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SELECTED KARST FEATURES OF THE SOUTHERN
VALLEY AND RIDGE PROVINCE, VIRGINIA

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INTRODUCTION

This publication is intended as a relative characterization of karst and its associated hazard potential for regional planning and preliminary evaluations. It is the third in a sequence of karst feature maps (Hubbard, 1983 & 1988) resulting from an initiative to map the karst of Virginia. The term "karst" refers to terrain characterized by solution of bedrock, underground drainage, and distinctive landforms and features such as sinkholes, solutionally etched and pinnacled bedrock, and caves. As on the previous karst maps, sinkholes and cave entrances are illustrated, but this map also indicates stream insurgences (sink-points) and springs. The distribution and intensity of the mapped features are intended to convey a comparative sense of the degree of karstification throughout the mapped region (including the two previous karst maps). Karst hazards are process driven and reflect the degree of stability of karst features and processes under the existing geomorphic (landscape) and hydrologic conditions. Karstlands are one of the more unstable terrains, especially in response to changes in land-use.

In Virginia, the most significant karst development is exhibited in the Paleozoic limestones and dolostones of the Valley and Ridge physiographic province. The southern segment of the Virginia portion of this province is presented in this report. The study area is bounded to the north by the Virginia-Kentucky and Virginia-West Virginia State boundaries, to the south by the Virginia-Tennessee boundary and the vicinity of Interstate route 81, to the east by Blue Ridge province, and to the west by meridian of longitude. Parts of three major drainage basins (the Powell River, Clinch River, and Holston River tributaries of the upper Tennessee River Basin, the Big Sandy River Basin, the New River Basin) are represented in the study area (inset map).

The regional distribution of carbonate rocks (un-shaded map areas defining limestone and dolostone map units) was compiled from published, manuscript, compilation and field interpretation maps on file at the Division of Mineral Resources (see Geologic References Used in Compilation of the Map). The areal distribution of carbonate rocks (un-shaded areas) generally defines the distribution of karst with the notable exception of where thin layers of non-carbonate rocks overlie karstified carbonate rocks. Non-carbonate rock mantled karst, where thinly mantled, may be recognized by the presence of sinkholes and caves in shaded map areas in strike alignment with fold structures. Sinkholes in non-carbonate rock mantled karst tend to be bedrock collapse sinkholes, which otherwise are rare. The various stratigraphic map units are lumped into seven geologic map units in this report. They are the same divisions used in the northern (with the exception of unit 7 - Mississippian limestones) and central karst reports: 7 – limestones (Upper Mississippian); 6 – noncarbonates (Lower Pennsylvanian to Precambrian, shaded map unit) that are dominantly clastic rocks except along the southeastern edge of the study area where volcanic and plutonic rocks also are present; 5 – limestones (Silurian, includes Devonian in northern and central maps); 4 – limestones of the Powell Valley, western, and central belts (Upper and Middle Cambrian); 3 – limestones of the eastern belt (Middle Ordovician); 2 – limestones and dolostones of the fault-truncated central belt (Lower Ordovician), not present in this report; and 1 – limestones and dolostones (Lower Ordovician and Cambrian).

WARNING! The selected karst features and geologic unit boundaries on this map may not be spatially located as depicted with respect to the cultural and hydrological base map features (Hubbard, 2001). The base map used in this report contains significant scale and spatial irregularities, especially with respect to cultural features. Refer to the MAP LIMITATIONS and DISCLAIMER sections of this report. Persons interested in the information contained in this report are advised to read the whole report. The data conveyed in this report is limited, has not been field checked, and is not suited for site specific use.

CHARACTERIZATION OF KARST

Virginia's Valley and Ridge province karstlands are developed in relatively impermeable Cambrian to Mississippian-aged carbonate rocks. The dissolution of these Paleozoic limestones and dolostones occurs at the rock surface and along partings and fractures within the rock. The surficial dissolution patterns of the bedrock are referred to as karren. Because of the folded and faulted nature of the Valley and Ridge carbonate rocks there are many fractures and open partings within the host rocks. These fractures and partings provide solutional paths for significant water movement through the deformed bedrock. After individual pathways within the bedrock solutionally enlarge to a size where the water flow through them becomes turbulent they are referred to as conduits. Some conduits enlarge to a size large enough for humans to pass through them and are termed caves. Appalachian karstlands typically contain a mantle or covering of unconsolidated overburden. This overburden cover insulates the underlying bedrock from the surface and the development of many of the bedrock/overburden interface drains, termed epikarst drains, that link the surficial drainage and the major conduits of the karst aquifer. The residual, colluvial, and alluvial overburden ranges from absent to more than 300 feet (90 m) in thickness. Extreme variations in overburden thickness can occur locally within lateral distances of a few feet in some areas. The unconsolidated overburden is subject to differential subsidence at sites where bedrock is preferentially dissolved. The resulting closed-contour depressions are called subsidence sinkholes. Other sinkholes form catastrophically as soil voids, that form at epikarst drains by the winnowing of overburden into solutional bedrock openings, fail and collapse through the soil column to the land surface. Most contemporary sinkhole failures are linked to variations in the local hydrology, either due to natural or human induced changes in groundwater levels or to changes in the amount or location of runoff. Sinkholes are under-drained by conduits or epikarst drains, but most epikarst drains are unnoticed by sinkholes or other subsidence features. As karst develops, there is a shift from surficial to subsurface drainage as surficial waters are captured by subsurface conduits and caves. Surface streams may lose their water over a distance or at a sink point, commonly called a insurgence (swallet).

