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GEOLOGICAL SURVEY CIRCULAR 801

Geologic Mapping of Kentucky—A History and Evaluation of the Kentucky Geological Survey—U.S. Geological Survey Mapping Program, 1960–1978

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Prepared in cooperation with the Kentucky Geological Survey

A discussion of the origin, operation, cost, and economic benefits of a major geologic mapping program

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By Earle R. Cressman and Martin C. Noger

ABSTRACT

In 1960, the U.S. Geological Survey and the Kentucky Geological Survey began a program to map the State geologically at a scale of 1:24,000 and to publish the maps as 707 U.S. Geological Survey Geologic Quadrangle Maps. Fieldwork was completed by the spring of 1977, and all maps were published by December 1978.

Geologic mapping of the State was proposed by the Kentucky Society of Professional Engineers in 1959. Wallace W. Hagan, Director and State Geologist of the Kentucky Geological Survey, and Preston McGrain, Assistant State Geologist, promoted support for the proposal among organizations such as Chambers of Commerce, industrial associations, professional societies, and among members of the State government. It was also arranged for the U.S. Geological Survey to supply mapping personnel and to publish the maps; the cost would be shared equally by the two organizations.

Members of the U.S. Geological Survey assigned to the program were organized as the Branch of Kentucky Geology. Branch headquarters, including an editorial staff, was at Lexington, Ky., but actual mapping was conducted from 18 field offices distributed throughout the State. The Publications Division of the U.S. Geological Survey established a cartographic office at Lexington to prepare the maps for publication.

About 260 people, including more than 200 professionals, were assigned to the Branch of Kentucky Geology by the U.S. Geological Survey at one time or another. The most geologists assigned any one year was 61. To complete the mapping and ancillary studies, 661 professional man-years were required, compared with an original estimate of 600 man-years.

A wide variety of field methods were used, but most geologists relied on the surveying altimeter to obtain elevations. Surface data were supplemented by drill-hole records, and several dozen shallow diamond-drill holes were drilled to aid the mapping. Geologists generally scribed their own maps, with a consequent saving of publication costs.

Paleontologists and stratigraphers of the U.S. Geological Survey cooperated closely with the program. Paleontologic studies were concentrated in the Ordovician of central Kentucky, the Pennsylvanian of eastern and western Kentucky, and the Mesozoic and Cenozoic of westernmost Kentucky.

In addition to financial support, the Kentucky Geological Survey provided economic data, stratigraphic support, and drill-hole records to the field offices. Geologists of the State Survey made subsurface structural interpretations, constructed bedrock topography maps, and mapped several quadrangles.

Some of the problems encountered were the inadequacy of much of the existing stratigraphic nomenclature, the uneven quality of some of the mapping, and the effects of relative isolation on the professional development of some of the geologists.

The program cost a total of $20,927,500. In terms of 1960 dollars, it cost $16,035,000; this compares with an original estimate of $12,000,000.

Although it is difficult to place a monetary value on the geologic mapping, the program has contributed to newly discovered mineral wealth, jobs, and money saved by government and industry. The maps are used widely in the exploration for coal, oil and gas, fluorspar, limestone, and clay. The maps are also used in planning highways and locations of dams, in evaluating foundation and excavation conditions, in preparing environmental impact statements, and in land-use planning.

PURPOSE OF THIS REPORT

In 1960, the U.S. Geological Survey and the Kentucky Geological Survey began a cooperative program to map geologically the entire State of Kentucky, an area of 40,400 square miles (104,636 km^2), at a scale of 1:24,000. The maps were to be published as 707 U.S. Geological Survey Geologic Quadrangle Maps. Fieldwork was completed by spring 1977, and all maps were published by the end of December 1978.

The Kentucky Cooperative Mapping program was unprecedented in terms of money, manpower, and time devoted to large-scale geologic mapping; and considering budget and manpower restraints, changing National priorities, and changing concepts of the proper missions of the U.S. Geological Survey, it is unlikely that similar projects will be undertaken in the foreseeable future. Nevertheless, it is appropriate, while participants and records are still available, to relate the origins of the program and the methods of operation, to summarize the costs, and to enumerate the economic benefits.

ORIGINS OF THE PROGRAM

This section is based partly on an article by Wallace W. Hagan (1961), Director and State Geologist of the Kentucky Survey, and partly on information in the files of the Branch of Kentucky Geology of the U.S. Geological Survey.

In 1949, the U.S. Geological Survey and the Kentucky Geological Survey entered into a program to produce complete topographic coverage of the State at a scale of 1:24,000. The program was promoted by the Kentucky Chamber of Commerce on the advice of the State Geologist, the late Daniel J. Jones. The mapping was completed by the late 1950's, and the topographic maps proved invaluable in promoting industrial development.

