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KARST GEOLOGY AND HYDROLOGY

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Henry W. Rauch and Eberhard Werner

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WEST VIRGINIA GEOLOGICAL AND ECONOMIC SURVEY

PREFACE

Carbonate rocks underlie many areas that are desirable for agriculture and urban development because they tend to be relatively flat and well-drained. In recent years, there has been considerable development of such areas and this has resulted in an increasing frequency of problems which are peculiar to karst terrains (terrains in which there has been considerable solution of soluble rocks). For instance, there have been structural failures such as subsidence of roads and buildings into collapsing sinkholes; adequate groundwater supplies have often been difficult to obtain; and water supplies have commonly become polluted. Many of these problems could be avoided by a better understanding of the characteristics of karst terrains. Therefore, there is currently a growth of interest in karst studies in many parts of the world. In the United States, the areas of prime concern are in the Appalachians and in the southeastern states.

In order to give karst researches a forum for reporting and discussing recent and ongoing investigations, the "Friends of Karst" have held conferences at irregular intervals. On 3-5 May, 1974, the Fourth Conference on Karst Geology and Hydrology was held in Mongantown under the co-sponsorship of the West Virginia Geological and Economic Survey and the Department of Geology and Geography of West Virginia University. The Survey has published the proceedings of this meeting in this volume, which contains 22 papers, 2 extended abstracts, and abstracts of the remainder of the 32 papers presented.

We would like to acknowledge the aid of Shelia Newman and James Carte of the Geological Survey. Without their editorial and production knowledge, this proceedings would have been difficult, if not impossible, to produce.

TABLE OF CONTENTS

History and Status of Geologic Research In the West Virginia Karst

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ABSTRACT—Since the first mention of West Virginia caves in the middle of the 18th century, a considerable amount of work has been done in studying the West Virginia karst. Scientific study in earth-science specialities is progressing rapidly. Early work was principally archeological and paleontological research. Other specialities did not develop until the groundwork of discovery and exploration was well under way. Systematic cave discovery and exploration began in the early 1940s and has continued so that now, in 1974, an estimated 2,500 West Virginia caves have been cataloged and 1,000 caves mapped. Several significant paleontological finds have occured, primarily of Pleistocene mammals; the most recent such find was the mastodon remains from Bowden Cave, which served to extend the known range of *Mammut americanum.* Meteorological work has been relatively slight; this has principally involved data recording and some work on the cave-breathing phenomenon. Cave minerals of West Virginia have not been studied extensively. Most geochemistry work has been in connection with hydrological studies; however, there is current interest in isotope geochemistry for absolute-age dating and paleoclimatological determinations. Hydrologic work in the West Virginia karst is extensive, with spring and ground-water studies in progress study everywhere.

Studies in cave genesis and development have been popular, with different subspecialities receiving attention at different times. Cave breakdown was the earliest to be studied. Structural featuares and their control on cave development have been extensively investigated during the past 10 years. A study of cave sediments of the Allegheny Front was completed recently.

Quantitative work and model building with field examples from West Virginia have just begun and should become popular in the near future. Environmental studies are underway or are about to be started in several West Virginia karst areas.

The future probably will see great emphasis on quantitative work and computer simulation (particularly in relation to environmental problems), and a continuation of the type of work done in the past.

INTRODUCTION

The earliest mentions of West Virginia caves exist only as incidental phrases in travelers' journals. The first scientific studies done in or around caves of the state were of archeological or paleontological deposits. As early as 1799, articles were published of paleontological finds (Jefferson, 1799; Wister, 1799). These articles refer to the find of Megalonyx bones in Organ Cave by Thomas Jefferson, and are the earliest reference to a West Virginia (then western Virginia) cave in any scientific article dealing with geological topics. Comments on this find, and references to it, are the only literature for about a hundred years (Cuvier, 1804; Barton, 1804; Harlan, 1834). Then in the late 1880's, the Indian pictographs were studied at Indian Cave (Two Lick Shelter), a rock shelter in Harrison County (Holmes, 1890). There also appears to have been some systematic exploration of caves during this period (Mercer, 1896). During the first half of the twentieth century, except for the report on the fossil mammal bones at Renick Quarry (Gidley, 1920), caves received little mention in the literature; the primary references of this period are the series of county geological reports produced by the West Virginia Geological and Economic Survey (WVGS) from 1900 to

1939 (Hennen, 1919; Reger, 1923, 1924, 1931; Reger and Price, 1926; Tilton, et al., 1927a, 1927b; Price, 1929; Price and Heck, 1939).

