U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

INTRODUCTION

Karst is a landscape produced by dissolution of rocks and the development of integrated subterranean drainages dominated by the flow of ground water in solutionally enlarged conduits. Karst landscapes typically include cave entrances, sinkholes, blind valleys, losing streams, springs and large and small-scale solution features on bedrock surfaces. Water-bearing rocks beneath the surface containing solutionally enlarged pores, fractures, or conduits are referred to as karst aquifers. About 40% of all ground water extracted in the United States comes from karst aquifers (Karst Waters Institute).

Karst means many things to many people. To most cavers and many speleologists, karst means areas containing caves. To engineers, home builders, local governments, and insurance companies karst is exemplified by the occurrence of sinkholes and subsidence hazard. To hydrologists, well drillers, and environmental consultants, the focus on karst may be more limited to karst aquifers and springs.

Precise figures are not available, but ground collapses in karst areas in the United States require hundreds of millions of dollars in repair and mitigation costs each year. Most karst in the United States is formed in either carbonate or evaporite rocks. This map depicts only areas of carbonate rock outcrop, the chief host for karst formation in the eastern United States.

The U.S. Geological Survey (USGS), in cooperation with the National Cave and Karst Research Institute (NCKRI), the National Speleological Society (NSS), and various State geological surveys is working on a new national karst map that will delineate areas of karst and karst-like features nationwide. This product attempts to identify potentially karstic areas of the Appalachian states as defined by the Appalachian Regional Commission (ARC), with the addition of the state of Delaware. This map is labeled preliminary because there is an expectation that it will be revised and updated as part of a new, national karst map. The ARC is a federal-state partnership that works with the people of Appalachia to create opportunities for self-sustaining economic development and improved quality of life. Its area is based on the location of counties in the Appalachian highlands and some socio-economically similar adjacent counties (fig. 1).

This product is intended to broadly delineate areas likely to contain karst features of any type, but primarily caves and sinkholes. Since this map displays data at a regional scale for a future depiction of karst areas at a national scale, it does not contain discrete karst features such as caves, sinkholes, and springs. Therefore, this dataset should not be used for site-specific research, but rather as an indicator that karst features may occur in, but not be limited to, certain areas.

METHODOLOGY

Many factors affect the development and degree of development of karst in a particular area. These include: bedrock lithology, climate, geologic structural setting, local hydrologic gradient, etc., and possibly a history of rising thermal or acidic waters. The areas delineated by this map were subdivided on the basis of only a few factors, expanded below. See Palmer (2007) for a comprehensive discussion of karst geology.

The study area includes parts of the Atlantic Coastal Plain, Piedmont, Blue Ridge, Valley and Ridge, Appalachian Plateaus, Adirondack, St. Lawrence Valley, Interior Low Plateaus, Central Lowland, and Gulf Coastal Plain Physiographic Provinces (Fenneman, 1946). Since the physiographic divisions, provinces, and sections reflect terrain texture, rock type, geologic structure and history, and erosional history, they broadly incorporate several of the factors known to influence karst development. As such, they have the potential to make a convenient and useful framework for organizing karst areas into regions.

It is assumed that in the eastern United States, where there is relatively abundant rainfall, karst will form in areas underlain by relatively soluble rocks such as limestone and dolomite. This was the approach taken by Davies and others (1984) in producing the National Atlas karst map at a scale of 1:7.5 million. A digital version, including the Geologic Information System (GIS) data, of the Davies and others map is available at the USGS National Atlas web page at: http://nationalatlas.gov/natlas/Natlasstart.asp.

Delineation of potentially karstic rocks for this map was based primarily on the bedrock geology and lithologic descriptions provided by individual state geologic maps. Most formation and group names and descriptions were checked against the online USGS geologic names lexicon (GEOLEX) for correct usage, additional lithologic descriptions, and primary references (http://ngmdb.usgs.gov/Geolex/geolex_home.html).

Level of induration, metamorphic grade, geologic/physiographic setting, large scale structural regime, and thickness of glacially derived overburden were also considered. The result was definition of seven general potentially karstic bedrock types (labeled "K_TYPE" in the GIS database). These are: 1). Coastal Plain unconsolidated calcareous sediments (CPU), 2). Coastal Plain carbonate rocks (CPCR), 3). Triassic and Jurassic basin-fill calcareous sedimentary rocks (TJB), 4). Gently folded to flat-lying carbonate rocks (GC), 5). Carbonates interbedded with relatively insoluble sedimentary rocks (IC), 6). Folded and faulted carbonate rocks (FFC), and 7) Marble (M). Several of these map units are further subdivided into areas overlain by significantly thick (>50 ft (15 m.)) glacially-derived surficial deposits. See the Description of Map Units for a more detailed discussion of each unit.

The boundary between the steeply folded and faulted rocks found chiefly in the Appalachian Valley and Ridge Province (FFC) and the gently-folded to flat-lying rocks found chiefly in the Appalachian Plateaus Province (GC) was delineated using the Allegany structural front from Williams (1978). This line approximates, but does not always coincide with the physiographic province boundaries.

