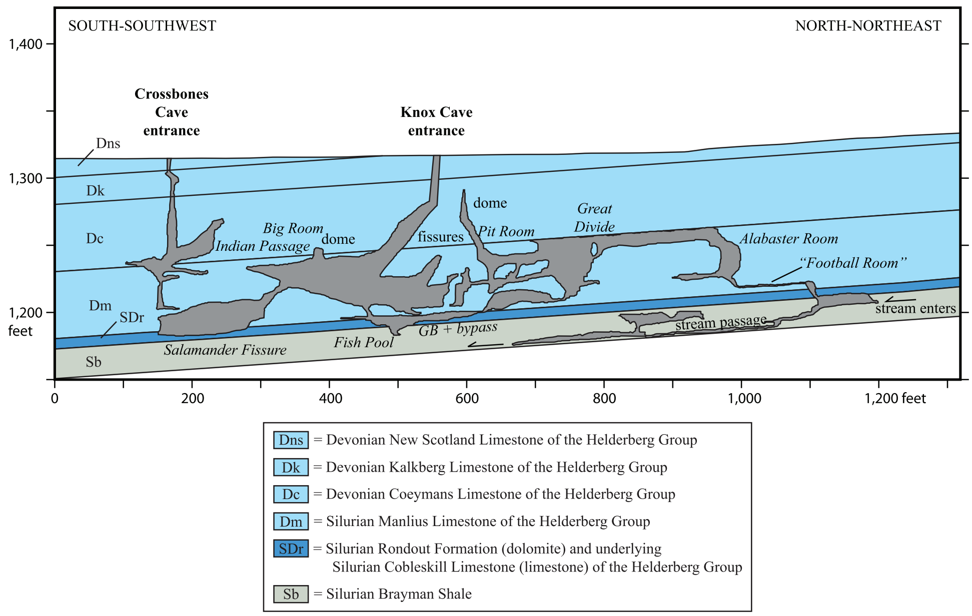

Figure 12. Geologic cross-section through Knox Cave and Crossbones Cave, Albany County, New York (modified from Palmer, 1963, 2000). GB = The Gunbarrel (a straight passage that is 15 m long and 35 cm in diameter). The vertical scale is in feet relative to sea level.

Hailes Cave, Albany County, NY (Site 5 on Fig. 2):

Cave Map: Map dated 1906 in Engle (1979).

Stratigraphy: Upper Silurian-Lower Devonian Manlius Limestone and the overlying Lower Devonian Coeymans Limestone (Fig. 9) of the Helderberg Group (Thurston, 1942; Schweiker, 1958; Kastning, 1975; Baker, 1976; Lundy, 2001).

Hydrology: The cave is relatively wet, and contains pools of water.

WNS Infection Report: Folsom (2008), Porter (2008a,b), the USGS NWHC (Quarterly Mortality Reports, 2008, Quarter 4), and supporting online material for Blehert et al. (2009).

Nature's Way Cave (Zinzow's Cave), Albany County, NY (Site 38 on Fig. 2):

Cave Map: Map dated 2000 in Haberland et al. (2000).

Stratigraphy: Upper Silurian-Lower Devonian Manlius Limestone and the overlying Lower Devonian Coeymans Limestone of the Helderberg Group (Hopkins, 1996a,b; Haberland et al., 2000; Martuscello, 2000).

Hydrology: The cave entrance is a spring, and the cave contains a stream, waterfalls, and sumps.

WNS Infection Report: Porter (2008a) and Armstrong (2009).

South Bethlehem Cave, Albany County, NY (Site 29 on Fig. 2):

Cave Map: Map dated 1968 in Kastning (1975).

Stratigraphy: Silurian-Devonian Helderberg Group (Schweiker, 1958; Kastning, 1968, 1975; Cullen et al., 1979). Most of the cave is within the Upper Silurian-Lower Devonian Manlius Limestone, although some parts extend into the overlying Lower Devonian Coeymans Limestone (Fig. 9).

Hydrology: Kastning (1968) stated that the lower passages of the cave drop down into water and siphons, whereas Cullen et al. (1979) stated that a standing pool of water is present in one area and that the rest of the cave is relatively dry except during times of extreme flood when water flows out of the lower entrance of the cave.

Cave Sediments: Mud is present throughout much of the cave (Kastning, 1968).

Cave Meteorology: The cave is "relatively dry" (Schweiker, 1958).

WNS Infection Report: Porter (2008a).

Surprise Cave (Mystery Cave), Sullivan County, NY (Site 42 on Fig. 1):

Cave Map: Map dated 1982 in Febroriello (1984) and Engel (2009).

Stratigraphy: Upper Silurian Rondout Formation and Lower Devonian Coeymans Limestone of the Helderberg Group (Peck, 1967; Febroriello, 1984; Engel, 2009).

Hydrology: The lower parts of the cave contain at least two active streams.

WNS Infection Report: Porter (2008a).

Hasbrouck Mine at Kingston, Ulster County, NY (Site 40 on Fig. 2):

Mine Map: None published.

Stratigraphy: Upper Silurian Rondout Formation of the Helderberg Group (Chu, 2006; Perlmann, 2006).

Mined Commodity: Limestone.

Hydrology: The lower levels of the mine are flooded.

WNS Infection Report: Porter (2008a). In addition, a WNS infection in Ulster County (NY) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

<u>Williams Preserve Mine, near Rosendale, Ulster County, NY</u> (Site 9 on Fig. 2):

Mine Map: None published.

Stratigraphy: Upper Silurian Rondout Formation of the Helderberg Group.

Mined Commodity: Limestone, mined during the 1800s and early 1900s.

WNS Infection Report: Porter (2008a) and the USGS NWHC (Quarterly Mortality Reports, 2008, Quarter 4).

<u>Williams Hotel Mine near Rosendale, Ulster County, NY</u> (Site 10 on Fig. 2):

Mine Map: None published.

Stratigraphy: Upper Silurian Rondout Formation of the Helderberg Group.

Mined Commodity: Limestone, mined during the 1800s and early 1900s.

WNS Infection Report: Porter (2008a,b), the USGS NWHC (Quarterly Mortality Reports, 2008, Quarter 4), and supporting online material for Blehert et al. (2009).

<u>Williams Lake Mine near Rosendale, Ulster County, NY</u> (Site 18 on Fig. 2):

Mine Map: None published.

Stratigraphy: Upper Silurian Rondout Formation of the Helderberg Group.

Mined Commodity: Limestone, mined during the 1800s and early 1900s.

WNS Infection Report: Porter (2008a). In addition, a WNS infection in Ulster County (New York) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

<u>Martin Mine near Rosendale, Ulster County, NY</u> (Site 30 on Fig. 2):

Mine Map: None published.

Stratigraphy: Upper Silurian Rondout Formation of the Helderberg Group.

Mined Commodity: Limestone, mined during the 1800s and early 1900s.

WNS Infection Report: Supporting online material for Blehert et al. (2009). In addition, a WNS infection in Ulster County (NY) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

<u>Breathing Cave, Burnsville Cove, Bath County, VA</u> (Site 60 on Fig. 1):

Cave Map: Map dated 1975 in Wefer and Nicholson (1982).

