An Appalachian Regional Karst Map and Progress Towards a New National Karst Map

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ABSTRACT

A new 1:1 million scale, lithology-based, digital karst map has been constructed for the Appalachian region. This map is serving as the nucleus for a new national karst map and as a test for methodologies used in developing the national karst map and data base. The map comprises data compiled from various state and regional sources. Issues encountered in the compilation process include unevenness between the various data sets in resolution, lithologic description, and classification. Regional geologic and karst data sets providing information on glacial deposits and cave and sinkhole locations are valuable components of the compilation and may also be used as tools for testing the validity of portions of the map and for creating derived products such as karst density maps. Compilation of the national karst map will become more difficult as it progresses to include semi-arid western states that contain evaporate karst, karst aquifers, karstic features propagated from buried evaporites into surface rocks of non-karstic lithology, and various features analogous to karst.

INTRODUCTION

In 2001 the U.S. Geological Survey Karst Applied Research Studies Through geologic mapping (KARST) Project began the task of constructing a new national karst map, which would improve on the Davies and others (1984) 1:7.5 million scale National Atlas karst map. The new map will be digitally-based and constructed, edited and updated in a GIS environment. The working resolution of the new map is 1:1 million scale with paper versions planned at scales of 1:7.5 and 1:2.5 million. As a first step, we are publishing a digital map of karst in the Appalachian states as a U.S. Geological Survey Open-File Report. Production of this map has revealed some of the problems and issues regarding compilation of diverse and inconsistent data sets supplied from various sources.

The Appalachian Region

The Appalachian region, as defined by the Appalachian Regional Commission (ARC) was used as an arbitrary geographic area for our initial compilation effort (fig. 1). This area, based on socio-economic and political factors, makes a compact swath covering the central and southern Appalachian Mountains, the Piedmont and parts of the eastern Midcontinent, Atlantic Coastal Plain, and the Gulf Coastal Plain. This area includes the states of New York, Pennsylvania, Ohio, Maryland, Virginia, West Virginia, Kentucky, North Carolina, Tennessee, South Carolina, Georgia, Alabama, and Mississippi. Included on our map, so that it will be complete to the Atlantic coast, are the states of New Jersey and Delaware.

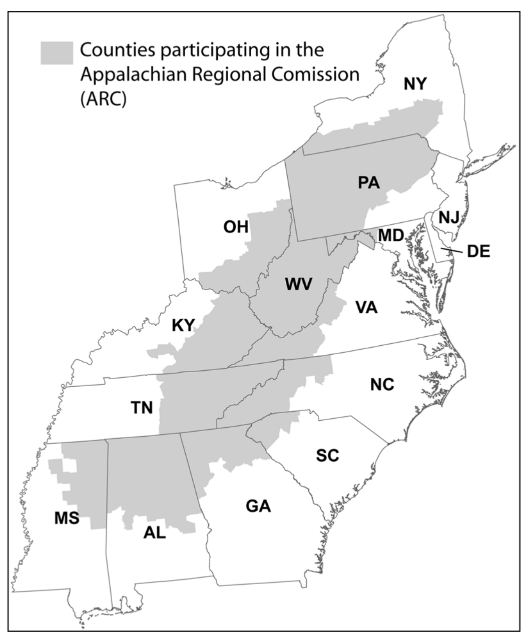

Figure 1. The Appalachian region as defined by the ARC, in gray. States of New Jersey and Delaware are included in this study for completeness to the Atlantic coast.

COMPILATION

Karst and Geologic data

Representatives of all of the state geological surveys in the region were contacted and invited to participate in a workshop on Appalachian karst sponsored by the U.S. Geological Survey and the Kentucky Geological Survey in September, 2002. States that could not attend were asked for sources of karst or geologic data or publicly available geologic data were located on the internet. Karst or geologic data at a scale of 1:1 million or larger were acquired for each state and loaded into ArcMap-ArcInfo for manipulation.