Serious and systematic biological research of West Virginia caves dates from the early 1930's, but systematic geological studies did not begin until the early 1940's, after the founding of the District of Columbia Speleological Society - later to become the National Speleological Society (NSS). It was at this time that William E. Davies began collecting information and cataloging the known caves of the state for eventual publication by the WVGS (Davies, 1949a). During this decade, reports of most of the better known caves appeared in issues of the NSS Bulletin. There was a noticeable progression of cave studies which was dependent on the distance of a study area from Washington, D.C., and on the availability of access routes (see fig. 1). Initial work began in the Eastern Panhandle counties, and progressed southward and westward. Another early locus was White Sulphur Springs, which provided access to Greenbrier and Monroe Counties. By 1945, there had been published reports on caves from all the "cave counties". By the end of decade, more than 400 caves had been described (Davies, 1949a). Although a majority of the work of this decade was in the discovery and exploration phase of karst research, there was a beginning of analytical geologic work with the study of cave breakdown by Davies (1949b, 1951).

The 1950's saw a continuation of cave discovery and exploration, as well as a steadily increasing frequency of "scientific" geological literature on West Virginia karst, which primarily appeared in publications of the NSS and its subdivisions. The Explorers Club of Pittsburgh became interested in West Virginia karst during this decade, and its members found, explored, and mapped caves in various parts of the state, eventually concentrating on the Swago Creek drainage basin of southern Pocahontas County (Nelson, 1956). William B. White was a member of this group and soon began serious study of the geology and hydrology of the area. As a result, West Virginia karst became known to an international audience of speleologists at the 3rd International Congress of Speleology (White, 1963), and to the geological community at large (White and Schmidt, 1964, 1966).

The 1960's saw a general increase in popularity of West Virginia karst - not only for explorers, but also for professional scientists. Numerous individuals and small groups began studies at this time. Several theses and dissertations resulted from this work, as well as too many publications to list here. (For a complete listing, see Werner, 1974.) The Swago Creek study provided much of the impetus for West Virginia karst studies during the 1960's. The people who had come to Swago Creek with the Explorers Club and the Pittsburgh Grotto of the NSS developed interests in other nearby areas or continued more detailed work (Zotter, 1963; Wolfe, 1964). By the middle of the decade, 625 West Virginia caves had been described and studied to some extent, and 75 had been mapped (Davies, 1965), with much of this increase due to the Swago Creek group.

Another group which made a significant contribution during the 1960's is the West Virginia Association for Cave Studies (WVACS), which has been active in the Greenbrier County karst, where they have been principally studying the "contact" caves of the Great Savannah. This area had yielded 100 miles of cave passage by the end of the decade (Rutherford, 1971a). WVACS has actively pursued a variety of karst studies in Greenbrier County to the present, although relatively few results have been published.

In 1967, a loose organization of individuals was formed principally to collect and publish information of value to karst scientists from studies of West Virginia karst. This organization, the West Virginia Speleological Survey (WVaSS), is presently preparing a series of cave surveys on a county by county basis, with the Randolph County report completed (Medville and Medville, 1971a), and others in various stages of completion. Also published will be reports of research projects, particularly complete theses and dissertations, whose length makes them unsuitable for journal publication. One has appeared to date (Werner, 1972a).

STATUS BY SPECIALTY

This section will briefly describe activity in the various subspecialties of the earth sciences as applied to the West Virginia karst. Table 1 summarizes the activity in each speciality throughout the history of study, and table 2 shows this activity in more detail for the last 35 years.