Stratigraphy: The cave is located within the Upper Silurian-Lower Devonian Keyser Limestone (Fig. 8) of the Helderberg Group (Deike, 1960; Douglas, 1964; Holsinger, 1975; White and Hess, 1982; Clemmer, 2005). Within the Keyser Limestone, the cave is confined almost entirely to a 77-foot thick unit of shaly limestone between two 12-foot thick beds of sandstone, which have been named informally the upper Breathing sandstone and the lower Breathing sandstone. These sandstone beds are tongues of the Upper Silurian Clifton Forge Sandstone (which interfingers with the Keyser Limestone).

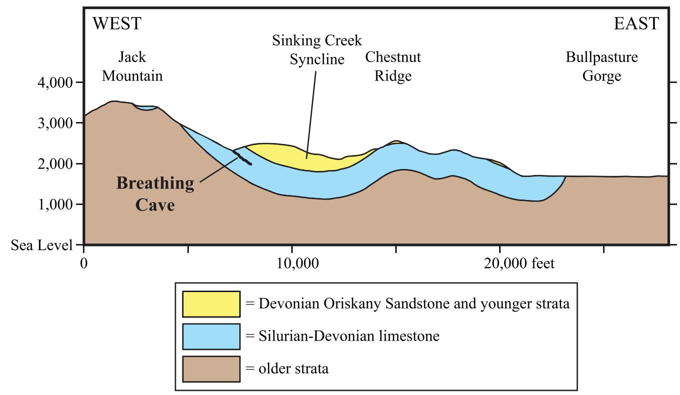

Figure 13. Geologic cross-section through Burnsville Cove (Bath County, Virginia), showing the location of Breathing Cave (modified from Deike, 1960). The vertical scale is in feet relative to sea level.

Hydrology: Surface water flows down Jack Mountain across relatively impermeable strata (Fig. 13). Near the cave, this water sinks into the limestone, and then resurges approximately 3 miles to the northeast at Bullpasture Gorge (Fig. 13).

Cave Sediments: Conglomeratic silt and sand, and cobbles up to 12 inches in diameter, are present in many passages (Deike, 1960). During the American Civil War, sediment in the cave was mined for nitrate to make gunpowder (Faust, 1964; Clemmer, 2005).

Cave Meteorology: Faust (1947) published early descriptions of oscillating air flow (the "Breathing Phenomenon") at Breathing Cave. Cournoyer (1954) published measurements taken during a 1.5 hour interval on January 9, 1954 that revealed air temperatures ranging from −3.3 to 11.1 °C, atmospheric pressure ranging from approximately 1002 to 1003 millibars, and 5 episodes of air flowing into the cave and then out of the cave at speeds attaining approximately 350 feet per minute. Cournoyer (1956) also published a subsequent set of measurements (taken at four locations during a 1.5 hour interval on December 10, 1955) that revealed air temperatures ranging from 0.6 to 10.6 °C. Finally, Moore (1958) stated that air temperature in the cave is approximately 11.1 °C throughout the year.

WNS Infection Report: Dasher (2009b), Lambert (2009), the Virginia Department of Conservation and Recreation (DCR) Natural Heritage Program (http://www.dgif.virginia.gov/wildlife/bats/white-nose-syndrome/

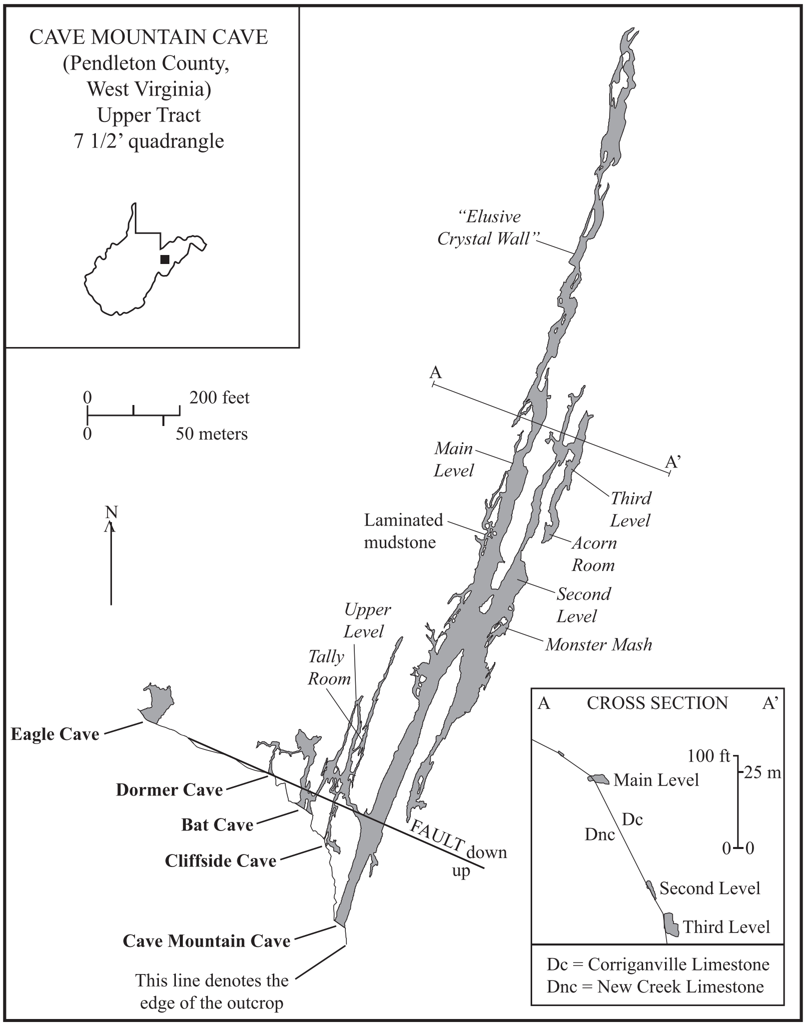

Figure 14. Map of Cave Mountain Cave, Pendleton County, West Virginia (from Swezey and Dulong, 2010). On the south side of the fault, the cave has formed in the Keyser Limestone of the Silurian-Devonian Helderberg Group. On the north side of the fault, the cave has formed in the New Creek Limestone and Corriganville Limestone of the Helderberg Group.

white-nose-syndrome-recommendations.pdf), and the Virginia Department of Game and Inland Fisheries (http://www.dgif.virginia.gov/news/release.asp?id=214). In addition, a WNS infection in Bath County (VA) was also confirmed by the USGS NWHC (Quarterly Mortality Reports, 2008, Quarter 4).

Carbonate Strata Of The Middle Part Of The Silurian-Devonian Helderberg Group

Five of the sites infected with WNS before September 2009 are located in caves in carbonate strata of the middle part of the Silurian-Devonian Helderberg Group, primarily at the boundary between the New Creek Limestone and the overlying Corriganville Limestone (Figs. 3 and 8). One of these sites is in Pennsylvania (Seawra Cave), and four of these sites are in West Virginia (Cave Mountain Cave, Saltpeter Cave, Hamilton Cave, Trout Cave).