Some states, such as Kentucky and Ohio, already had a state-scale karst map completed (Appendix 1). Those karst areas were simply incorporated into the map and assigned the appropriate attributes. For other areas it is assumed that, in the eastern U.S., where there is sufficient rainfall, carbonate areas, extracted from bedrock maps would suffice as proxies for areas of karst. Geologic units with no carbonates in their unit description were deleted. Lithologic unit descriptions from the original data sets were cross-checked against descriptions in the U.S. Geological Survey National Geologic Map Database (http://ngmdb.usgs.gov/Geolex/geolex_home.html). References to data sources for each state are listed in Appendix 1.

Since the resolution of the individual data sources varied from scales of 1:1 million to 1:24,000 the distance between vertices in the polygon boundaries was generalized in ArcInfo to a spacing of 150 meters for uniformity and to eliminate some of the very small polygons and curves that would not be visible at the working scale of 1:1 million. Also, all polygons with an area of less than 40,000 m^2 were deleted, as they are too small to portray visibly on the map.

Each polygon was then assigned the following attributes: 1). K_TYPE = an abbreviation for the karst type; state = state name; REF_CODE = reference code, an alphanumeric code to the data source(s).

Structural data

After the areal distribution of potentially karstic rocks was mapped, a scanned and georegistered image of a Tectonic lithofacies map of the Appalachian orogen (Williams, 1978) was used as a visual template for segregating folded and faulted rocks east of the Allegheny structural front from flat-lying to gently dipping rocks to the west. The rationale for this division is the strong influence that the structural nature of the host bedrock has on cave passage patterns and, presumably, other karst features (Palmer, 2000).

Glacial data

Because glacial beveling and cover by glacial sediments has a profound effect on karst distribution in the northern portion of the United States, data on thickness of glacial sediments were integrated into the karst map. Fortunately, a digital dataset of glacial sediment cover for the United States east of the Rocky Mountains already exists (Soller and Packard, 1998). Areas with glacial cover exceeding 50 ft thick (fig. 2) were extracted from this dataset and intersected with the karst areas to define areas of potential karst buried under glacially derived sediments.

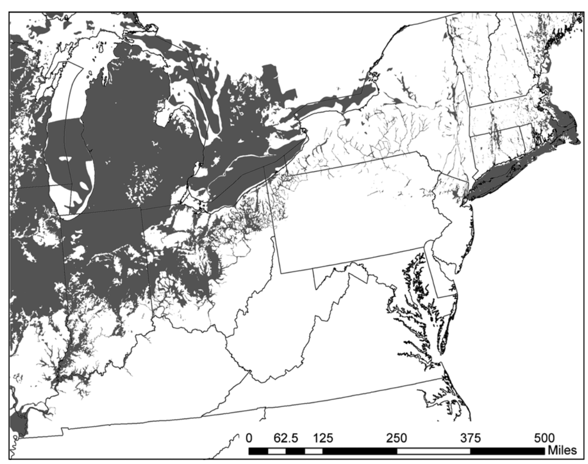

Figure 2. Distribution of glacial sediments greater than 50 ft thick (in gray) in part of the Appalachian region. Derived from data from Soller and Packard (1998).

RESULTS

A draft, first version of the Appalachian karst map is shown in figure 3. A portion of the Davies and others map (1984) is shown in figure 4 for comparison. The most substantial apparent difference between the two maps is the better resolution of the new map, 1:1 million vs 1:7.5 million. The new map also includes more Atlantic Coastal Plain units as potentially karstic than did Davies and others (1984).

This is the first iteration in a process of compilation and refinement of the map. Publication as a digital product will facilitate release of revised versions as corrections and adjustments are made in the future.