Areas overlain by widespread glacially derived sediments of 50 ft or greater (>15 m.) thickness were classified as a different map unit. This thickness is arbitrary and was selected because it is assumed to be thick-enough to obscure the surface expression of all but the largest karst features and was one of the thickness classes of the GIS data set used to overlay glacial sediments over the karst map (Soller and Packard, 1998). Pavey and others (2002) noted that in Ohio, sinkholes were expressed through as much as 20 ft of non-carbonate material. No attempt has been made in this version to address the effects of glacial removal of rocks and karst from northern parts of the map area during the Pleistocene.

In some states, for example Kentucky (Paylor and Currens, 2001) and Ohio (Pavey and others, 2002), a state karst map already existed, and these data were incorporated into this map and reclassified to match the scheme used here.

KARST IN THE STATES

This map was compiled from a variety of sources at regional and state scales. Source data sets had resolutions ranging from scales of 1:1,000,000 to 1:24,000. Although every effort was made to resolve discontinuities across state boundaries, some still exist as a result of differences in scale, mapping philosophy, and comprehensiveness of lithologic descriptions between the disparate data sets. This compilation, printed at a scale of 1:2,000,000, is intended to be used at scales of 1:1,000,000 and smaller. This map should not be used for site-specific analysis. The karst distribution of each state is discussed separately, with a brief description of the physiographic setting, data sources, and principal karst and cave areas. A note is made of past NSS national conventions held in each state. Most NSS conventions were accompanied by a guidebook with references to the caving resources in the state or region where the meeting was held. The GIS data are also organized by state with each polygon incorporating a state attribute. This product is intended as an overview, and not an exhaustive discussion or bibliography of the caves and karst of the Appalachian states. All website addresses were checked at the time of publication. Because of the ephemeral nature of such addresses, no guarantee is made of their currency or even existence at the time of reading.

New York

New York's diverse physiography includes parts of the Atlantic Coastal Plain, Piedmont, Valley and Ridge, Adirondack, St. Lawrence Valley, Appalachian Plateaus, and Central Lowland Provinces.

Potential karst units for New York were derived from a rock-type map produced by the New York State Geological Survey at a scale of 1:1,000,000 (Fickies and Fallis, 1996). This map identified areas of carbonate rock classified as: limestone and dolostone with shale, limestone and dolostone with sandstone and shale, marble and marble with inter-layered crystalline rock. Because of this scheme, potential areas in the karst of mixed lithologic units are overstated. Areas of soluble rock overlain by thick deposits of glacially derived sediment may be found locally throughout the state. These overlying sediments profoundly affect the expression of most karst features. These areas were identified by extracting polygons indicating a glacial overburden greater than 50 ft thick from the dataset of Soller and Packard (1998) and intersecting them with the polygons delineated in the New York rock type map (Fickies and Fallis, 1996).

There are no potentially karstic units identified in the Atlantic Coastal Plain of New York. In the Piedmont in the southeastern part of the state, marble and marble with interlayered crystalline rock occurs in Orange County.

In the narrow Valley and Ridge Province, areas of Paleozoic carbonate rock outcrop were mapped as potentially karstic units (K_TYPE=FFC and FFCG). A belt of Silurian and Devonian limestone and dolomite extend from southeastern part of the state, marble and marble with interlayered crystalline rock occurs in Orange, Sullivan, Ulster, and Green Counties. At the north end of the province, Cambrian and Ordovician limestone and dolostone crop out in Rensselaer, and Washington Counties. These rocks continue to crop out to the north in the St. Lawrence Valley Province in Essex and Clinton Counties and along the shore of the St. Lawrence River in Franklin and St. Lawrence Counties.

The Adirondack Province comprises metamorphic rocks and contains marble and marble with interlayered crystalline rock (K_TYPE=M and MG). These areas currently overstate the actual extent of potentially karstic rocks.

Two belts of Silurian to Devonian dolostone and limestone trend from east to west across the northern part of the Appalachian Plateaus Province from Albany County into Onondaga County. These belts continue to the west into the Central Lowlands through the counties south of Lake Ontario to the Niagara River. These areas are classified as K_TYPE=GC and GCG.

The most popular caving area in New York is the area along the eastern edge of the Appalachian escarpment southwest of Albany. The largest concentration of caves extends from the Onesquethaw Creek Valley westward to the area of Cobleskill. Howe Caverns, New York's best known commericial cave, is developed in the Silurian-Devonian Coeymans, Manlius, and Rondout Limestones in this area of Schoharie County. A description of caves in Schoharie County was published by the NSS in 1966.

New York has hosted one NSS national convention, in Cobleskill in 1991.

Pennsylvania

Pennsylvania spans, from east to west, the Piedmont, Blue Ridge, Valley and Ridge, and Appalachian Plateaus Provinces and is underlain by chiefly Paleozoic sedimentary rocks. Pleistocene glacial sediments, locally more than 50 ft thick, overly the bedrock in northern parts of the state (Soller and Packard, 1998).

Potentially karstic units for Pennsylvania were derived from a digital version of the 1:250,000-scale state geologic map published on the internet by the Pennsylvania Geological Survey (Miles and others, 2001).

In the Piedmont, primarily in Chester County, Lower Paleozoic marbles that may be karstic (K_TYPE=M) include the Cockeysville, Franklin, and Wakefield Marbles. Triassic limestone conglomerates are found in Mesozoic basins in a northeast to southwestward-trending belt in Berks, Lancaster, Lebanon, York, and, Adams Counties (K_TYPE=TJB).