<u>Seawra Cave, Mifflin County, PA</u> (Site 68 on Fig. 1):

Cave Map: Map dated 1960 in Dayton et al. (1981).

Stratigraphy: Silurian-Devonian Helderberg Group (Stone, 1932, 1953; Dayton et al., 1981).

Cave Meteorology: The air temperature is reported to be 13.9 °C, and the cave is described as being relatively dry (Stone, 1932).

WNS Infection Report: Bat Conservation and Management, Inc. (http://www.batmanagement.com/wns/WNSphotoalbum1/index.html) and the Pennsylvania Department of Conservation and Natural Resources (http://www.dcnr.state.pa.us/news/resource/res2009/09-0311-resource.aspx#blurb2).

<u>Cave Mountain Cave, Pendleton County, WV</u> (Site 59 on Fig. 1):

Cave Map: Map dated 2001 in Dasher (2001).

Stratigraphy: Silurian-Devonian Helderberg Group (Davies, 1965; Dyas, 1976a,b; Dasher, 2001; Swezey and Dulong, 2010). A northwest-trending fault is present about 200 feet inside the main entrance of the cave (Fig. 14). On the south side of this fault (i.e., between the cave entrance and the fault), the cave passages have developed within the Keyser Limestone of the Helderberg Group. On the north side of this fault, the cave passages have developed along the contact between the New Creek Limestone and the overlying Corriganville Limestone of the Helderberg Group.

Hydrology: Most of the cave is relatively dry with no flowing water, although some stalactites drip water near the front part of the cave on the Main Level and the underlying Second Level (Fig. 14).

Cave Sediments: Mud, sand, and gravel are present in most of the cave. Large breakdown blocks are common in places. A laminated mudstone on the Main Level (Fig. 14) is interpreted as a lacustrine deposit (Swezey and Dulong, 2010). In addition, lenses of rust-red clay within unconsolidated sand are present in the rear of the Main Level (Haas, 1960). This clay is a mixture of very fine-grained quartz and metahalloysite, which is a hydrated alumina silicate [$Al_4Si_4(OH)8O_{10}•8H_2O$]. During and before the American Civil War, sediment in the cave was mined for nitrate to make gunpowder (Davies, 1965; Anonymous, 1970; Ellen and Garton, 2001). Nitrate samples from the sediment range from about 300 to 2,200 parts per million (Hoke, 2005).

WNS Infection Report: Anonymous (2010), Dasher (2009b), Stihler (2009), and the West Virginia Division of Natural Resources (http://www.fws.gov/northeast/whitenose/WVPressRelease13Feb09.pdf).

<u>Saltpeter Cave, Pendleton County, WV</u> (Site 72 on Fig. 1):

Cave Map: Map dated 1997 in Dasher (2001).

Stratigraphy: Lower Devonian Corriganville Limestone of the Helderberg Group (Davies, 1958, 1965; Dasher, 2001).

Hydrology: The cave is reported to be very dry (Dasher, 2001).

WNS Infection Report: Anonymous (2010) and Dasher (2009b).

<u>Hamilton Cave, Pendleton County, WV</u> (Site 57 on Fig. 1):

Cave Map: Map dated 1988 in Dasher (2001).

Stratigraphy: Silurian-Devonian Helderberg Group (Davies, 1958; Palmer, 1975; Dyas, 1977; Medville, 2000a; Dasher, 2001). The front part of the cave is a maze of passages that have developed at the contact of the New Creek Limestone and the overlying Corriganville Limestone, whereas the back part of the cave consists of northeast-trending passages (without well-developed maze morphologies) that have developed primarily in the New Creek Limestone.

Hydrology: Most of the cave is relatively dry with no flowing water, although in a few rooms some stalactites drip water and damp mud is present on the floor.

Cave Sediments: Mud is present on the cave floor in many places.

Cave Meteorology: Dyroff (1977) published an account of a one-day study (April 10, 1977), which found that air flowed consistently out of the cave during the morning and afternoon, and that the average air temperature inside the cave was 11.7 °C. Hoke (2009a,b) reported that air always flows out of the cave during the winter, and that data loggers just inside the cave entrance recorded air temperatures that ranged from 12.8 °C at the beginning of winter to 10.8 °C at the end of winter.

WNS Infection Report: Anonymous (2010), Dasher (2009b), Hoke (2009a,b), Stihler (2009), and the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

<u>Trout Cave, Pendleton County, WV</u> (Site 58 on Fig. 1):

Cave Map: Map dated 1993 in Dasher (2001).

Stratigraphy: Silurian-Devonian Helderberg Group, in most places at the contact between the New Creek Limestone and the overlying Corriganville Limestone (Davies, 1958; Haas, 1961; Palmer, 1975; Medville, 2000b; Dasher, 2001). However, Swezey (2003) noted that at least one location (the "Square Room") extends from the Corriganville Limestone into the overlying Lower Devonian Shriver Chert (Fig. 8).

Hydrology: The cave is relatively dry, with no flowing water.

Cave Sediments: Mud, sand, and gravel are present in the cave. Breakdown blocks are common near the entrance. During the American Civil War, sediment in the cave was mined for nitrate to make gunpowder (Faust, 1964; Davies, 1965; Powers, 1981; Ellen and Garton, 2001; Taylor, 2001). Analysis of one sediment sample revealed a nitrate concentration of about 2,100 parts per million (Swezey et al., 2004).

Cave Meteorology: Davies (1958) reported air temperatures of approximately 12 °C, Hoke (2001) reported air temperatures ranging from 6.7 to 8.9 °C, and Swezey et al. (2004) reported air temperatures ranging from 6 to 13 °C and relative humidity ranging from 81 to 92 percent. In addition, Dyroff (1977) published an account of a one-day study (April 10, 1977), which found that during the morning when the outside air temperature was 0 °C, air flowed into the cave along the bottom of the cave passage and air flowed out of the cave along the top of the cave passage. In that study, the mean air temperature was 8.9 °C approximately 500 feet inside the cave, although the air temperature near the ceiling was several degrees warmer than the air temperature near the floor. During the afternoon when the outside air temperature was 12.8 °C, the air currents reversed so that warm air flowed in along the top of the cave passage and cooler air flowed out along the bottom of the cave passage. Despite this reversal in flow directions, the mean air temperature inside the cave remained at 8.9 °C.

WNS Infection Report: Anonymous (2010), Dasher (2009b), and USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

Carbonate Strata of the Upper Part of the Silurian-Devonian Helderberg Group

Only one site infected with WNS before September 2009 is located in the upper part of the Silurian-Devonian Helderberg Group (Figs. 3 and 8). This site is a cave in New York named Lasell's Hell Hole.

Lasell's Hell Hole, Schoharie County, NY (Site 27 on Fig. 2):

Cave Map: Undated map in Hopkins (1996b).