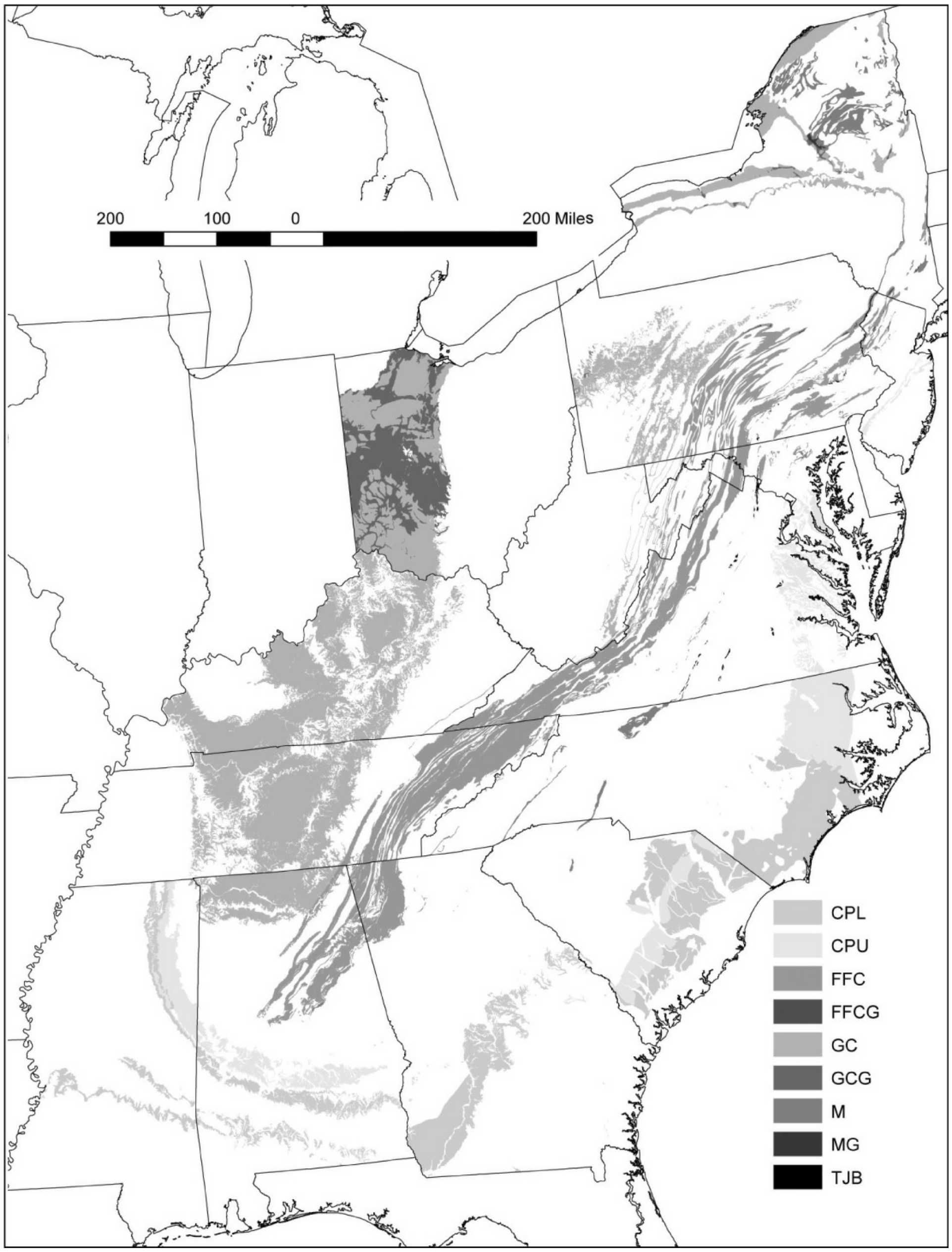

Figure 3. Draft map of Appalachian karst. CPL = Coastal Plain limestones; CPU = Coastal Plain unconsolidated calcareous sediments; FFC = folded and faulted carbonate rocks; FFCG = folded and faulted carbonate rocks with glacial cover greater than 50 ft thick; GC = flat-lying to gently folded carbonate rocks; GCG = flat-lying to gently folded carbonate rocks with glacial cover greater than 50 ft thick; M =marble; MG = marble with glacial cover greater than 50 ft thick; TJB = Triassic and Jurassic basin-fill carbonates.

Description of karst units

Karst-type map units in the new map incorporate lithology, regional structural style, and glacial sedimentary cover greater than 50 ft thick. Further subdivisions and refinements will be made as the project progresses. Full descriptions of the karst-type map units currently assigned follows:

CPU- Coastal Plain unconsolidated: Coastal Plain deposits of unconsolidated, calcareous sediments. Includes chalks, marls, and units with shelly buildups. Dissolution may result in subtle, shallow subsidence sinkholes.

CPL- Coastal Plain limestones: indurated, flat-lying, carbonate rocks. Dissolution may result in solution, collapse, and cover-collapse sinkholes.