Though Kentucky had complete topographic coverage by 1959, the status of geologic mapping (fig. 1) was woefully inadequate for a State containing so much mineral wealth. County geologic maps at a scale of 1:62,500 were available for about two-thirds of the State, but less than one-third were available in printed form. The county maps were mostly on planimetric bases, and although the quality of the mapping varied, most was of a reconnaissance nature. Furthermore, in many of the areas, the units mapped were biostratigraphic or chronostratigraphic and did not adequately portray the lithologic character of the bedrock. In the eastern Kentucky coal field, several 7½-minute quadrangles had been mapped and published by members of the Fuels Branch of the U.S. Geological Survey; two quadrangles had been mapped in a clay study by members of the Mineral Deposits Branch of the U.S. Geological Survey, but were as yet unpublished. These projects were part of a cooperative program between the State and Federal Surveys.

On February 21, 1959, the Kentucky Society of Professional Engineers, impressed by the utility of recently completed topographic maps, passed a resolution urging the preparation of a geologic map of the State. The resolution was presented to Governor A. B. Chandler, the Kentucky Legislative Research Commission, the Kentucky Department of Economic Development, the Kentucky Chamber of Commerce, and the Kentucky Geological Survey. W. W. Hagan, who had been appointed State Geologist and Director of the Kentucky Geological Survey in 1958, then contacted the Kentucky Department of Economic Development, which gave support to the proposal. Recognizing that the U.S. Geological Survey was the only organization with sufficiently trained manpower to undertake such a large geologic mapping program, Hagan contacted T. B. Nolan, Director of the U.S. Geological Survey, by letter in March. At Nolan's suggestion, Hagan met in April with Associate Director A. A. Baker and Chief Geologist W. H. Bradley of the U.S. Geological Survey, who expressed interest in the proposal. Hagan and Preston McGrain, Assistant State Geologist, then sought and received endorsements for the program from the Kentucky Geological Survey Advisory Board, the Kentucky Chamber of Commerce, local Chambers of Commerce, the Kentucky Oil and Gas Association, the Indiana-Kentucky Geological Society, the Kentucky Geological Society, the University of Kentucky, the Chesapeake and Ohio and Louisville and Nashville Railroads, Reynolds Metals, coal company operators, and the clay and fluorspar industries. He also received support from officials in the administration of Governor Chandler, who was in the last year of his term.

It is obvious from the above list of supporters that the main selling point of the program was the value of geologic maps in finding and exploiting mineral deposits and in promoting industrial development.

From July 10 to 17, 1959, Hagan met with various members of the U.S. Geological Survey in Washington, where a tentative agreement was reached on the scope, methods of operation, and finances. Both parties agreed on a 10-year program, during which time the entire State would be mapped at a scale of 1:24,000. The maps were to meet the standards already established by the Geologic and Water Resources Divisions of the U.S. Geological Survey for general geologic maps and to be published as multicolored maps.[1] The cost of the entire program was estimated to be $12,000,000, with the two organizations sharing the cost equally. The Kentucky Geological Survey was to include $900,000 for the program in the State biennial budget ($300,000 for Fiscal Year 1961 and $600,000 for Fiscal Year 1962); and the U.S. Geological Survey was to seek matching funds.

In January 1960, Bert Combs was inaugurated as Governor of Kentucky. One of the major concerns of the new administration was the chronic economic depression in several parts of the State,

[1] The standards, promulgated in a memorandum by the Chief Geologist of the U.S. Geological Survey in 1956, included the following: (1)The mapping should be on a scale of 1:63,360 or larger. (2) A topographic base is essential. Planimetry, contour interval, and detail of contouring should meet the standards established by the Federal Board of Surveys and Maps. (3) All geologically significant units mappable at the scale should be shown. "Mappable" refers to that which can be identified by the field geologist using lens and pick, but little else in the way of special chemical, paleontologic, or other analyses. (4) Structure should be adequately portrayed. (5) Explanation should be concise and express the distinctive characteristics and principal variations in lithology of map units and also in thickness. (6) The accuracy of location of faults and contacts shonld be shown by appropriate symbols. (7) Geologic interpretations should be internally consistent.