Stratigraphy: Lower Devonian Kalkberg Limestone, New Scotland Limestone, and Becraft Limestone (Fig. 8) of the Helderberg Group (Schweiker et al., 1958; Davis et al., 1966; Eckler, 1966; Gregg, 1974; Kastning, 1975; Baker, 1976; Hopkins, 1996b). The cave entrance is a 62-foot deep pit in the Becraft Limestone, and the contact between the Becraft Limestone and the underlying Kalkberg Limestone is visible within the first 10 feet of the pit. The Kalkberg Limestone in this area is a relatively thin upper tongue of the main Kalkberg Limestone (Fig. 9).

Hydrology: The New Scotland Limestone at this site is a shaly limestone that inhibits the downward flow of water (Baker, 1976). In other words, the New Scotland Limestone is relatively impermeable and forms a hydrological confining unit beneath the cave-bearing interval. Dye tracing indicates that water in Lasell's Hell Hole exits at Sitzer's Spring, which is said to be 0.5 miles east of the dye injection site (Baker, 1976).

WNS Infection Report: Porter (2008a).

H. Carbonate Strata of the Devonian Onondaga Limestone

Only one site infected with WNS before September 2009 is located in the Devonian Onondaga Limestone (Figs. 3 and 8). This site is Clarksville Cave in New York.

Clarksville Cave (Ward-Gregory Cave), Albany County, NY (Site 16 on Fig. 2):

Cave Map: Map dated 1995 in Engel (1999).

Stratigraphy: Lower part of the Middle Devonian Onondaga Limestone (Gregg, 1974; Kastning, 1975; Cullen et al., 1979; Rubin, 1986, 1991; Engel, 1999, 2009).

Hydrology: A perennial stream flows through much of the cave.

Cave Meteorology: Porter (2004) described several months of air temperature records at two locations in the cave. At one location, air temperature ranged from 7.8 to 8.3 °C from mid-March through late June 2003, and air temperature increased from 8.3 to 10.6 °C from late June through late August 2003. At the other location, air temperature ranged from 4.4 to 9.4 °C from late October 2003 through early July 2004, with the lower temperatures occurring from late January to late February.

WNS Infection Report: Porter (2008a,b), Armstrong (2009), and Youngbaer (2009a).

Devonian Schist

Only one site infected with WNS before September 2009 is located in Devonian schist (metamorphosed mudstone; Figs. 3 and 8). This site is Elizabeth Mine in Vermont.

Elizabeth Mine, Orange County, VT (Site 13 on Fig. 1):

Mine Maps: Undated maps in Howard (1969), Annis et al. (1983), and Slack et al. (2001).

Stratigraphy: Lower Devonian Gile Mountain Formation, which consists of schist, quartzite, and amphibolite (Howard, 1959a,b, 1969; Annis et al., 1983; Slack et al., 1993; Kierstead, 2001; Slack et al., 2001; Balistrieri et al., 2007). The Gile Mountain Formation is approximately equivalent stratigraphically to the Lower Devonian siliciclastic strata shown in Figures 3 and 8.

Mined Commodities: Iron from 1793 to 1809, pyrrhotite from 1809 to 1830, and copper from 1830 to 1919 and from 1943 to 1958.

WNS Infection Report: USGS NWHC (Quarterly Mortality Reports, 2008, Quarter 4). A WNS infection in Orange County (VT) was also reported by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1), although it is not clear whether this 2009 report describes the infection at Elizabeth Mine or at a different location.

Mississippian Strata

No WNS-infected caves or mines were identified in Mississippian strata (Figs. 3 and 15) prior to September 2009. However, in March 2010, Cassell Cave in Pocahontas County of West Virginia became the first WNS infection site identified in Mississippian strata (reported online at http://www.forums.caves.org/viewtopic.php?f=58&p=84299). The lack of WNS infection sites in Mississippian strata prior to March 2010 is notable because the Mississippian carbonate interval is one of the three major cave-forming intervals in the Appalachian region (the other two intervals being the Cambrian-Ordovician carbonate strata and the Silurian-Devonian carbonate strata; Fig. 3). In the Appalachian Basin, most caves in Mississippian strata (including Cassell Cave) have formed in the lower Greenbrier Limestone (Fig. 15). In southwestern Pennsylvania, however, many caves have formed in the Mississippian Loyalhanna Member of the Mauch Chunk Formation (Fig. 15), which is a quartz sandstone that is cemented by calcite (Krezoski et al., 2006).

Pennsylvanian Strata

Four of the sites infected with WNS before September 2009 are located in Pennsylvanian strata (Fig. 3). These sites are abandoned coal mines in the State of Pennsylvania (two mines at Carbondale, the Dunmore Mine, and the Shickshinny Mine).

Two mines at Carbondale, Lackawanna County, PA (Sites 66 and 67 on Fig. 1):

Mine Map: None published.

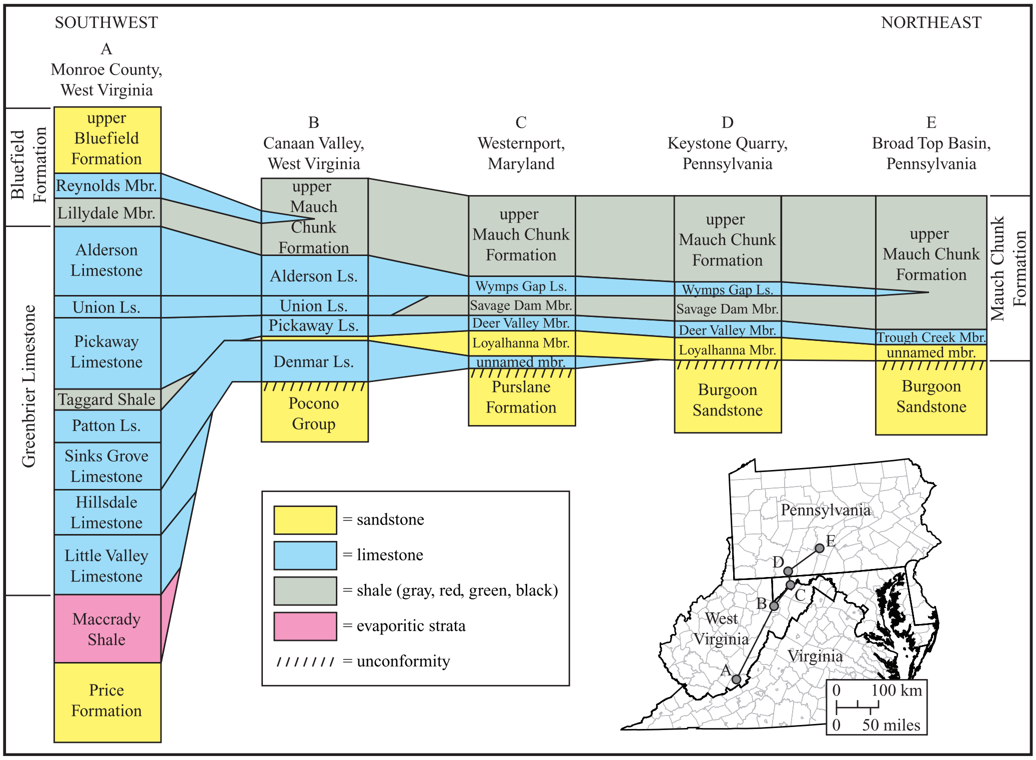

Figure 15. Southwest to northeast cross-sections of the Mississippian Greenbrier Limestone and associated strata from southern West Virginia to central Pennsylvania (modified from Wells, 1950; Cecil et al., 2004). Horizontal and vertical distances are not to scale.