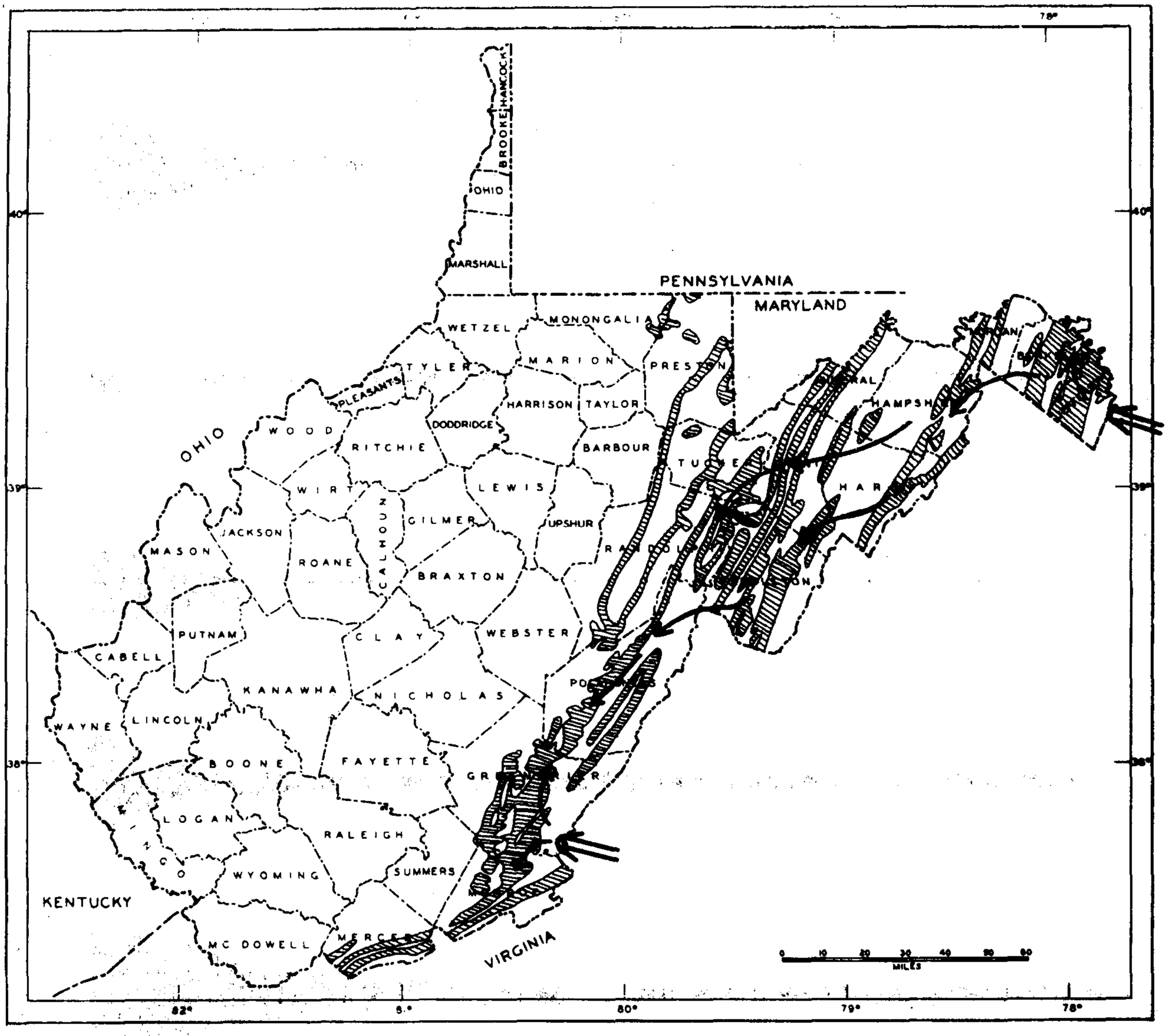

Figure 1. A map of West Virginia, showing the karst areas (hatched areas), and the early cave discovery and exploration trends (indicated by arrows).

CAVE GEOGRAPHY

A necessary prerequisite for any systematic or detailed scientific study of karst features, particularly of caves, is the locating and mapping of these features. Without this groundwork over the last 30 years, any other work would have been made very difficult, if not impossible.