FFC- Folded, faulted carbonate rocks: Limestone and dolomite in structurally deformed zones zones. May be intensely folded and faulted, commonly well jointed, possibly with cleavage. 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.

FFCG- Folded, faulted carbonate rocks with glacial cover: Limestone and dolomite in structurally deformed zones covered by 50 ft (15 m) or more of unconsolidated, glacially derived sediment. May be intensely folded and faulted, commonly well jointed, possibly with cleavage. Karst features usually not apparent at surface but solution features probably present at depth.

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 lithologic and bedding-plane control.

GCG- Gently-folded and flat-lying carbonates rocks with glacial cover: indurated limestone and dolomite that has not been strongly deformed covered by 50 ft (15 m) or more of unconsolidated glacially derived sediment. Predominantly found in interior plateaus and lowlands. 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. 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 the sediment-rock interface.

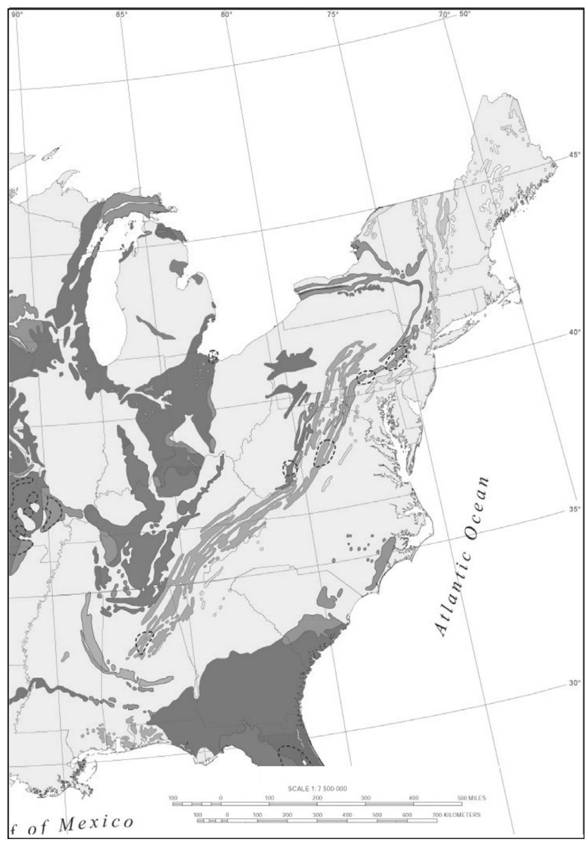

Figure 4. A portion of the digital version of Davies and others (1984) map showing karst areas, in gray tones, in the Appalachian region (Tobin and Weary, 2004).

TJB- Triassic and Jurassic basin fill calcareous sediments. Includes calcareous conglomerates and minor lacustrine limestones. Dissolution may result in solution and subsidence sinkholes and small caves.

DISCUSSION

Problems

Most of the major problems in the new map are differences in delineation of karst areas across state boundaries on state geologic maps. Karst areas for the state of Pennsylvania and the edges of the adjoining states are shown on figure 5 to illustrate some of these differences. Notice that areas delineated as karstic in western Pennsylvania are not currently identified in Ohio and West Virginia. These areas were, however, shown in a gross manner in the Davies and others (1984) (fig. 4) map.

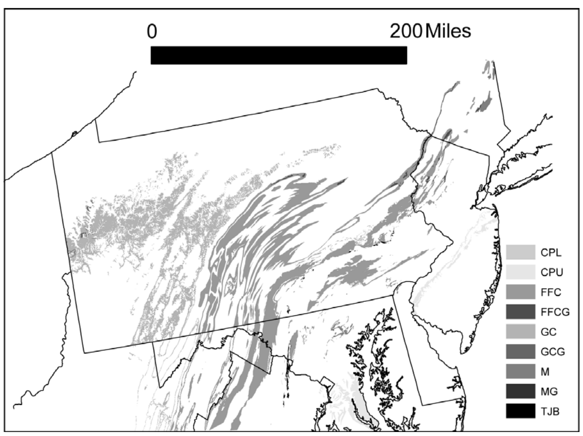

Figure 5. The Pennsylvania portion of the new Appalachian karst map showing discontinuities across boundaries of neighboring states. Explanation of map units as in figure 3.