Stratigraphy: A coal bed or coal beds of the Pennsylvanian Llewellyn Formation.

Mined Commodity: Coal (anthracite).

WNS Infection Report: The Pennsylvania Game Commission (http://www.portal.state.pa.us/portal/server.pt/gateway/PTARGS_0_2_112129_9109_615025_43/http%3B/pubcontent.state.pa.us/publishedcontent/publish/marketingsites/game_commission/content/wildlife/wildlife_diseases/white_nose_syndrome/wns_documents/2009_press_releases_019_09.pdf) and the Pennsylvania Department of Conservation and Natural Resources (http://www.dcnr.state.pa.us/news/resource/res2009/09-0311-resource.aspx#blurb2).

<u>The Dunmore Mine, Lackawanna County, PA</u> (Site 55 on Fig. 1):

Mine Map: None published.

Stratigraphy: A coal bed or coal beds of the Pennsylvanian Llewellyn Formation (Baughman and Gadinski, 1997).

Mined Commodity: Coal (anthracite).

WNS Infection Report: USGS NWHC (Quarterly Mortality Reports, 2008, Quarter 4).

<u>The Shickshinny Mine, Luzerne County, PA</u> (Site 56 on Fig. 1):

Mine Map: None published.

Stratigraphy: A coal bed or coal beds of the Pennsylvanian Llewellyn Formation.

Mined Commodity: Coal (anthracite).

WNS Infection Report: The Pennsylvania Department of Conservation and Natural Resources (http://www.dcnr.state.pa.us/news/resource/res2009/09-0311-resource.aspx#blurb2).

Jurassic Strata

Only one of the sites infected with WNS before September 2009 is located in strata of Jurassic age (~200 to 146 Ma, according to Gradstein et al., 2004). This site is a mine in Connecticut named New-Gate Prison Mine.

<u>New-Gate Prison Mine, Hartford County, CT</u> (Site 65 on Fig. 1):

Mine Map: Undated map in Huntington (1963).

Stratigraphy: Redbeds and sandstone of the Jurassic Portland Formation of the Newark Supergroup (Huntington, 1963; Penn and Gray, 1987).

Mined Commodity: Copper, mined prior to 1837.

WNS Infection Report: Suggested by Kocer (2009) and reported by Anonymous (2009a). In addition, a WNS infection in Hartford County (CT) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

UNKNOWN LOCATIONS

In addition to the sites described above, nine sites infected with WNS before September 2009 have been identified by state and county location, but the names of these sites and more detailed location information are not available. These nine sites are displayed on a map by Cal Butchkoski of the Pennsylvania Game Commission available online at http://www.portal.state.pa.us/portal/server.pt/gateway/PTARGS_0_2_112129_9109_615025_43/http%3B/pubcontent.state.pa.us/publishedcontent/publish/marketingsites/game_commission/content/wildlife/wildlife_diseases/white_nose_syndrome/images/wnsmap.jpg. Versions of Butchkoski's map have been published in Blehert (2009) and Turner and Reeder (2009). The available information about these sites is listed below as follows:

1) One cave in Onondaga County, NY (Site 45 on Fig. 1).
2) One site in Hamilton County, NY (Site 46 on Fig. 1).
3) One cave in Washington County, NY (Site 47 on Fig. 1): Although an exact site name was not given, a WNS infection in Washington County (NY) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).
4) One site in Washington County, VT (Site 14 on Fig. 1). Although an exact site name was not given, a WNS infection in Washington County (VT) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).
5) One mine in Windham County, VT (Site 11 on Fig. 1). Although an exact site name was not given, a WNS infection in Windham County (VT) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).
6) One mine in Grafton County, NH (Site 50 on Fig. 1). WNS infection at this site was also reported at the following website: http://www.wildlife.state.nh.us/Newsroom/News_2009/News_2009_Q3/bats_WNS_July_09.html. Although an exact site name was not given, a WNS infection in Grafton County (NH) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).
7) One mine in Merrrimack County, NH (Site 49 on Fig. 1). WNS infection at this site was reported at the following website: http://www.wildlife.state.nh.us/Newsroom/News_2009/News_2009_Q3/bats_WNS_July_09.html.
8) One mine in Franklin County, MA (Site 23 on Fig. 2).
9) One site in Hartford County, CT (Site 32 on Fig. 2). WNS infection at this site was suggested by Kocer (2009). This site is not the New-Gate Prison Mine site (Site 65 on Fig. 1), which is also located in Hartford County (CT). Although an exact site name was not given, a WNS infection in Hartford County (CT) was confirmed by the USGS NWHC (Quarterly Mortality Reports, 2009, Quarter 1).

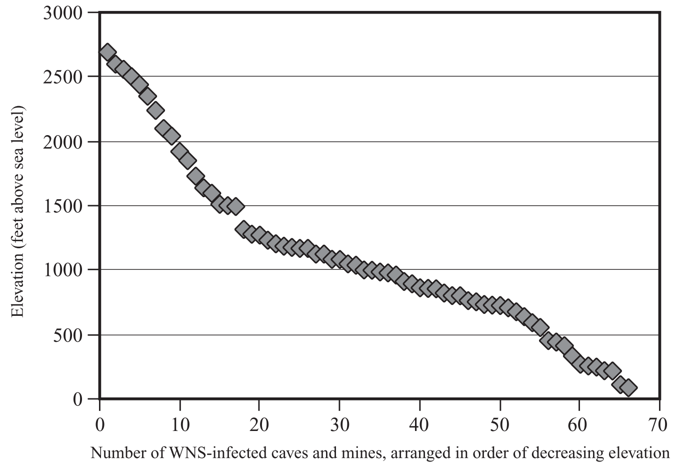

Figure 16. Elevation (feet above sea level) of caves and mines infected with WNS before September 2009, arranged in order of decreasing elevation. Data are given in Table 1.

DISCUSSION

The data presented in this paper reveal that sites infected with WNS before September 2009 are characterized by a wide range of geographical parameters (latitude, longitude, elevation, type of bat hibernaculum). These data also show that the infected sites encompass a wide range of geological parameters (lithology, age of strata) and meteorological parameters (air temperature, humidity).

GEOGRAPHICAL PARAMETERS

The sites infected with WNS before September 2009 are found throughout a wide geographical range in the eastern United States, but most of these sites are located in the State of New York. In order of abundance, the infected sites are listed according to State as follows: New York (n=33), Vermont (n=10), Pennsylvania (n=8), Massachusetts (n=6), Virginia (n=5), West Virginia (n=4), Connecticut (n=4), New Jersey (n=3), and New Hampshire (n=2). The preponderance of infected sites in New York is probably related to the location of the initial infection site. As stated above, the WNS infection is thought to have appeared first in a cave connected to Howe Caverns in New York, and to have spread subsequently to all of the other sites.