No karstic units were identified in the Blue Ridge Province of Pennsylvania.

In the Valley and Ridge Province, including the Hamburg klippe, potentially karstic rock units range from Early to Late Paleozoic ages. These are classified K_TYPE=FFC. Units (listed alphabetically) include the: Allentown, Annville, and Axemann Formations; Beekmantown Group, Bellefonte and Axemann Formations, undivided, Benner and Loysburg Formations undivided, Bloomsburg and Mifflintown Formations, undivided, Buffalo Springs Formation, Buttermilk Falls Limestone, Chambersburg, and Coburn Formations, Coburn through Nealmont Formations, undivided, Conestoga Formation, Decker through Poxono Island Formations, undivided, Elbrook and Epler Formations, the Hamilton Group, Hershey through Annville Formations, undivided, Hershey and Myerstown Formations, undivided, Jacksonburg Formation, Keyser Formation through Clinton Group undivided, Keyser through Mifflintown Formations undivided, Keyser and Tonoloway Formations undivided, Kinzers, Ledger Formation, and Leithsville Formations, limestone of Hamburg sequence, limestone of the Martinsburg Formation, Lower (Middle?) Cambrian rocks, undifferentiated, lower members of Gatesburg Formation, undivided, Mahantango, and Marcellus Formations, Mauch Chunk Formation (only in the south and western parts of the state where it contains the Loyalhanna, Greenbrier, Wymps Gap and Deer Valley Limestone Members, spans both Valley and Ridge and Plateau Provinces), the Millbach Formation, Millbach and Schaefferstown Formations, undivided, Mines Member of the Gatesburg Formation, the Nittany Formation, Nittany and Stonehenge/Larke Formations, undivided, Onondaga Formation through Poxono Island Formation, undivided, the Onondaga, Ontelaunee, Pinesburg Station, Pleasant Hill, Richland, and, Rickenbach Formations; Ridgeley Formation through Coeymans Formation undivided, Rockdale Run and Shadygrove Formations; Shriver, Mandata, Corriganville, and New Creek Members of Old Port Formation undivided; the Snitz Creek Formation; Snitz Creek and Buffalo Springs Formations, undivided; the St. Paul Group; the Stonehenge Formation; Stonehenge and Larke Formations; the Tomstown Formation; Valentine Member of Benner Formation; Vintage, Warrior, and Wills Creek Formations; Wills Creek Formation through Mifflintown Formation, undivided; Zooks Corner and Zullinger Formations. Some of these units are locally overlain by glacially derived sediments in parts of Monroe, Luzerne, Columbia, and Lycoming Counties in the northeast part of the state (K_TYPE=FFCG).

In the Appalachian Plateau of Pennsylvania, units that are potentially karstic (K_TYPE=GC, GCG) include: the Mauch Chunk, and Allegheny Formations, and Monongahela Group. Areas defined by these formations greatly overstate the potential karst area, as both are primarily clastic units; however, each contains limestone known to be karstic. The Mississippian Mauch Chunk Formation contains the Loyalhanna, Greenbrier, Wymps Gap, and Deer Valley Limestone Members and the Pennsylvanian Allegheny Formation contains the Vanport Limestone Member. The Loyalhanna and Vanport Limestones are the primary cave-bearing units in western Pennsylvania (White, 1976). Areas underlain by the Allegheny Formation taken from the state geologic map were reduced and altered based on the description of the distribution of the significant limestone facies in that unit by Rice and others (1994).

The Pennsylvanian Monongahela Group, which crops out in the southwestern corner of the state, contains the Benwood limestone (informal unit, also called the Sewickley Member of the Uniontown Formation in the past (Berryhill and others, 1971)) which is significantly thick (as much as 70 ft). No references mentioning the presence of caves were found for the Benwood, but it does contain karst springs and must at least have solutionally enlarged joints and bedding planes, if not minor caves. It is classified in this report as K_TYPE=IC. The greatest potential for caves in the Benwood probably occurs adjacent to incised river valleys, much like the caves in the Vanport Limestone described by Sasowsky and others (2003). The outcrop area of the Benwood limestone extends to the west, across the northern West Virginia panhandle into eastern Ohio and to the southwest into northern West Virginia and southeastern Ohio.

The Pennsylvania Geological Survey has been actively mapping karst features and maintains an online database at: http://www.dcnr.state.pa.us/topogeo/hazards/sinkhole/default.asp. Karst feature maps at county scale are available as Pennsylvania Geological Survey Open-file Reports for several Pennsylvania counties, including Adams, Berks, Bucks, Centre, Chester, Cumberland, Dauphin, Franklin, Lancaster, Lebanon, LeHigh, Montgomery, Northhampton, and York (http://www.dcnr.pa.us/topogeo/pub/openfile.aspx). Karst density maps are also available for Center County (Reese and Kochanov, 2005) and South-Central and Southeastern Pennsylvania (Kochanov and Reese, 2003).

Pennsylvania currently hosts nine commercial caves scattered across the state from east to west in the Piedmont, Valley and Ridge and Appalachian Plateau provinces. Several regional or county-based descriptions of Pennsylvania caves have been published: Ashbrook (1991), LaRock (1976), Mostardi and Durant (1991), Reich (1974), Snyder (1989), and White (1976).

One NSS annual convention was hosted in Pittsburgh, Pennsylvania, in 1954.