These areas represent the extent of the Pennsylvanian Allegheny Formation and the Mississippian Mauch Chunk Formation (Miles and others, 2001). The Allegheny Formation comprises chiefly clastic rocks, but also contains the Vanport Limestone which contains caves and other karst features. Likewise, the Mauch Chunk Formation includes the Loyalhanna, Greenbrier, Wymps Gap, and Deer Valley Limestones. The Loyalhanna and Greenbrier Limestones, in particular, contain caves and other karst features. The Vanport was probably not included in the state karst map of Ohio (Pavey and others, 2002) because it thins to less than 10 ft thick west of the Ohio River.

Some belts of carbonate units equivalent-in-part to the Mississippian Mauch Chunk Formation- continue on into Maryland and West Virginia but are thinner and discontinuous having been subdivided from the thicker clastic units in those states (Peper and others, 2001; West Virginia Bureau of Public Health, 1998).

Ongoing work to compile and refine karst maps of Pennsylvania by Bill Kochanov at the Pennsylvania Geological Survey (oral commun., 2005) will be incorporated in the Appalachian map in the future to revise the extent of karst within that state and will probably resolve most of the boundary mismatches with Maryland and West Virginia. In addition the extent of the Vanport Limestone will probably be extended to the west, feathering-out in eastern Ohio.

A section of the Appalachian karst map centered on the Atlantic Coastal Plain areas of North and South Carolina is shown on Fig. 6. The medium and dark gray areas delineate potentially karstic units derived from individual state data sources. There is not good matching between the mapped Coastal Plain units across the state borders. Differences in lithologic descriptions and each state's classification and grouping scheme affect the aerial extent of the units. Some areas of potential karst, especially in the unconsolidated units, are undoubtedly overstated. Areas of light gray on figure 6 show the extent of potentially karstic units derived from a database for the entire Atlantic Coastal Plain (Newell and others, unpublished data) and areas of very dark gray indicates the overlap of that data set with kart areas delineated by the individual state data. Use of the regional data set eliminates most of the discontinuities between the state boundaries, but, because it is focused on surficial units it does not include some important bedrock limestone units such as the Eocene Castle Hayne Limestone in eastern North Carolina.

Resolution of these problems in the Coastal Plain will require combining the information from the various data sets and a search for more detailed information on the distribution of calcareous sediments and whether there are, in fact, karst features in some of these units.

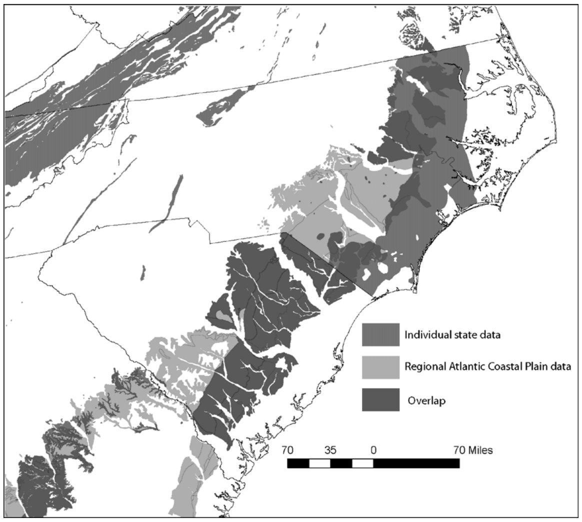

Figure 6. The North and South Carolina part of the new Applachian Karst map showing discontinuities in data sets.

Reported cave locations in the U.S., east of the Mississippi River, plotted on the Appalachian karst map are shown on figure 7. Because they cross state lines and are, presumably, evenly sampled, regional data sets such as this are valuable for checking the accuracy of the karst delineation. Data sets for other karst features, such as sinkhole and spring locations also exist, although most are limited to a particular state or smaller area. If some of these data can be acquired and joined together they will enable further geostatistical analyses of karst across large areas. The density of caves within a part of the Appalachian karst map is shown in figure 8 as an example. This particular plot was generated purely for demonstration purposes, with little thought to rigorous statistical meaning, and should not be taken seriously at this point. It does, however, show interesting patterns in the variation of cave density, with concentrations of caves in central Kentucky, the northeastern corner of Alabama and the southwestern tip of Virginia. Future studies of regional karst feature distribution should lead to new ideas about the effect of tectonism, lithologic facies, hydrologic regime, glaciation, and other factors on the intensity of karstification.