There are four types of features we see in karst and can use to help define or characterize karst: karren, sinkholes, caves, and subsurface drainage. In a basic karst, the karren pattern and the larger pattern of bedrock topography channel precipitation runoff to minor and major bedrock drains. Many of the larger drains are obvious gaping conduits (cave entrances) in closed depressions and some of these are the sink-points for surface streams. Other large drains or cave entrances have been geomorphically isolated, by stream capture and erosion, from normal flow regimes and only are active as overflow features during extreme precipitation and flood events. Even though the entrances to many caves are no longer or rarely hydrologically active, distal portions of these caves may be active hydrological components of the aquifer. The internal drainage within the bedrock can be quite complex, especially in deformed carbonate host rock where the natural plumbing network of caves can be thought of as a leaky system of redundant and possibly interconnected conduits of varied sizes and configurations. Studies of the caves can provide clues to the complexity of an aquifer. Such studies, coupled with tracer studies of surface insurgences and springs during low, normal, and high flow hydrologic regimes may provide some understanding of the overflow patterns of the karst aquifer. In covered karst, much of the active surficial drainage is mediated by overburden. Sinkholes are obvious insurgence points for runoff, however drainage occurs along the soil/bedrock interface to these infiltration points and many other masked epikarst drains even in the interim between runoff generating storm events.

Featured Elements

As on the two previous karst maps for the northern (Hubbard, 1983) and central (Hubbard, 1988) portions of the Valley and Ridge Province of Virginia, sinkholes and cave entrances are plotted on this map. This southern karst map also depicts springs and insurgences (swallets).

The 31,239 sinkholes illustrated on this map are defined as shallow and basin-like to steep-sided and funnel-shaped, closed contour depressions in unconsolidated overburden. These sinkholes are subsidence features; may be subjected to karst flooding; are recharge and potential contaminant pathways to the karst aquifer. The term sinkhole is used in this report to include a number of different closed-contour karst features such as: blind valley, doline, karst window, closed polje, and uvala. General references to these features include Monroe (1970), Jennings (1971), Sweeting (1973), and Field (1999).

The sinkholes (Figure 1) were identified by stereoscopic viewing of cloudless late fall or winter or early spring scenes of low altitude (12,000 feet; 3,600 m), panchromatic aerial photography. They range from a minimum of about 30 feet (9 m) across to the 22,300 feet (4.2 miles; 6.8 km) long Dungannon polje. Only questionable features were field checked to refine closed-depression topographic signatures. Although the use of remote sensing methods with stereo-pairs of low altitude photography usually results in the identification of many sinkholes not identified on standard topographic maps, those observed represent a fraction of the actual number of sinkholes in a karst area. Most of the remotely sensed sinkholes that are not seen on their respective topographic map are those at elevations between the contour intervals of the map. During field reconnaissance of questionable features, many other sinkholes were observed that had not been sensed remotely and which were of size ranges above and below the practical minimum observable size of 30 feet (9 m) in diameter. Many of these non-sensed sinkholes were in wooded areas or were too shallow either for shadow definition or to differentiate with wing-tilt generated false slope topography on unrectified photo imagery.

Caves are defined as naturally occurring voids, large enough for a person to enter (figure 2). Presently, 3946 caves are known statewide. They range in length from a minimum of 15 feet (5 m) to over 21 miles (34 km). The overwhelming majority of these caves formed by solution of the host carbonate rock along partings and fractures. They develop as groundwater flowpaths and under phreatic conditions; they represent usable storage in the carbonate host rocks of the Valley and Ridge province. Many of our known caves are paleosoteric segments that are no longer active as recharge pathways, however they generally continue beyond the humanly untraversable boundaries, we know as their ends, and are linked to the karst aquifer and represent potential contaminant pathways. Only entrance locations are provided on this map. Location references include Douglas (1964), Holsinger (1973), and the Virginia Speleological Survey (P.G. Lucas, proprietary data, 1992-2001).