New Jersey

New Jersey occupies parts of the Coastal Plain, Piedmont, and Valley and Ridge Physiographic Provinces.

Potentially karstic areas of New Jersey were identified by the distribution of carbonate rock units on state geology maps (Dalton, R.F., 1996a; Owens and others, 1995a and b). This selection was done by Donald Monteverde, New Jersey Geological Survey, who provided vector graphic files, which were then converted to GIS.

In the Coastal Plain, the Cretaceous Mount Laurel Formation contains sufficient calcareous material, chiefly bivalve shells, so that broad, shallow sinkholes are produced by solution. The Eocene Vincentown Formation, a highly calcareous greensand, is also susceptible to dissolution. There is also development of solution and flow conduits in these relatively unconsolidated materials, and thus, no cave formation and very little potential for collapse. These areas are classified K_TYPE=CPU.

In the Piedmont and Valley and Ridge Provinces karst occurs in the Proterozoic Franklin and Wildcat Marbles (Monteverde and Dalton, 2002)(K_TYPE=M).

Karst occurs in the Valley and Ridge Province in the Jacksonburg Limestone, Kittatinny Supergroup, and Middle Paleozoic carbonates of Late Silurian and Early Devonian age (K_TYPE=FFC and FFCG).

Glaciation apparently has had a major effect on the distribution of karst features in New Jersey. Only 11 of 142 known New Jersey caves are located south of the glacial terminal moraine (Monteverde and Dalton, 2002). However, Dalton (1996b) suggested increased sinkhole development south of the terminal moraine due to a more mature weathering profile.

"Caves of New Jersey" (Dalton, 1976) describes caves in the state.

Delaware

Delaware is not, technically, one of the Appalachian states but it has been included in this map because it is surrounded by Appalachian states. Most of Delaware lies in the Atlantic Coastal Plain Province, with the exception of a small area in the northernmost part of the state that lies in the Piedmont.

The only areas identified as potentially karstic in Delaware are a few places delineated by the outcrop of Cockeysville Marble in the extreme northernmost part of the state (Spoljaric and others, 1976)(K_TYPE=M). It is possible that areas of potentially karstic Coastal Plain units identified in New Jersey may extend along strike to the southwest from New Jersey, across the upper Delaware Bay, and into northern Delaware. Only one cave , Beaver Valley cave in Newcastle County, is reported from Delaware. This is not a solution cave, rather a rock shelter and fissure cave in insoluble metamorphic rock (Speece, 1977).

Maryland

Maryland spans an area, from east to west, of Atlantic Coastal Plain, Piedmont, Valley and Ridge, and Allegheny Plateaus Provinces. Lithologic units and descriptions for areas from the Coastal Plain are from an unpublished map of the Atlantic Coastal Plain (W.L. Newell, unpub. data, 2008). Descriptions of rocks from the rest of the state were obtained from a lithogeochemical map of the Chesapeake Bay watershed (Peper,and others, 2001).

Outcrop areas of Calvert, Choptank, and St. Marys Formations, undivided, which contain local concentrations of shelly calcareous material, are the only potentially karstic areas identified in the Maryland part of the Atlantic Coastal Plain (K_TYPE=CPU).

In the Maryland Piedmont, the Cockeysville Marble crops out in Howard and Baltimore Counties and the Wakefield Marble occurs in Frederick and Carroll Counties. Caves and sinkholes are reported in these units (Franz and Slifer, 1971)(K_TYPE=M).

The Frederick Valley, in Frederick County, is an inlier of Valley and Ridge-type rocks and Triassic and Jurassic basin rocks in the Piedmont Province. Triassic and Jurassic limestone-clast conglomerates of the Leesburg Member of the Bull Run Formation extend northward along the western edge of the Culpeper basin from Loudoun County, Virginia through the southern half of Frederick County. These conglomerates are known to be karstic (K_TYPE=TJB). The Cambrian Frederick Formation is the primary karstic unit in the Frederick Valley. It is overlain by the Grove Formation which has a smaller areal extent but develops a higher density of karst than the Frederick (Brezinski, 2004)(K_TYPE=FFC).