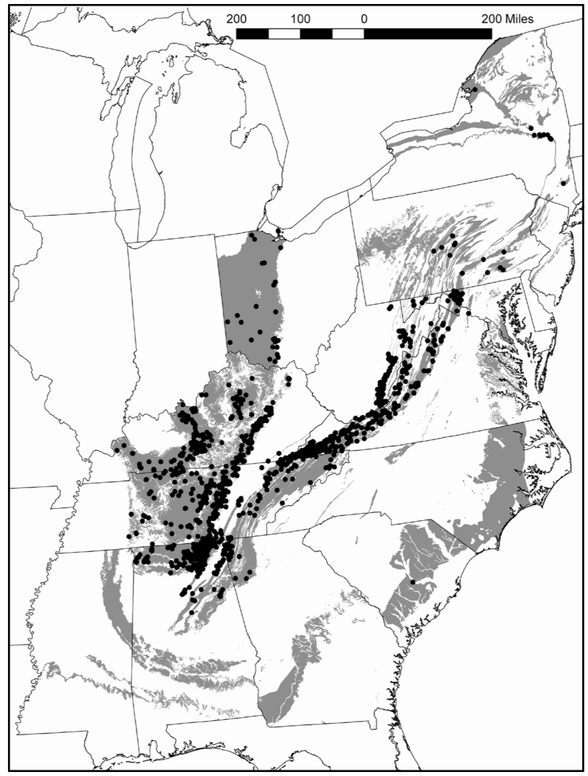

Figure 7. Cave locations (black dots, n=1395) plotted on karst areas in the Appalachians. Cave location data from David Culver, American University, 2004, written communication.

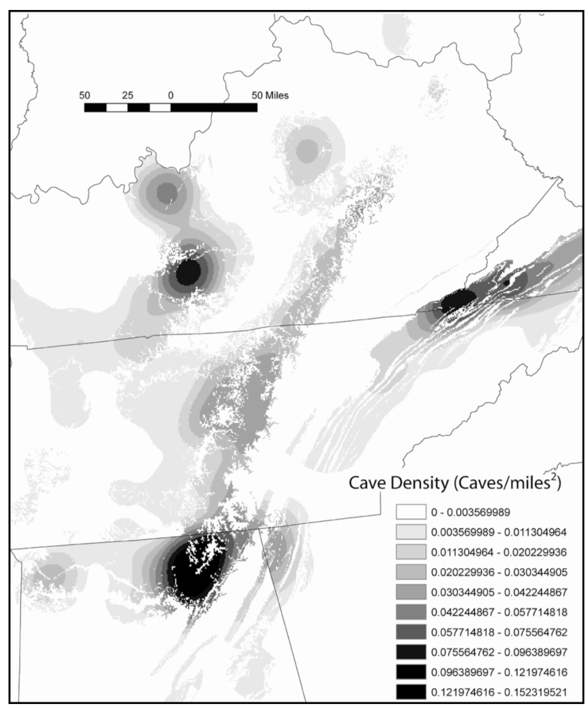

Figure 8. Cave density mapped within the Appalachian karst polygons.

As the nucleus formed by the Appalachian karst map is solidified, state by state coverages, forming the new National Karst map, will be accreted to it. Classifying karst areas in the western part of the country will be a challenge. West of the 32.5-in. mean precipitation line, the nature of wearthering and expression of karst features in the United States changes (fig. 9; Epstein and Johnson, 2003). Issues include mapping buried karst, deeply buried evaporates that propagate karst features to non-karstic rocks at the surface, and where to cut the continuum from surface karstic rocks into karst aquifers. A U.S. Geological Survey sponsored workshop involving the state geological surveys of Kansas, Arkansas, Illinois, Iowa, Nebraska, and Wisconsin focusing on these issues will be held August 17 and 18, 2005 at the Kansas Geological Survey. Hopefully we can make some real progress towards generating rules of thumb for mapping these phenomena.