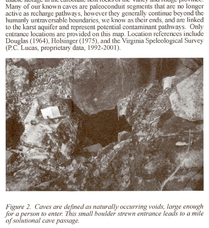

Figure 2. Caves are defined as naturally occurring voids, large enough for a person to enter. This small boulder stream entrance leads to a mile of solutional cave passage.

Hydrology

The 627 stream insurgences (swallets) (Figure 3) illustrated on this map were generally sensed by the same methods as the sinkholes. Because of the nature of the internal drainage in karst, much of the surficial drainage is intermittent and dependent on precipitation and hydrology with precipitation rate and history. Almost all karst sinkholes represent potential sites of insurgence. Of the 627 surficial streams with stream insurgences that were remotely sensed from aerial photographs are mapped as insurgences. These features, which may be sinkholes or other subsurface features, may be subject to karst flooding, represent recharge and potential contaminant pathways to the karst aquifer.

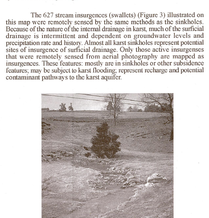

Figure 3. The stream insurgences (swallets), illustrated on this map, were remotely sensed by the same methods as the sinkholes.

The 618 springs marked on this map were located by remote sensing of low altitude aerial photography and topographic map locations (Figure 4). Because of the characteristic flashy flow of karst conduits, some of the springs depicted may be of an intermittent nature, but were observed flowing under hydrological conditions imaged on the aerial photography.

These selected karst features are linked to potential karst hazards that are discussed in a separate section of this publication. Map patterns of the selected sinkholes, cave entrances, and springs indicate and Simply commonly betray the influence of various geologic factors affecting karst development, including lithology, structure, hydrology, and the character of overburden.

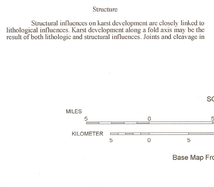

Figure 4. The springs marked on this map were located by remote sensing of low altitude aerial photography or copied from topographic maps.

Lithology

Lithology is of primary importance to karst development. The sinkholes, caves, and insurgences illustrated in this report are, at least in part, the result of dissolution of carbonate rock. Most of the sinkholes and insurgences are formed in the residual or colluvium/alluvium (overburden) mantling the carbonate bedrock. A very small percentage of sinkholes and insurgences occur in non-carbonate rocks because of the dissolution of an underlying carbonate strata and the subsequent collapse or subsidence of overlying non-carbonate strata. Examples of this condition are found in the East Stone Gap area, where the Wildcat Valley Sandstone overlies carbonate rocks of the Hancock Formation (see geologic maps of Henika, 1988 and Nolde and others, 1986).

Lithologic influences on karst development are grossly demonstrated on a regional scale in this report. Careful examination of the karst map reveals numerous northeasterly trends of sinkholes, caves, insurgences, and springs. Some of these linear or curvilinear concentrations of sinkholes, caves, insurgences, and springs are developed in specific carbonate strata and can be identified by strike oriented trends of features which extend parallel to the mapped contacts of the geologic map units.

Structure

Structural influences on karst development are closely linked to lithological influences. Karst development along a fold axis may be the result of both lithologic and structural influences. Joints and cleavage in folded and faulted carbonate rocks influence karst development through increased permeability through fractures (Hubbard, 1984) and subsequent solutional conduit development. Some linear trends of karst features have been demonstrated to coincide with fold axes (Hubbard, 1981).

In the southern karst area, as in the northern (Hubbard, 1983) and central (Hubbard, 1988) areas, both anticlinal and synclinal structures were observed to show enhanced karst development. Regional scale examples include the Powell Valley anticline in Lee County and its plunging nose in Wise County (A on Figure 5); the dome-like Burke's Garden anticline in Tazewell County (B on Figure 5); the Early Grove anticline at Shelleys in Scott and Washington Counties (C on Figure 5); a complex of adjacent anticlinal and synclinal folds in Wards Cove and Thompson Valley and Short and Knob Mountains in Tazewell County (D on Figure 5); the Rye Cove syncline in Scott County (E on Figure 5; Hubbard and Holsinger, 1984). In the folded and faulted Valley and Ridge province, structure commonly is responsible for the gross pattern of carbonate rock exposed to weathering processes.