The available data show that the known elevations of sites infected with WNS before September 2009 range from 84 to 2693 feet above sea level, although there is no specific elevation around which most of these infected sites are clustered (Fig. 16). These data suggest that elevation alone may not exert a strong control on the spread of WNS. However, all of the sites infected with WNS prior to September 2009 are restricted to the eastern side of the Appalachian Basin geological province and locations immediately north and east of the Appalachian Basin. It is not apparent why WNS has spread primarily north, south, and east from the initial infection site, rather than to the west. One possible explanation is that the Appalachian Mountains may present some barrier to the spread of WNS, even though elevation alone does not appear to exert a strong control. For example, the presence of the Appalachian Mountains may influence bat migration pathways (re: bat transmission of WNS) as well as human travel patterns (re: human transmission of WNS). The first occurrence of WNS infection west of the Appalachian Mountains occurred in March 2010, at a commercial cave in the Dunbar Cave State Natural Area, Montgomery County, Tennessee (reports available online at http://www.dunbarcave.org/ and at http://www.theleafchronicle.com/article/20100324/NEWS01/100324016/Bat-in-Clarksville-s-Dunbar-Cave-tests-positive-for-deadly-fungusC:/Documents%20and%20Settings/schillers/My%20Documents/Advisement).

All of the sites infected with WNS before September 2009 are bat hibernacula, but the WNS infection is not restricted to one specific type of hibernacula. According to the data in Table 1, 44 of the sites infected with WNS before September 2009 are natural caves, 28 of these infected sites are abandoned mines, and 3 of these sites are of undetermined settings. The preponderance of natural cave settings is probably due to the fact that natural caves make up the preponderance of locations where bats hibernate in large groups.

Geological Parameters

With respect to lithology, most of the sites infected prior to September 2009 are located in sedimentary rocks (n=53), although some of the infected sites are located in metamorphic rocks (n=10), igneous rocks (n=3), and undetermined geological settings (n=9). Of the infected sites that are known to be in sedimentary rocks, 46 are located in carbonate strata, and 7 are located in sandstone or mudstone. The infected sites that are known to be in metamorphic rock are located in both meta-sedimentary and meta-igneous rock, whereas the infected sites that are known to be in igneous rocks are located in granite and serpentinite. In this list, amphibolite and granite gneiss are considered to be metamorphosed igneous rocks. The preponderance of WNS infection sites being located in carbonate strata is probably due to the fact that most bat hibernacula are natural caves in carbonate strata.

With respect to stratigraphic age, the sites infected with WNS before September 2009 are located in rocks that range from Precambrian to Jurassic. However, it is interesting to note that none of these sites (pre-September 2009) are located in rocks of Mississippian, Cretaceous, or Triassic age. Nine of the known infection sites are located in Precambrian-Cambrian igneous or metamorphic rocks, 19 of the sites are located in Cambrian-Ordovician carbonate strata, 5 of the sites are located in Ordovician-Silurian non-carbonate strata (gneiss, schist, sandstone), 27 of the sites are located in Silurian-Devonian carbonate strata, 1 site is located in Devonian schist, 4 sites are located in Pennsylvanian coal-bearing strata, and 1 site is located in Jurassic sandstone. Nine sites are situated in an unknown stratigraphic context.

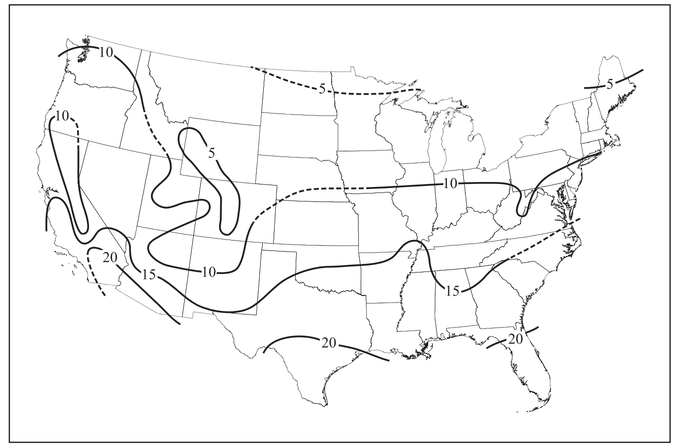

Figure 17. Map of mean cave temperatures (degrees Celsius) in the United States (from Moore and Sullivan, 1978, p. 28). This map is based primarily on theoretical calculations, rather than measured data.

It is not clear why most of the WNS-infected sites are located in Silurian-Devonian carbonate strata. However, the initial infection site is believed to be a cave that is connected to Howe Caverns, which are commercial caverns located in Silurian-Devonian carbonate strata. Thus, the preponderance of infection sites in Silurian-Devonian carbonate strata may have something to do with the location and setting of the initial infection site. Likewise, it is not clear why no infected sites were identified in Mississippian strata prior to March 2010, even though many caves are present in Mississippian limestone. However, Mississippian strata are located to the west of most of the other identified sites (Fig. 1), and thus the lack of infected sites in Mississippian strata (prior to March 2010) may be related to some of the geographical parameters discussed above. [Note: The first appearance of WNS infection in Mississippian strata was reported in March 2010 from Cassell Cave in Pocahontas County, West Virginia (reported online at: http://www.forums.caves.org/viewtopic.php?f=58&p=84299)].

Meteorological Parameters

Information on temperature and humidity conditions in caves and mines might be useful for predicting the spread of WNS because *Geomyces destructans* apparently prefers cold, humid conditions. Unfortunately, not much data have been published on meteorological conditions in caves or mines, and much of the available data are single measurements taken on only one day. Nevertheless, a brief review of some governing principles and assumptions is presented below, followed by a discussion of the meteorology of the WNS-infected sites.

It is generally assumed that the air temperature in a cave is approximately equal to the annual average outside air temperature at a given location (e.g., Davies, 1958). This assumption has been used to produce a map of assumed cave temperatures in the United States (Fig. 17). Fowler (1941), however, noted that the assumption of cave temperature being approximately equal to the annual average outside air temperature appears to be true only of caves or portions of caves that have a very low rate of air circulation.

For a cave without flowing water and with only one entrance, air circulation is usually limited and the air temperature in deep parts of the cave is controlled by the temperature of the surrounding rock, which is approximately equal to the average annual air temperature at the surface (Wigley and Brown, 1976; Moore and Sullivan, 1978). The air temperature at the surface is controlled by daily and seasonal temperature fluctuations, which in turn are functions of latitude and altitude. The effects of air temperature fluctuations at the surface diminish as heat moves down through the rock. Thus, fluctuations in air temperature are greater at cave entrances and in shallow caves, and these fluctuations diminish at greater distances from the cave entrances and greater depths below the surface. In some instances, where a cave extends directly downward from the entrance, the air temperature in the cave may be cooler than one might predict (Moore and Sullivan, 1978). With these caves, which are called "cold-trap caves," dense cold air flows into the cave during the winter. During the summer, however, air circulation ceases and the cold air is trapped in the cave.