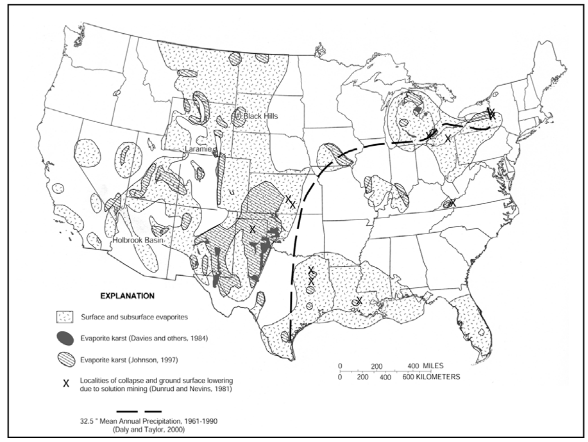

Figure 9. Map showing distribution of outcropping and subsurface evaporate rocks in the United States and areas of reported evaporate karst. The 32.5-in. mean-annual-precipitation line approximates the boundary between eastern and western karst (from Epstein and Johnson, 2003, fig. 5)

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Soller, D.R. & Packard, P.H. (1998). Digital representation of a map showing the thickness and character of Quaternary sediment in the glaciated United States east of the Rocky Mountains: U.S. Geological Survey

Digital Data Series DDS-38, scale 1:1,000,000. http://pubs.usgs.gov/dds/dds38/shape.html

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APPENDIX 1

State by state annotated sources for karst and geologic data (in alphabetical order)

Alabama - Szabo, M.W., Osborne, W.E., Copeland, C.W., Jr., and Neathery, T.L., 1988, Geologic Map of Alabama: Geological Survey of Alabama, Special Map 200; digital version: Digital geologic map of Alabama, Beta Version 1, 2002: Geologic Survey of Alabama, scale 1:250,000. [Used for entire state]

Delaware - Nenad Spoljaric, Jordan, R.R., Generalized geologic map of Delaware, revised 1976 by Pickett, T.E.: Delaware Geological Survey, 1 sheet, scale ca. 1:600,000. [Map scanned and digitized at U.S. Geological Survey; Used for entire state]

Georgia - Alhadeff, J.S., Musser, J. W., Sandercock, A.C., and Dyar, T.R., 2001, Digital environmental atlas of Georgia: Georgia Geologic Survey Publication CD-1, ver. 2., scale 1:250,000. [Used for entire state]

Kentucky –Paylor, R.L., and Currens, J.C., 2002, Karst Occurrence in Kentucky: Kentucky Geological Survey, KGS Map and Chart 33, scale 1:500,000. http://www.uky.edu/KGS/water/general/karst/karstgis.htm . [Used for entire state].

Maryland - Peper, J.D., McCartan, L.B., Horton, J.W., Jr., and Reddy, J.E., 2001, Preliminary lithogeochemical map showing near-surface rock types in the Chesapeake Bay watershed, Virginia and Maryland: U.S. Geological Survey Open-File Report 01-187, resolution 1:500,000.Maryland part based on the Cleaves, 1968, Geologic map of Maryland. http://pubs.usgs.gov/openfile/of01-187/ [Used for entire state, except Coastal Plain]

Newell, W. L, Prowell, D., Kranz, D., Powars, D., Mixon, R., Weems, R., Stone, B., and Willard, D., Surficial geology and geomorphology of the Atlantic Coastal Plain: U.S. Geological Survey, unpublished data.; [Used in Coastal Plain only]

Mississippi - Online data from Mississippi Automated Resource Information System (MARIS) at: http://www.maris.state.ms.us/HTM/Data%20Warehouse/Statewide_alpha.htm. No metadata available (4/2004) scale 1:500,000. [Map units compared with descriptions on published paper maps: 1. Bicker, A.R. Jr., (compiler) 1985, Geologic Map of Mississippi: Mississippi Geological Survey, scale 1:500,000. 2. Booth, D.C. and Schmitz, D.W. (compilers), 1983, Economic minerals map of Mississippi: Mississippi Bureau of Geology, Mississippi Mineral Resources Insititute, scale 1:500,000.]