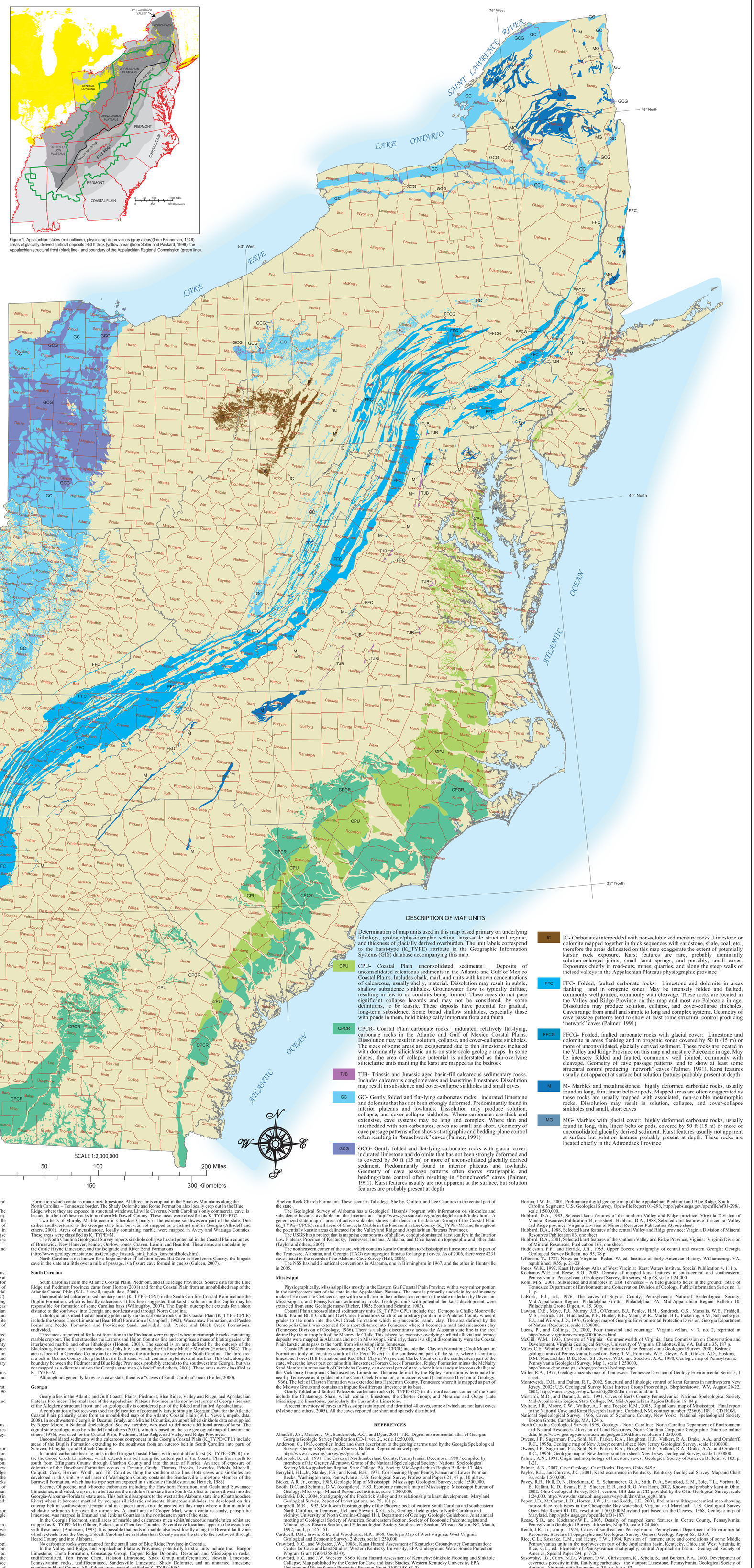
In the Valley and Ridge Province, potentially karstic units include: the Tomstown Dolomite, and the Waynesboro Formation, Elbrook Limestone, Conococheague Limestone, Stonehenge Limestone, Rockdale Run Formation, Pinesburg Station Dolomite, Chambersburg Limestone and St. Paul Group undivided [previously called the Stones River Group], Tonoloway Limestone, and the Helderberg Group (K_TYPE=FFC). The Tomstown Dolomite in the Great Valley area of Washington County contains more caves than any other formation in Maryland (Franz and Slifer, 1971).

The Greenbrier Limestone is the primary karst forming unit in the Appalachian Plateaus Province and Maryland's longest cave, Crabtree Cave, in Garret County, is developed in it (K_TYPE=GC).

Duigon (2001) reported on the karst hydrogeology of the Hagerstown Valley (Great Valley).The relationship between the stratigraphy and karst development in the Frederick Valley has been described by Brezinski (2004). The "Caves of Maryland" (Franz and Slifer, 1971) is the classic state cave publication, superceding an earlier book by Davies (1950). The Maryland Geological Survey hosts a karst and a cave information page on the internet http://www.mgs.md.gov/esic/features/caves.html.

The NSS held its 1952 annual convention in Hagerstown, Maryland.

Figure 1. Appalachian states (red outlines), physiographic provinces (gray areas)(from Fenneman, 1946), areas of glacially derived surficial deposits >50 ft thick (yellow areas)(from Soller and Packard, 1998), the Appalachian structural front (black line), and boundary of the Appalachian Regional Commission (green line).



Base map from National Atlas of the United States, March 5, 2003, http://nationalatlas.gov

Albers conical equal area projection. 1983 North American Datum

DESCRIPTION OF MAP UNITS

Determination of map units used in this map based primary on underlying lithology, geologic/physiographic setting, large-scale structural regime, and thickness of glacially derived overburden. The unit labels correspond to the karst-type (K_TYPE) attribute in the Geographic Information Systems (GIS) database accompanying this map.