Table 3 shows the status of cave location, exploration, and mapping for 1965 and 1974 on a county basis. The total number of caves known today is estimated to be about 2500, of which approximately 1000 have been mapped. Many of the remaining 1500 are too small to warrant any map. Thus the last nine years saw a 400% increase in the number of known caves, and a 1300% increase in the number of cave maps. Based on estimates by the individuals involved in the area surveys, it is conceivable that the present numbers might double in the next ten years, after which there should be relatively little further increase.

PALEONTOLOGY

The earliest work was in this field. However, only fairly recently were paleontological workers once again active in the West Virginia karst. The recent finding of mastadon remains in the Bowden Cave System has extended the known range of that animal (Monongahela

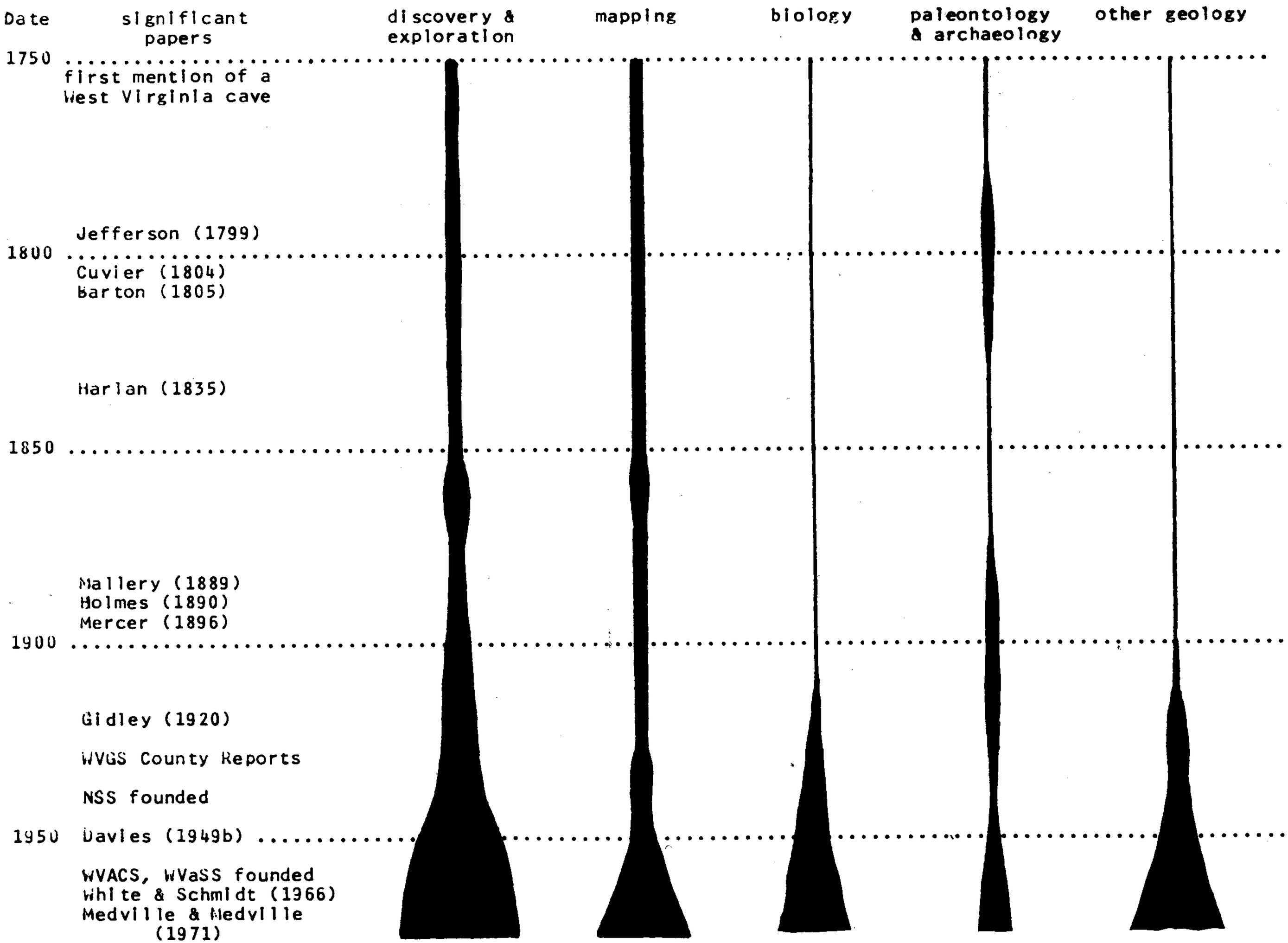

Table 1. Summary of Karst research of all types in West Virginia from its beginning to the present. The width of the bar shows relative activity within each field. It is not intended to indicate comparisons between fields.

Date	Caves Known	Caves Mapped	Meteorology	Mineralogy	Geochemistry	Hydrology	Geology
1940			temperature readings only, usually in connection with cave surveys				breakdown Davies (1949b)
1950.	400 (Davies, 1949b)	50					Davies (1951)
				speleothems White (1957)	basic water chemistry		cave origins and development Sanders (1959)
1960.	520 (Davies, 1959)	60	temperature & humidity Davies (1960)				
						dye tracing Zotter (1963)	
			climatic variation				Wolfe (1964)
	625 (Davies, 1965)	75	Cropley (1965)			areal hydrology White & Schmidt (1966)	
			resonant breathing Plummer (1969)			subterranean diversion Duncan et al. (1968)	sediments White & White (1968)
1970				speleothems Broughton (1972)	isotope dating & climatology Thompson (1971)	... subterranean drainage basins Jones (1973)	Wolfe (1970) underground floodplain Jones (1971)
	2500 (est. 1974)	1000					