For caves with more than one entrance, air temperature and pressure differences inside and outside the cave may create an air flow pattern that is referred to as a "chimney effect" (Wigley and Brown, 1976; Moore and Sullivan, 1978). In this situation, a temperature difference produces a pressure difference between the cave entrances, and air flows either into or out of the cave in order to equilibrate the temperature and pressure differences between the entrances. This effect is usually more prominent where a cave has two entrances at very different elevations.

Some caves exhibit a phenomenon of oscillating air flow in and out of the cave (referred to as "cave breathing"). This phenomenon was the subject of much speculation and study during the 1940s through 1960s (Faust, 1947; Cournoyer, 1954, 1956; Plummer, 1962; Wigley, 1967). A review by Lewis (1991) suggests that many reports of "cave breathing" are caused by variations in atmospheric pressure at the entrance of a cave, although falling water in a resonant cavity may also cause the phenomenon of "cave breathing."

For caves in which water flows, cave air temperature may be affected by the water (Wigley and Brown, 1976; Moore and Sullivan, 1978). For example, where relatively warm water flows into a cave, this water may transport warmth into the cave further than would be transported by air flow alone. In contrast, where relatively cold water flows into a cave (e.g., caves that receive large quantities of snowmelt in the spring), this water may transport cold air into the cave further than would be transported by air flow alone. In addition, the flow of water can induce the flow of air adjacent to the water, thus generating air currents deeper in the cave than would otherwise occur.

From the sparse data available, the sites infected with WNS before September 2009 appear to have air temperatures ranging from 0 to 13.9 °C. Most of these temperatures are within the range of 5 °C and 10 °C that is reported as being optimal for growth of *Geomyces destructans*. If Blehert et al. (2009) are correct that *G. destructans* does not grow at temperatures greater than 20 °C, then mapping the distribution of a 20 °C temperature threshold would be important for predicting the spread of WNS. Judging from the sparse data that are available, a 20 °C cave temperature threshold is likely to lie south of most of the continental United States (Fig. 17) and north of Puerto Rico (where air temperatures in many caves are approximately 25 to 26 °C; Rodríguez-Durán, 1998).

The available measurements on air temperatures from these caves and mines infected with WNS before September 2009 do not show clear geographic correlations such as one might expect from Figure 17. Although most of the recorded air temperatures in the infected caves and mines range from 4.4 to 13.9 °C, there does not appear to be any particular correlation of cave (or mine) air temperature with latitude (Fig. 18A), longitude (Fig 18B), or elevation (Fig. 19). This lack of apparent correlation could be caused by a variety of reasons. For example, some of the infected caves and mines have single entrances, whereas other infected caves and mines have multiple entrances. Some of the infected caves and mines may be associated with air circulation patterns such that the sites function as "cold-trap caves" or "cold-trap mines." In addition, some of the infected caves and mines have flowing water, whereas others do not. Finally, it is possible that some data may be erroneous because of human effects (e.g., the presence of humans may increase the air temperature in a cave when measurements are taken).

The data on humidity at sites infected with WNS before September 2009 are sparser than the data on air temperature. Published data are available from only four sites, showing a range of humidity measurements from 68 to 100 percent. With regards to *Geomyces destructans*, a humidity threshold below which the fungus does not grow has not been identified, although anecdotal field evidence suggests that the fungus may prefer relatively high humidity.

As with the air temperature data, there does not appear to be any particular correlation of cave or mine humidity with latitude (Fig. 20A), longitude (Fig 20B), or elevation (Fig. 21). However, reliable measurements of cave humidity can be very difficult to obtain (Wefer, 1991; Mitchie, 2006), and certain correlations might become apparent if more data were available.

Other Environmental Parameters

It is possible that several other environmental parameters may influence WNS, in addition to the geographical, geological, and meteorological parameters discussed above. For example, there may be a relation between WNS and the chemistry of cave sediments. Likewise, there may be a relation between WNS and the presence and (or) distribution of other

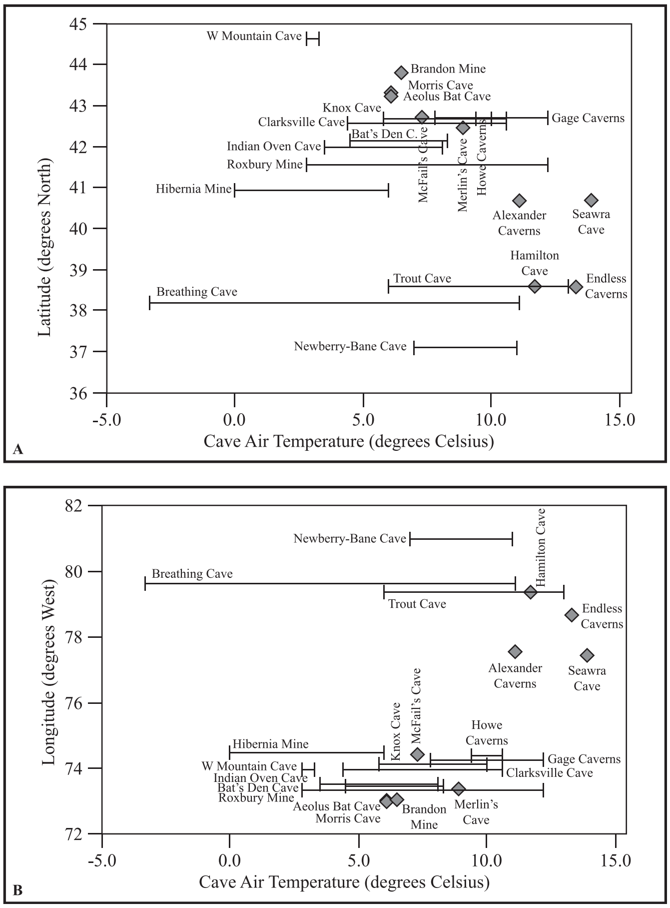

Figure 18. A (upper chart) = Cave air temperature versus latitude. B (lower chart) = Cave air temperature vs. longitude. Latitude and longitude data were calculated for the WNS-infected sites while constructing Figures 1 and 2. However, specific latitude and longitude values are not given in Table 1 for reasons of cave security. Where only one temperature measurement is recorded, this value is represented by a diamond. Where multiple temperature measurements are recorded, the most frequent value is represented by a diamond and the full range of values is represented by the horizontal lines that extend from the diamond.

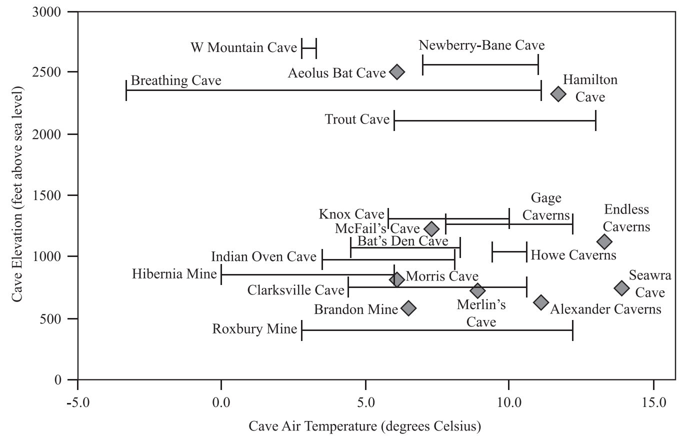

Figure 19. Cave air temperature versus elevation. Elevation data are given in Table 1. Where only one temperature measurement is recorded, this value is represented by a diamond. Where multiple temperature measurements are recorded, the most frequent value is represented by a diamond and the full range of values is represented by the horizontal lines that extend from the diamond.

fauna besides bats. At present, it is not known if WNS affects other animals (e.g., cave rats). Finally, there may be a relation between WNS and specific behaviors of bats.