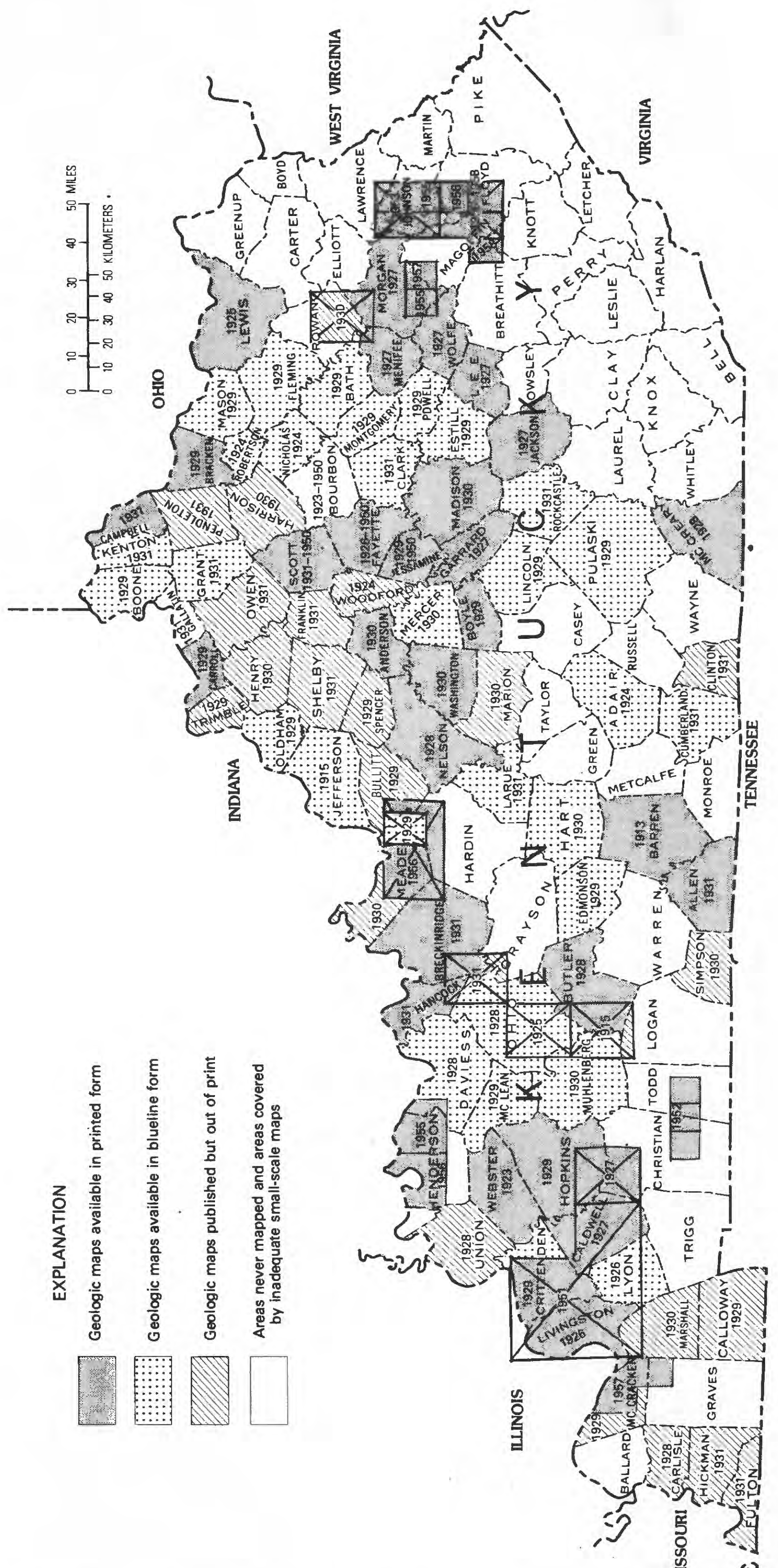


FIGURE 1.—Status of areal geologic mapping in Kentucky, prior to the beginning of the Statewide areal mapping program. (All maps indicated are of scale 1:62,500 or larger.)

and Lieutenant Governor Wilson Wyatt undertook economic development as his prime responsibility. Hagan discussed the mapping proposal with Wyatt, who became a firm supporter. The State budget, containing the requested appropriation, was approved without change by the State legislature in March.

The supplemental appropriation of $300,000 requested by the U.S. Geological Survey was approved by Congress with the support of Senator John Sherman Cooper of Kentucky near the end of August; and the cooperative agreement between the two Surveys was signed on September 2, 1960. By the end of November, 30 geologists from the U.S. Geological Survey had been assigned to the project, and mapping was underway.

In summary, several factors were responsible for the initiation of the mapping program. Three factors, apparent from the above discussion were: (1) The initiative of the Kentucky Society of Professional Engineers, who recognized the potential value of geologic maps and proposed that the State be mapped; (2) the acumen of the State Geologist, who seized on the opportunity presented by the resolution of the Kentucky Society of Professional Engineers and promoted support among a wide variety of influential organizations; and (3) the advent of a State administration committed to improving the economy of Kentucky.

OPERATIONS

Although the supplemental appropriation required to finance the first year of the program was not passed by Congress until the end of August 1960 and the cooperative agreement was not signed until September 2, 1960, the program actually started on July 1 of that year with the arrival of A. D. Zapp in Lexington to take charge of the project for the U.S. Geological Survey. Fieldmen began arriving in the State later in July.