Table 2. Karst research in West Virginia in the earth sciences since 1940. Specific topics of study and representative or notable papers published during this period are indicated.

Table 3. Status of exploration and mapping of caves of West Virginia for 1965 and the present.

County	Davies (1965) known	Davies (1965) mapped	present known	present mapped	status*	data from
Barbour	0	0	7	1	3	Garton (pers. comm.)
Berkeley	20	4	(55)#	(13)#	3	Gulden (pers. comm.)
Grant	20	3	20	3	5	
Greenbrier	123	18	500	200	2	Baroody (pers. comm.)
Hampshire	8	0	8	0	5	
Hardy	14	0	14	0	5	
Harrison	11	0	1	0	5	
Jefferson	13	4	#	#	3	Gulden (pers. comm.)
Marion	0	0	1	0	4	Garton (pers. comm.)
McDowell	1	0	1	0	5	
Mercer	14	1	14	1	5	
Mineral	7	1	7	1	5	
Monongalia	5	0	14	10	3	Garton (pers. comm.)
Monroe	57	9	250	110	2	Hempel (1975)
Morgan	1	0	1	0	4	Gulden (pers. comm.)
Nicholas	2	0	2	0	5	
Ohio	0	0	10	4	3	Garton (pers. comm.)
Pendleton	75	17	100	50	4	
Pocahontas	165	12	450	85	3	Medville (pers. comm.)
Preston	8	1	50	14	3	Garton (pers. comm.)
Randolph	46	1	220	40	1	Medville and Medville (1971a)
Tucker	23	2	23	2	4	
Upshur	0	0	2	0	3	Garton (pers. comm.)

* 1 - survey completed and published, 2 - survey essentially complete, 3 - survey active and more than half complete, 4 - survey active but no further information, 5 - no survey or no information.
\# data for Berkeley and Jefferson counties is combined.

Grotto, 1971). John Guilday and his associates from the Carnegie Museum of Pittsburgh have been investigating some caves, particularly in Pendleton County, for about the past 15 years (Guilday and Hamilton, 1973).

METEOROLOGY

Some of the earliest quantitative work in caves was the measurement of temperature and humidity during the mapping work of the early 1940's. Much of this data is now poorly accessible, since it was published only in newsletters of local caving groups. Recently, there has been some interest in the cave breathing phenomenon (Plummer, 1969), and in seasonal and climatic effects on cave meteorology (Cropley, 1965), but little work appears to be in progress at the present time.