New Jersey - Vector graphic files of karst units of New Jersey were supplied by Donald Monteverde, New Jersey Geological Survey and were converted to GIS at the U.S. Geological Survey. These units were extracted from: 1.) Dalton, R.F., 1996, Bedrock geologic map of northern New Jersey: U.S. Geological Survey, Miscellaneous Investigations Series, I-2540-A, scale 1:100,000. 2.) Owens, J.P., Sugarman, P.J., Sohl, N.F., Parker, R.A., Houghton, H.F., Volkert, R.A., Drake, A.A., and Orndorff, R.C., 1995, Geologic map of New Jersey: central sheet: New Jersey Geological Survey, scale 1:100,000. 3.) Owens, J.P., Sugarman, P.J., Sohl, N.F., Parker, R.A., Houghton, H.F., Volkert, R.A., Drake, A.A., and Orndorff, R.C., 1995, Geologic map of New Jersey: southern sheet: New Jersey Geological Survey, scale 1:100,000. [Used for entire state.]

New York - Fickies, R.H. and Fallis, E., 1996, Rock Type Map of New York State: New York State Geological Survey, Open file Report 1g1222, scale 1:1,000,000. [GIS data provided by the New York Geological Survey; Used for entire state.]

North Carolina - North Carolina Geological Survey, 1999, Geology - North Carolina: North Carolina Department of Environment and Natural Resources -Division of Land Resources, North Carolina Corporate Geographic Database online data, http://www.geology.enr.state.nc.us/gis/geol250d.htm. resolution 1:250,000. [Calcareous rocks extracted based on description of map units. Used for entire state.]

Ohio - Pavey, R.R., Hull, D. N., Brockman, C. S., Schumacher, G. A., Stith, D. A., Swinford, E. M., Sole, T.L., Vorbau, K. E., Kallini, K. D., Evans, E. E., Slucher, E. R., and R. G. Van Horn, 2002, Known and probable karst in Ohio, 2002: Ohio Geological Survey, EG-1, version, GIS data on CD provided by the Ohio Geological Survey, scale 1:24,000. [Polygons generalized and reclassified. Used for entire state.]

Pennsylvania - Miles, C.E., Whitfield, G.T. and other staff and interns of the Pennsylvania Geological Survey, 2001, Bedrock geologic units of Pennsylvania, based on: Berg, T.M., Edmunds, W.E., Geyer, A.R., Glover, A.D., Hoskins, D.M., MacLachlan, D.B., Root, S.I., Sevon, W.D., and Socolow, A.A., 1980, Geologic map of Pennsylvania: Pennsylvania Geological Survey, Map 1, scale 1:250000. http://www.dcnr.state.pa.us/topogeo/map1/bedmap.aspx [Carbonate units extracted based on map descriptions. Used for Entire state.]

South Carolina - Horton, J.W. Jr., 2001, Preliminary digital geologic map of the Appalachian Piedmont and Blue Ridge, South Carolina Segment: U.S. Geological Survey, Open-file Report 01-298, http://pubs.usgs.gov/openfile/of01-298/, scale 1:500,000. [Carbonate units extracted based on unit labels and descriptions of units found in the U.S. Geological Survey Geologic names lexicon: http://ngmsvr.wr.usgs.gov/Geolex/geolex_home.html; Used for Blue Ridge and Piedmont Provinces only.]

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Virginia - Virginia Division of Mineral Resources, 2003, Digital representation of the 1993 geologic map of Virginia: Virginia Division of Mineral Resources Publication 174 [CD-ROM; 2003, December 31]. Adapted from Virginia Division of Mineral Resources, 1993, Geologic map of Virginia and Expanded Explanation: Virginia Division of Mineral Resources, scale 1:500,000. [Calcareous rocks extracted based on description of map units. Used for entire state.]

West Virginia - West Virginia Bureau of Public Health, 1998, Karst regions derived from 1968 geological map of West Virginia: West Virginia GIS Technical Center, online data http://wvgis.wvu.edu/data/dataset.php?action=search&ID=133, resolution 1:250,000. [Used for entire state.]