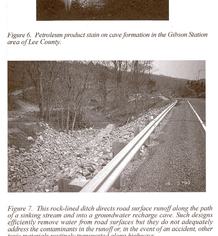

Figure 5. Both anticlinal and synclinal structures were observed to show enhanced karst development. Regional scale examples include the Powell Valley anticline in Lee County and its (A) plunging nose in Wise County; (B) dome-like Burke's Garden anticline in Tazewell County; the (C) Early Grove anticline at Shelleys in Scott and Washington Counties; a (D) complex of adjacent anticlinal and synclinal folds in Wards Cove and Thompson Valley and Short and Knob Mountains in Tazewell County; the (E) Rye Cove syncline in Scott County.

Figure 6. Petroleum product stain on cave formation in the Gibson Station area of Lee County.

PSEUDOKARST FEATURES

Two types of pseudokarst "sinkholes" have posed identification problems in this study area. Sinkhole-like features, known as sag ponds, are common in some landfills depending, but similar pseudokarst features formed by rockfalls of ridge forming Silurian sandstones in the study area. A local example of a debris dam closed depression, known as the Cosmic Nest (Figure 9), is located on Cumberland Mountain in Lee County, near Cosmic, Virginia (Douglas, 1964). This sinkhole formed as a result of the processing and piling of sandstone debris in the early 1940s (Currier, 1945) and was active (until about 1917 - Stone and Stose, 1937) and unnoticed (Stead and Stose, 1943). Residual/replacement ores of the Shady Dolomite formed in paleo-epikarst drains and were worked by open cut and pit mining techniques. After years of erosion, these excavations resemble sinkholes. Some mined features are serving in a reactivated role as epikarstic drains and presently are active karst features.

Figure 7. This rock-lined ditch directs road surface runoff along the path of a sinking stream and into a groundwater recharge cave. Such designs efficiently remove the runoff from the highway, but do not treat it nor address the contaminants in the runoff or, in the event of an accident, other toxic materials transported along highways.

DISTRIBUTION OF KARST HAZARDS

The potential geo-hazards of karst terrains can be categorized into three major concerns: 1) differential subsidence or collapse, 2) pollution of groundwaters, and 3) sinkhole flooding.

Although the closed-contour depressions we refer to as sinkholes occur even in unconsolidated, non-karst Valley and Ridge sinkholes form by the differential settling of overburden materials. Settling or subsidence of overburden results from various mechanisms (Stewart, 1976), including compaction due to loading, compaction due to dewatering, settling as materials are removed by groundwater flow, and piping of materials into void space, and instantaneous collapse into void space. Many of these processes are naturally and continuously active in karst areas. Human's attempts to prevent or deter these dynamic processes may result in their acceleration or additional process generated hazards.

A field of sinkholes is readily recognized as a site requiring special development considerations. Fortunately, not all karst areas are densely populated with sinkholes, caves, and insurgences. It is important to understand that the stability of karstland is a function of the past and present geomorphological and hydrological interactions. Changes in land-use, especially change toward more intensive uses, may enhance karst hazards even where no sinkholes presently exist.

Fluctuation of groundwater level, either natural or over extended time periods, are known as a cause of sinkhole formation and ground subsidence (Foose, 1967 and 1968; Foose and Humphreville, 1979; Newton and Hyde, 1971; Newton and others, 1977; Newton, 1976). Especially in arid areas where the groundwater level is above the soil/bedrock interface. The size of these features increases with the thickness of unconsolidated debris and with the magnitude of the groundwater lowering (Foose, 1968). The more rapid the reduction in water level, the more violent and commonly extensive the collapse/subsidence the subsidence and or collapse of the overlying and surrounding soil/rock. Virtually any change overlying karst terrain, if it does result in lowering to greater than the depth of groundwater level, poses a potential for subsidence if there are sufficiently great fluctuations of groundwater levels. Rapid groundwater withdrawals from water wells can result in local destabilization of soils above the bedrock surface and subsidence or collapse of dewatered soil/bedrock interface voids. Long-term groundwater-level reductions occur during droughts and may result in subsidence problems. Collapse or subsidence also may be initiated after soil materials comprising soil void roofs have dried-out from a lowering of groundwater levels and these materials are rewetted (heavy rainfall). Excessive hydration results in a reduction of the shear strength of overburden materials and the potential for soil arch failure and collapse into void spaces. The propagation of sinkholes by karst groundwater level fluctuation is a concern because groundwater resource utilization for residential and subsurface land-use can trigger subsidence.