CPU- Coastal Plain unconsolidated sediments: Deposits of unconsolidated calcareous sediments in the Atlantic and Gulf of Mexico Coastal Plains. Includes chalk, marl, and units with known concentrations of calcareous, usually shelly, material. Dissolution may result in subtle, shallow subsidence sinkholes. Groundwater flow is typically diffuse, resulting in few to no conduits being formed. These areas do not pose significant collapse hazards and may not be considered, by some definitions, to be karstic. These deposits have potential for gradual, long-term subsidence. Some broad shallow sinkholes, especially those with ponds in them, hold biologically important flora and fauna

CPCR- Coastal Plain carbonate rocks: indurated, relatively flat-lying, carbonate rocks in the Atlantic and Gulf of Mexico Coastal Plains. Dissolution may result in solution, collapse, and cover-collapse sinkholes. The sizes of some areas are exaggerated due to thin limestones included with dominantly siliciclastic units on state-scale geologic maps. In some places, the area of collapse potential is understated as thin-overlying siliciclastic units mantling the karst are mapped as the bedrock

TJB- Triassic and Jurassic aged basin-fill calcareous sedimentary rocks. Includes calcareous conglomerates and lacustrine limestones. Dissolution may result in subsidence and cover-collapse sinkholes and small caves

GC- Gently folded and flat-lying carbonates rocks: indurated limestone and dolomite that has not been strongly deformed. Predominantly found in interior plateaus and lowlands. Dissolution may produce solution, collapse, and cover-collapse sinkholes. Where carbonates are thick and extensive, cave systems may be long and complex. Where thin and interbedded with non-carbonates, caves are small and short. Geometry of cave passage patterns often shows stratigraphic and bedding-plane control often resulting in "branchwork" caves (Palmer, 1991)

GCG- Gently folded and flat-lying carbonates rocks with glacial cover: indurated limestone and dolomite that has not been strongly deformed and is covered by 50 ft (15 m) or more of unconsolidated glacially derived sediment. Predominantly found in interior plateaus and lowlands. Geometry of cave passage patterns often shows stratigraphic and bedding-plane control often resulting in "branchwork" caves (Palmer, 1991). Karst features usually are not apparent at the surface, but solution features are probably present at depth

IC- Carbonates interbedded with non-soluble sedimentary rocks. Limestone or dolomite mapped together in thick sequences with sandstone, shale, coal, etc., therefore the areas delineated on this map exaggerate the extent of potentially karstic rock exposure. Karst features are rare, probably dominantly solution-enlarged joints, small karst springs, and possibly, small caves. Exposures chiefly in road-cuts, mines, quarries, and along the steep walls of incised valleys in the Appalachian Plateaus physiographic province

FFC- Folded, faulted carbonate rocks: Limestone and dolomite in areas flanking and in orogenic zones. May be intensely folded and faulted, commonly well jointed, commonly with cleavage. These rocks are located in the Valley and Ridge Province on this map and most are Paleozoic in age. Dissolution may produce solution, collapse, and cover-collapse sinkholes. Caves range from small and simple to long and complex systems. Geometry of cave passage patterns tend to show at least some structural control producing "network" caves (Palmer, 1991)

FFCG- Folded, faulted carbonate rocks with glacial cover: Limestone and dolomite in areas flanking and in orogenic zones covered by 50 ft (15 m) or more of unconsolidated, glacially derived sediment. These rocks are located in the Valley and Ridge Province on this map and most are Paleozoic in age. May be intensely folded and faulted, commonly well jointed, commonly with cleavage. Geometry of cave passage patterns tend to show at least some structural control producing "network" caves (Palmer, 1991). Karst features usually not apparent at surface but solution features probably present at depth

M- Marbles and metalimestones: highly deformed carbonate rocks, usually found in long, thin, linear belts or pods. Mapped areas are often exaggerated as these rocks are usually mapped with associated, non-soluble metamorphic rocks. Dissolution may result in solution, collapse, and cover-collapse sinkholes and small, short caves

MG- Marbles with glacial cover: highly deformed carbonate rocks, usually found in long, thin, linear belts or pods, covered by 50 ft (15 m) or more of unconsolidated glacially derived sediment. Karst features usually not apparent at surface but solution features probably present at depth. These rocks are located chiefly in the Adirondack Province

West Virginia

West Virginia is situated chiefly in the Valley and Ridge and Appalachian Plateaus Provinces with a very thin sliver of Blue Ridge along the northeastern edge of the eastern panhandle in Jefferson County. No karst is reported in the Blue Ridge. The Valley and Ridge in the eastern part of the state comprises folded and faulted Paleozoic sedimentary rocks. Upon weathering and erosion, the coarser siliciclastic rocks form ridges, and the shales and carbonate form rocks valleys. Karstic units in these areas are classified K_TYPE=FFC. The Applachian Plateaus in the western part of the state comprise gently folded to flat lying upper Paleozoic rocks, which are exposed in broad areas or dendritic belts along incised stream valleys. Karstic units in this area are classified K_TYPE=GC. Most of West Virginia karst is developed along linear carbonate valleys in Cambrian to Mississippian carbonates in both the Valley and Ridge and Appalachian Plateaus Provinces.

A digital karst map of West Virginia was produced by the West Virginia Bureau of Public Health (1998) by extracting the limestone and dolomite units from the statewide geologic coverage (Cardwell and others, 1968) to create a separate karst GIS coverage. This was used as the basis for the West Virginia portion of this map along with the addition of areas of the Pennsylvanian Monongahela Group in Monongalia, Marion, and Harrison Counties in the north-central part of the state. The Monongahela Group includes the Benwood limestone (informal unit), which is significantly thick (as much as 70 ft)(K_TYPE=IC). No references mentioning the presence of caves were found for the Benwood. The aerial extent of the Monongahela Group was digitized from a scan of the West Virginia state geologic map (Cardwell and others, 1968), but arbitrarily limited to approximately the area indicated by Davies and others (1984) in chiefly Monongalia, Marion, and Harrison Counties. Small, sparsely distributed areas of this unit also occur in Preston and Mineral Counties. Unfortunately Davies and others (1984) did not document the reasons for classifying this unit as karstic.