MINERALOGY

West Virginia cave minerals have not been studied as extensively as those from other localities. There have been a few speleothem descriptions (White, 1957; Broughton, 1972), but no systematic studies, either past or present.

GEOCHEMISTRY

A considerable amount of work has been done on the geochemistry of karst ground water incidental to hydrologic studies. Currently, this type of work is being done in many parts of the West Virginia karst. This work is discussed in detail by William K. Jones in another paper (Jones, 1974).

A different type of geochemical study is that of isotope analysis. Thompson and his colleagues have

used oxygen isotope analysis for paleoclimatic determinations (Thompson, 1971). They have also used radioactive isotope methods for dating speleothems from West Virginia caves (Thompson, 1973); Thompson, et al., 1973). This as well as other types of geochemical work may be expected to continue.

HYDROLOGY

There has been interest in ground-water hydrology of the West Virginia karst from the earliest days of scientific study, and this interest has continued to the present. William K. Jones discusses this topic at length in another paper of these proceedings (Jones, 1974).

GENERAL GEOLOGY

A number of other subdisciplines of geology are grouped in the classification of "Geology" in table 2. In general, this classification covers that literature which presents data for and attempts explanation of cave origin and development, including studies of sediments done to unravel the history of cave development.

Early studies related to the development of West Virginia caves were by Davies (1949b, 1951) on the effects of breakdown, but no investigations of breakdown appear to have been made since the study by White and White (1969) in the late 1950's. More recently, attempts have been made to define the effect of structural featues on cave development (Eddy and Williamson, 1970; Medville and Medville, 1971b; Rutherford, 1971b; Werner, 1972b).

In recent past, there has been considerable interest in sediments of the Greenbrier limestone karst, as indicated by a doctoral dissertation just completed by Thomas E. Wolfe. A preliminary version was presented at the 1969 AAAS annual convention (Wolfe, 1970).

Some investigations of erosion rates in caves have been done (Coward, 1971). Computer models to simulate the development of karst featues, particularly hydrologic patterns, have been built and tested against several West Virginia karst basins (Coward and Ford, 1973). Because the Greenbrier Group varies greatly, stratigraphic effects on cave development can readily be studied (Werner, 1973).

Several areal studies, currently in progress by West Virginia University students involve the investigation of ground water, general geology, and karst geomorphology. Albert Ogden is studying the Greenbrier outcrop in Monroe County; James Wigal is working in the vicinity of the Great Savannah of Greenbrier County; and James Young in investigating the hydrology of the Germany Valley area of Pendleton County. Other work by West Virginia University students, reported in these proceedings, is the work by Keith Kirk to locate cave passage by geophysical methods (Kirk, 1974), and work by J. C. Hempel to determine the relation of pit development to lithology in the Union Limestone (Hempel, 1974).

SPECULATIONS FOR THE FUTURE

For some time yet to come, areal studies will continue until all karst terrains have been investigated. Those areas which have not as yet been systematically covered in the search for caves should be surveyed by WVaSS within the next ten years.

Studies in connection with environmental problems will become increasingly popular, first in terms of water quality but soon also in terms of land subsidence. Problems of waste disposal peculiar to karst will become prevalent with increasing development, and these will have to be solved. Contamination of ground-water with gasoline, sewage, solid-waste leachate, and road salts, which are already serious problems elsewhere, are becoming more frequent in West Virginia—particularly in the more developed Eastern Panhandle counties. The same can be said for lowered water tables and associated subsidence.

In many ways, the future will see the application of new techniques in the West Virginia karst, in particular within the Greenbrier limestone outcrop. This terrain shows sufficient variation and complexity for the testing of techniques, but it is not so complex that conclusions are difficult to reach (as is the case in some other, currently popular, karst terrains). We can expect considerable experimentation with geophysical methods of locating and mapping caves, and possibly of tracing ground-water flow.