The use of sinkholes for "drainage outfalls" is risky. Even the best conceived building project alters the equilibrium of the landscape. Ground surfaces are disturbed and artificial and impermeable surfaces are introduced. Increases of runoff are generated by impermeable surfaces and changes in cover vegetation. The use as outfalls of apparently "stable" sinkholes, which show no active subsidence or localized flooding prior to development, is tempting but should be avoided. Increased hydrologic input to sinkholes can reactivate subsidence or collapse of existing features as well as generate new problems (Crawford, 1980). The larger the volume of outfall the greater the risk.

Pollution of groundwater resources is a well-known problem in karst. Sinkholes represent recharge points for the karst aquifer. Liquid wastes dumped into sinkholes or caves can enter the karst aquifer undiluted. Dumped waste materials, leaks, spills, or other discharges that enter the ground and subsequently the karst aquifer may compromise nearby public water supplies, residential wells, or recreational waters. Case examples include groundwater contamination by: detergent in the Jonesville area of Lee County; petroleum products in the Gibson Station area of Lee County (Figure 6) and Powell Valley in Wise County; leachate of sawdust in The Cedars area near Jonesville in Lee County. The detergent that contaminated the Jonesville public water supply was reportedly associated with an oil-drilling operation during the Spring of 1984 (Virginia Water Resources Research Center, 1984). The Gibson Station petroleum product contamination was determined to have originated from a leaking underground storage tank, which was subsequently removed (Hubbard and Hallour, 1985). Powell Valley groundwater contamination by petroleum product was a reoccurring problem during the 1990s. Leachate from sawdust piles in Powell Valley has contaminated groundwater and cutgrassed the Lee County iospod from one of its two known habitats in 1987. This species of iospod was subsequently listed as a Federally protected Endangered Species and action was taken to remediate the site. The groundwater quality has improved, but the iospod has yet to repopulate this groundwater habitat. Storm water runoff from road surfaces transport contaminants such as heavy metals, petroleum products, road salts, and hydrocarbons (Stephenson and Hubbard, 1993). At many sites in southwest Virginia runoff from highways direct road surface runoff to groundwater recharge points such as conduits and cave entrances (Figure 7). Such designs efficiently remove water from road surfaces but they do not adequately address the contaminants in the runoff. An even greater concern is how efficiently such designs will direct the hazardous wastes and other non-biodegradable materials transported along highways into karst aquifers in the event of an accident. U.S. Department of Transportation (DOT) and Environmental Protection Agency data indicate that highway transportation of hazardous materials is a relatively high-risk industry (Padgett, 1993).

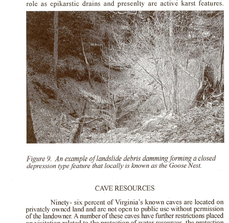

Figure 9. An example of landslide debris damming forming a closed depression type feature that locally is known as the Goose Nest.

CAVE RESOURCES

Ninety- six percent of Virginia's known caves are located on privately owned land and are subject to access rights and to the protection of the landowner. A number of these caves have further restrictions placed on visitation related to the protection of water resources, the protection of threatened or endangered species and their habitat, and archaeological, paleontological, and other scientific studies. Virginia's caves are protected by the Virginia Cave Protection Act (Code of Virginia Title 10.1, Chapter 10, Sections 10.1-1000 through 10.1-1008.) or the Federal Cave Resources Protection Act of 1988 (Pub. L. 100-691, Nov. 18, 1988, 102 Stat. 4546 (Title 16, Sec. 4301 et seq.)). For further information regarding cave resources, please contact: the Virginia Speleological Survey, HC06 03 Box 194, Huntville, Virginia 24487; the Virginia Cave Board, Virginia Division of Natural Heritage, Department of Conservation and Recreation, 217 Governor Street, 3rd Floor Richmond, VA 23219.

MAP LIMITATIONS

The data conveyed on this map: karst features, geological boundaries, and Acreage basins were mapped at a precision suitable for presentation at the regional scale of 1:250,000. For the majority of the sinkholes mapped, the minimum symbol size exceeds the size of the actual feature by as much as an order of magnitude. In some places the density of sinkholes prevented adjustments of individual karst features with respect to the oversized symbols representing cultural map features resulting in distortions in the relationships of cultural and karst features (Hubbard, 2001). Very few of the remotely sensed karst features illustrated on this map were field checked. There has been no work done, at the date of publication, to determine a reliability estimate of any of the sinkholes, insurgences, or springs by ground truthing. Not field accuracy checks been done for the interpretive rock unit contacts in unpublished map areas. When field reconnaissance of questionable interpretive features was made, many sinkholes, that were not remotely sensed, were observed. Hydrological drainage basin boundaries were based on topographic data.

No data depicted on this map are suitable for site-specific studies.

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