Conclusions

As of September 2009, 75 known sites in the United States contained bats that were infected with the white-nose syndrome (WNS) fungus named *Geomyces destructans*. WNS appears to have spread from an initial infection site in a cave that is connected to commercial caverns (Howe Caverns) in New York, and by the end of August 2009 WNS had been identified in at least 74 other sites in the eastern United States. These WNS-infected sites extend from New Hampshire to Virginia, but most of the sites are located in the State of New York (33 of 75). The elevations of these WNS-infected sites (for which data are available) range from 84 to 2693 feet above sea level, but there is no specific elevation at which most of the infected sites are located. The infected sites include both natural caves and mines, although most of the known infected sites for which data are available are natural caves (n=44). In terms of geological setting, the infected sites are located in sedimentary, metamorphic, and igneous rocks, although most of the infected sites for which data are available are located in sedimentary rocks (n=53). Of the infected sites that are known to be in sedimentary rocks, 46 are in located carbonate strata and 7 are located in sandstone or mudstone. Furthermore, these WNS-infected sites are located in rocks that range in age from Precambrian to Jurassic, although as of the end of August 2009 no infected sites were located in strata of Mississippian, Cretaceous, or Triassic age. The majority of the infected sites for which data are available are located in either Silurian-Devonian carbonate strata (n=27) or Cambrian-Ordovician carbonate strata (n=19). Meteorological data are sparse, but most of the recorded air temperatures range from 0 to 13.9 °C in caves and mines infected with WNS before September 2009, and humidity measurements range from 68 to 100%.

Many questions still remain about the nature and origin of WNS, and it is not yet clear which environmental parameters may exert controls on the distribution and behavior of WNS. Based on the information presented in this paper, it appears that the spread of WNS will not be restricted by the elevation of the sites, the lithology in which caves or mines are located, or the age of the strata in which caves or mines are located. Air temperature of 20 °C is reported to be a temperature threshold above which *Geomyces destructans* does not grow, and this temperature threshold is likely to lie south of most of

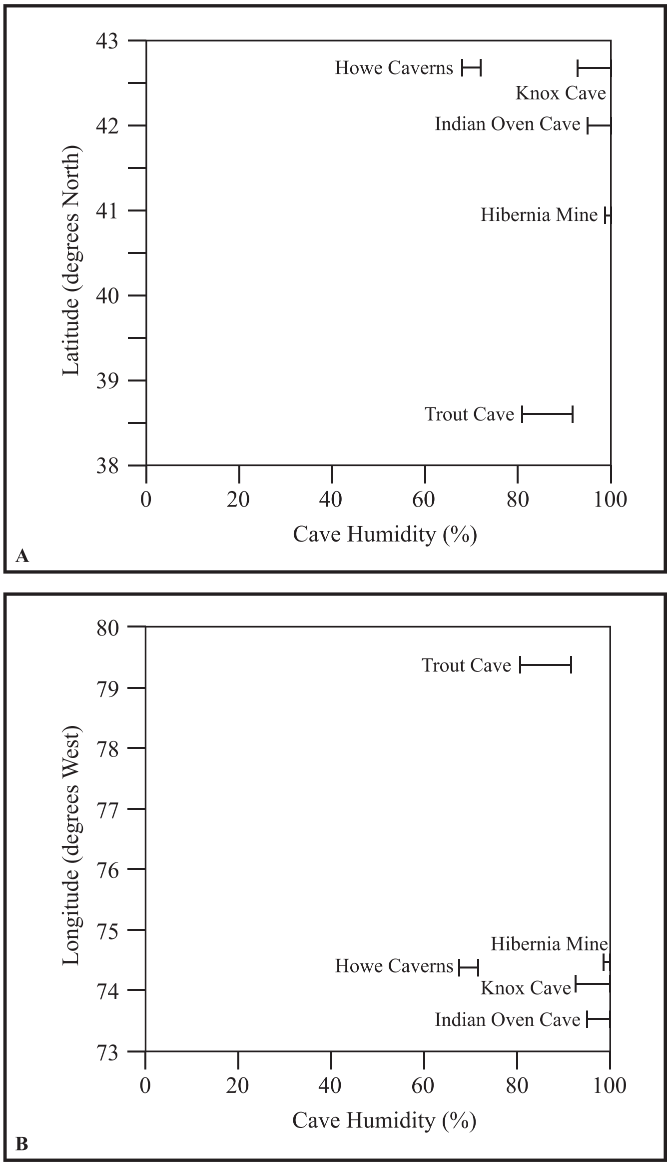

Figure 20. A (upper chart) = Cave humidity vs. latitude. B (lower chart) = Cave humidity vs. longitude. Latitude and longitude data were calculated for the WNS-infected sites while constructing Figures 1 and 2. However, specific latitude and longitude values are not given in Table 1 for reasons of cave security. For each location, the range of measured values is denoted by vertical and horizontal lines.

the continental United States and north of Puerto Rico. It is also possible that the spread of WNS may be restricted by low humidity, although a humidity threshold below which the fungus does not grow has not been identified.

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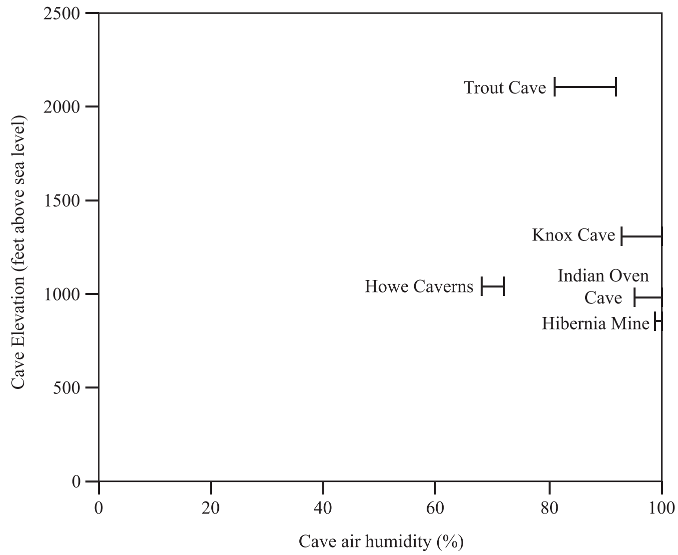

Figure 21. Cave air humidity vs. elevation. Elevation data are given in Table 1. For each location, the range of measured values is denoted by vertical and horizontal lines.

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