The main effort will probably be in the use of quantitative methods. Morphometric analysis of various karst landforms will be applied to the area, and presumably will show the degree of interrelation of various factors controlling development of caves and surface karst. Simulation models will be further tested on West Virginia karst terrain, and predictive models which could be applied to land use planning may be developed.

In general, we can expect some innovation and considerable development of new techniques of study in the West Virginia karst, both because of the nature of the karst area and because of the groundwork which has been laid here.

CONCLUSION

The caves and karst areas of West Virginia have been studied for some time. They were not the first in the world or even in this country to be investigated; however, neither have they been neglected. Generally, studies of the West Virginia caves have been approximately contemporaneous with studies elsewhere, lagging only slightly behind the more popular areas of Virginia, Pennsylvania, and the Kentucky-southern Indiana karst. As time has progressed, this lag has become shorter and shorter, until some types of studies are now done here first and then elsewhere. In a number of ways, West Virginia has become a leading area for karst research.

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Karst Hydrology in West Virginia— A Review of Research

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ABSTRACT—Karst features are developed on marine limestones and dolomites ranging in age from Cambrian to Mississippian in the eastern and southeastern counties of West Virginia. Flow conditions in the carbonate aquifers range from predominantly diffuse through the highly fractured rocks of Jefferson and Berkeley Counties to generally channeled in the relatively flat-lying carbonates in Greenbrier and Monroe Counties. Obtaining adequate water supply and ground-water pollution are major problems in the large karst plateaus of the southeastern part of the State.

West Virginia karst drainage systems have been investigated by many researchers, and a variety of special dye-tracing and interpretive techniques have been developed.

INTRODUCTION

Interest in the drainage phenomena of West Virginia's carbonate terrains can be traced back to the names early settlers gave to streams and villages. Lost River, Sinking Creek, Lost Run, Spring Creek, and Cave Spring are common names in the karst areas. Communities with names such as Fort Spring, Old Sweet Spring, and Sinks Grove reflect the original settlers' awareness of the karst landscape and drainage systems. Today many of the residents in carbonate areas of the State are dependent upon water from karst aquifers. Research in karst hydrology in West Virginia has been stimulated by the need for water supply information, and to supplement interpretations in geologic and physiographic studies of karst terrains and caves. Karst development is most extensive on marine limestones ranging in age from Cambrian to Mississippian. These carbonates crop out along a line from Mercer County northeast to Preston County and in all counties east of this line (fig. 1). Detailed stratigraphic descriptions of these units are given in geologic reports of the West Virginia Geological and Economic Survey, and in McCue and others (1939). Because of the diverse stratigraphic, physiographic, and hydrologic settings, the flow conditions through the carbonate aquifers (and the corresponding karst features) vary considerably in different parts of the State. The purpose of this paper is to discuss the different hydrologic conditions in the major carbonate aquifers of West Virginia and to review the major studies of these aquifers. The stratigraphic names used are those in use by the West Virginia Geological & Economic Survey (Cardwell and others, 1968) and do not necessarily conform to the current usage of the U. S. Geological Survey.

JEFFERSON AND BERKLEY COUNTIES

Cambrian and Ordovician carbonates are exposed over broad areas of these counties, and the carbonate aquifers provide the most productive sources of ground water within the region (Bieber, 1961). Discharge from the carbonates ranges from 300,000 to 600,000 gallons per day per square mile. The water is generally very hard and may locally be contaminated by nitrate (Hobba and others, 1973). Many of the towns and industries depend upon springs in karst areas for water supply. Most of the supply for the city of Martinsburg comes from two springs (Kilmer Spring and Big Spring, fig. 2), and the town of Inwood depends on springs and wells in carbonate rocks for domestic and industrial water (Graeff, 1953; Jeffords, 1945 a,b).

The rocks of these counties are highly folded and faulted, and the carbonate sequences are usually exposed at the surface in anticlinal valleys. The topography of the karst areas is gently rolling plains with shallow dolines and occasional ribbon-like ridges of karren exposed parallel to the regional strike. Caves in this area are usually shallow, and extensive passage development is rare in the highly fractured rocks (Davies, 1958; Davies and LeGrand, 1972).