Similar to Virginia, West Virginia was the location of some of the earliest cave exploration and research in the United States. The "Caverns of West Virginia" revised, supplemented, and republished by the West Virginia Geological Survey (Davies, 1958; 1965) is the classic state cave book. More recently the West Virginia Speleological Survey has issued a series of bulletins on West Virginia caves and karst (http://www.wvasss.org/). Jones (1997) published a Karst Hydrology Atlas of West Virginia with numerous spring descriptions and dye-trace maps.

West Virginia has several notable karst areas. The eastern Panhandle, comprising Berkeley and Jefferson Counties has numerous sinkholes, springs and caves developed in lower Paleozoic carbonates of the Great Valley. Caves are most plentiful in areas adjacent to the Potomac River, which incises the valley along the northern state border. Pendleton County is famous for areas of chiefly Ordovician and Devonian limestone with numerous caves and other karst features developed in them. Germany Valley, a broadfoot anticline in Ordovician limestone in the west-central part of Pendleton County, contains Schoolhouse, Hellhole, and other historically notable caves. To the west of the Allegheny structural front, belts of Mississippian Greenbrier Limestone crop out and produce some of West Virginia's largest caves and most spectacular sinkhole plains. The most intense karst development is in the area of the valley in Pocahontas, Greenbrier, and Monroe Counties in the southeastern part of the state. Notable caves in this area include Organ Cave and the Friars Hole system.

West Virginia has hosted 4 NSS national conventions: Charleston, 1951; Morgantown, 1976; Elkins, 1983, and Daily, 2000.

Ohio

Ohio lies in the Appalachian Plateaus, Interior Low Plateaus, and Central Lowland Provinces. The karst areas for Ohio were derived from a state karst map developed by the Ohio Geological Survey (Pavey and others, 2002) that shows areas of known and probable karst. Most Ohio karst is developed on relatively flat-lying Ordovician, Silurian, and Devonian carbonate rocks in the Central Lowlands in the southwest part of the state. Most of the Silurian rocks are dolomite and Devonian karstic rocks are limestone and shaley limestone. Most of the Silurian rocks are dolomite. The bedrock of the northern part of the state is overlain by glacially derived sediments that profoundly suppress the expression of karst features. These areas were identified by extracting polygons indicating a glacial overburden greater than 50 ft thick from the dataset of Soller and Packard (1998) and intersecting them with the polygons delineated in the New York rock type map (Fickies and Fallis, 1996).

In the Appalachian Plateaus a small area of potentially karstic rocks was added to the eastern edge of the state in Mahoning County. This is based on reported caves and karst features in the Pennsylvanian-aged Vanport Limestone in Pennsylvania (Sasowsky and others, 2003) and the existence of similar lithology in eastern Ohio (Rice and others, 1994). In addition, areas of Monongahela Group, that contain the Benwood limestone (informal unit) outcrop were extended from Pennsylvania to the southwest into Ohio. West Virginia Panhandle and in Belmont, Jefferson, and Harrison Counties the eastern part of Ohio (K_TYPE=IC). These areas are arbitrarily cut off to the west approximating areas mapped by Davies and others (1984). Unfortunately, that publication does not document the reasons for classifying this unit as karstic. These areas are chiefly clastic. In Bedrock with some thick limestones exposed in the sides of stream valleys. The Ohio Geological Survey does not classify this unit as karstic and only a few informal, references were found mentioning small karst springs and thin karst aquifers in these rocks. Future work may refine the areas delineated or may support elimination of the areas from further consideration.

The USGS is mapping components of shallow, conduit-dominated karst aquifers in the Interior Low Plateaus Province of Kentucky, Tennessee, Indiana, Alabama, and Ohio based on topographic and other data (Taylor and others, 2005).

Caves in Ohio are distributed relatively evenly across the western part of the state in areas without thick glacial deposits. Six commericial caves are currently operating in Ohio, two on South Bass Island in Lake Erie, and the rest in the central part of the state.

Virginia

The state of Virginia spans the Atlantic Coastal Plain, Piedmont, Blue Ridge, Valley and Ridge, and Appalachian Plateaus Provinces. Bedrock units with carbonate lithologies were identified from map descriptions accompanying the digital state geologic map (Virginia Division of Mineral Resources, 2003). Mapped areas of carbonate rocks in the Valley and Ridge Province were further edited over regional karst maps of Hubbard (1983, 1988, 2001) to improve detail and accuracy. Data from an unpublished map of the Atlantic Coastal Plain (W.L. Newell, unpub. data, 2008) were used to modify some Coastal Plain areas near the Virginia-North Carolina state line in the southeastern part of the state.

In the Coastal Plain, parts of the Chesapeake Group develop broad, shallow sinkholes due to dissolution of shell concentrations, chiefly in the Yorktown Formation. Some of these sinkholes contain ecologically significant wetlands (K_TYPE=CPU).