The main source of recharge to the aquifers is direct infiltration of precipitation. Direct capture of surface drainage is rare, but some of the surface streams appear to lose some of their water as they cross the carbonates

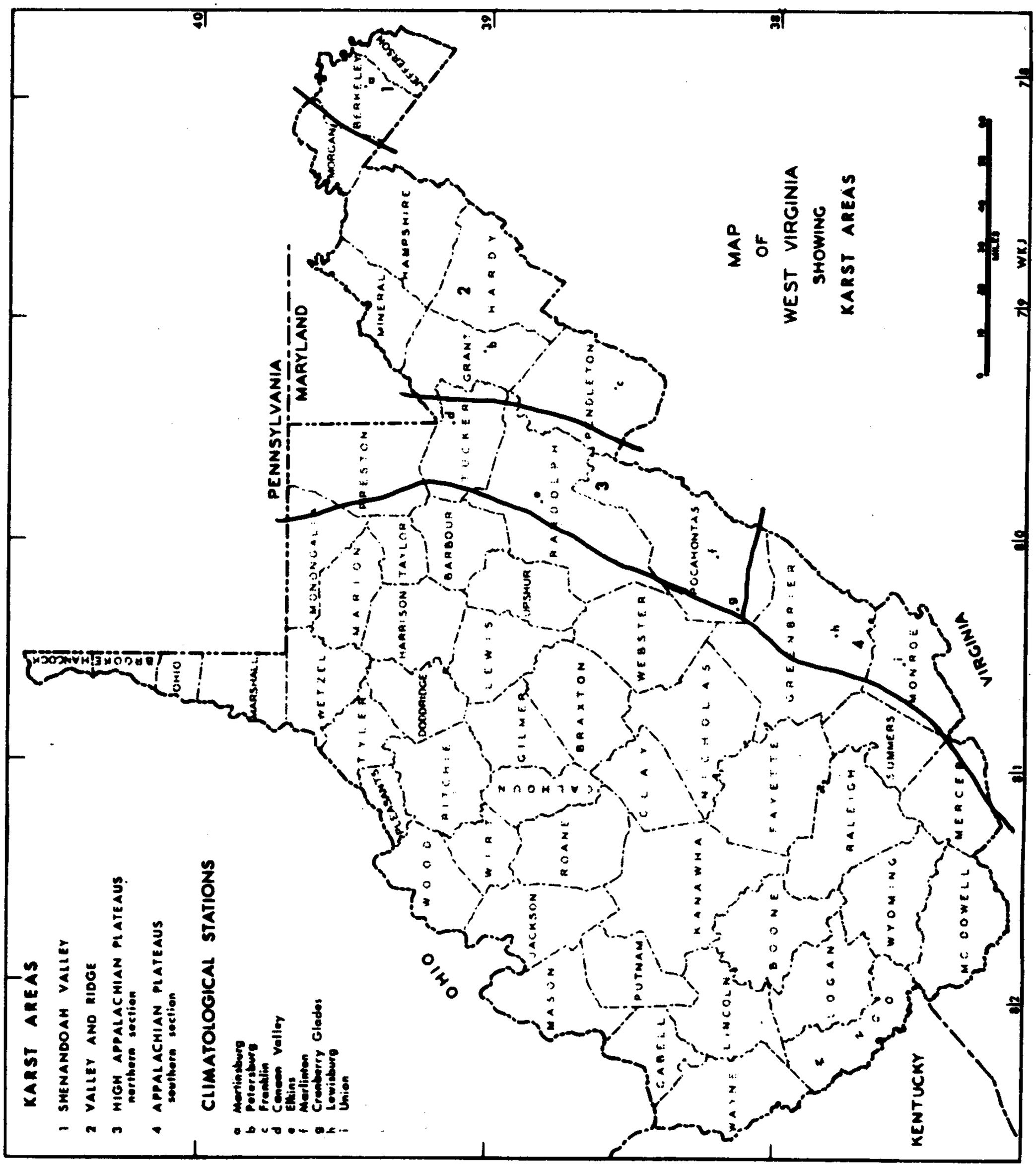

Figure 1. Map showing generalized karst areas of West Virginia.