In the Piedmont, a small area of Frederick Limestone extends to the south across the Potomac River from Frederick County, Maryland into the northern part of Loudoun County, Virginia (K_TYPE=FFC). Triassic to Jurassic rift basins in the Virginia Piedmont contain Newark Supergroup conglomerates, some of which contain a large percentage of limestone clasts. The Leesburg Member of the Balls Bluff Siltstone in the northern Culpeper basin is known to contain sinkholes, small caves, and karst springs (Douglas, 1964) (K_TYPE=TJB). This karst area extends from Loudoun County, Virginia to the north into Frederick County, Maryland, where it is a significant karstic unit (Brezinski, 2004). The Everona Limestone crops out in a narrow band from southwest to northeast in central Orange County. A small area of Candler Formation limestone crops out in western Buckingham County. Both are classified as K_TYPE=FFC.

Narrow belts of banded marble Alligator Back Formation crop out in the Blue Ridge and Piedmont in Franklin, Pittsylvania, Campbell, Appomattox, Amherst, Nelson, and Buckingham Counties. Small areas of unnamed marble also crop out along the eastern part of the Blue Ridge in Madison, Culpeper, and Loudoun Counties. All of these units are classified K_TYPE=M.

In the Valley and Ridge, potentially karstic units (K_TYPE=FFC) include: the Beekmantown Group [particularly in the Great Valley]; Chepultepec and Copper Ridge Formations undivided; Conococheague Formation; Cove Creek Limestone; Edinburg Formation, and Lincolnshire and New Market Limestones, undivided; Elbrook Formation; Greenbrier Limestone; Hancock Formation, Rose Hill Formation and Clinch Sandstone, undivided [only the Hancock is a carbonate]; Hardy Creek Limestone through Dot Limestone; Juniata, Oswego, Martinsburg (Reedsville and Dolly Ridge Formations), and Eggleston Formations, undivided [only the Dolly Ridge and Eggleston are carbonates]; Juniata, Reedsville, Trenton, and Eggleston Formations [only the Trenton and Eggleston are carbonates]; Knobs Formation, Paperville Shale, and Lenoir and Moshein Limestones, undivided [the Knobs and Paperville are not carbonates] ; Lower Devonian and Silurian rocks, undifferentiated [includes the Helderberg Group carbonates and the Oriskany Sandstone]; Mascot and Kingsport Dolomites, undivided; Moccasin or Bays Formation through Blackford Formation [only the Moccasin is a carbonate]; Nolichucky and Honaker Formations undivided; Nolichucky Formation and Maryville Limestone undivided; Ridgeley Sandstone, Helderberg and Cayuga Groups, undivided [limestone and dolomite in the Helderberg Group are the chief carbonates]; Sequatchie Formation, Reedsville Shale, Trenton Limestone, and Eggleston Formation undivided; Tomstown Dolomite; Shady Dolomite; Waynesboro Formation and Tomstown Dolomite undivided. A small area near the town of Saltville, Smyth County, has experienced local subsidence associated with historic extraction of salt and gypsum from the Maccrady Shale.

No potentially karstic units were mapped in the Appalachian Plateaus Province, located in the extreme southwestern part of the state, where most of the bedrock is Pennsylvanian siliciclastic rocks.

Virginia is one of the earliest states with a cave exploration legacy, including America's first published cave map, drawn by Thomas Jefferson (1787). Classic Virginia cave references include: "The Caverns of Virginia" (McGill, 1933), "The Caves of Virginia" (Douglas, 1964) and "Description of Virginia Caves" (Holsinger, 1975). As of 2002 the Virginia Cave Survey reported more than 4000 cave mark (Lucas and Collings, 2002).

Sinkhole distributions in various parts of Virginia have been mapped by the Virginia Department of Mineral Resources (Hubbard, 1983, 1988, 2001).

Most Virginia karst occurs in the Valley and Ridge Province along the western margin of the state. The Shenandoah Valley area is well-known for show caves including Luray Caverns and Grand Caverns (Weyers Cave); both developed in lower Paleozoic carbonate rocks. Further to the west in Highland and Bath Counties, Burnsville Cove is famous as the home of Breathing Cave and the Butler Cave-Sinking Creek system and the location of numerous karst geological investigations (White, 2003). The Burnsville Cove caves are developed in Silurian-Devonian carbonates. Karst is very well developed in areas of Greenbrier Limestone in Scott, Lee, and Wise Counties in the far western part of the state. The longest cave in Virginia, the Omega Cave system, is located in Wise County.

Virginia has hosted five NSS national conventions: Natural Bridge, 1955 and 1957; Mountain Lake, 1963; and Blacksburg, 1971 and 1995.

Kentucky

Kentucky spans, from east to west, parts of the Valley and Ridge, Appalachian Plateaus, Interior Low Plateaus, and Mississippi Alluvial Plain Provinces. The Kentucky Geological Survey has published a karst map of the state at 1:500,000 scale (Paylor and Currens, 2001) that divides the state into areas of high, moderate, and low potential for karst development, based on lithology. This map was accepted in its entirety for coverage of the karst areas of Kentucky, except the areas with low karst potential which were deleted, and the areas of moderate to high potential that were combined and mostly classified as potential karst in gently-folded to flat-lying carbonates (K_TYPE= GC). In future versions these areas may be delineated. Most Kentucky karst is developed on Mississippian limestone along the edge of the Appalachian Plateaus in the eastern part of the state and in the western part of the state in areas flanking the Jessamine (Lexington) dome and the Cincinnati arch. A solitary thin belt of karstic Mississippian limestone is also exposed along