Organizationally within the U.S. Geological Survey, the Kentucky program was given Branch status within the Regional Geology Subactivity, which was later changed to the Office of Environmental Geology. The program was administered as a single project, with the Branch Chief also serving as Project Chief. The Branch Chiefs and their tenures are listed below:

A. D. Zapp	July 1960 to March 1961
P. W. Richards	April 1961 to June 1970
W. W. Olive	July 1970 to June 1975
E. R. Cressman	July 1975 to September 1978

Richards was Branch Chief during the early stages when many of the policies and procedures were developed, and he maintained the program on schedule for 9 years; by the end of his tenure, two-thirds of the state had been mapped. He deserves a large share of the credit for the success of the program.

Branch headquarters was established at Lexington. The headquarters staff consisted of the Branch Chief, an Administrative Officer, a secretary, and a clerk. In addition, a Technical Reports Unit was established at Branch Headquarters to edit maps (but not manuscripts), prior to Branch Chief approval. The Technical Reports Unit consisted of an editor, assisted at various times during the project by an assistant editor or by geologists assigned to editorial duties for short periods. Editors in charge of the Technical Reports Unit and their dates of tenure are as follows:

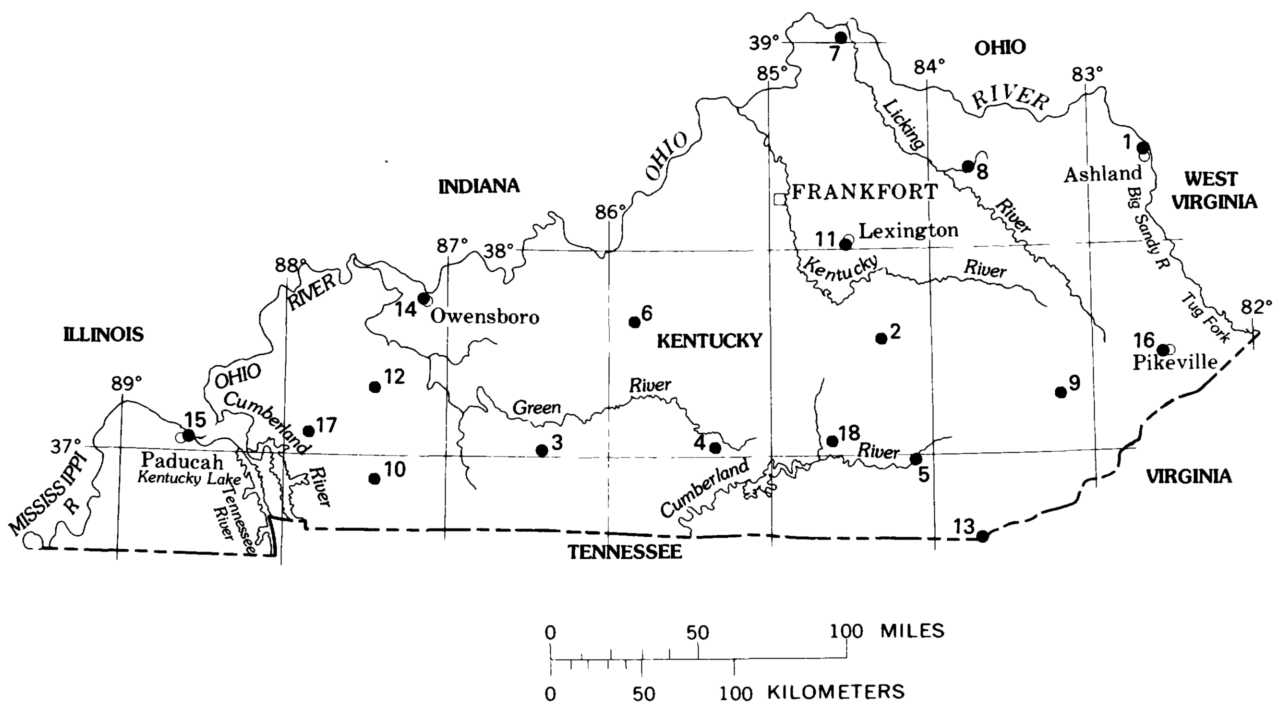
D. E. Wolcott	September 1961 to August 1964
W C Swadley	September 1964 to July 1966
J. S. Pomeroy	August 1966 to April 1968
D. F. B. Black	May 1968 to December 1970
R. C. McDowell	January 1970 to February 1971
F. R. Shawe	March 1971 to July 1973
D. B. Weir	August 1973 to November 1977

Two of the editors deserved special mention because of their work during the critical circumstances when they served. Wolcott and Branch Chief P. W. Richards were largely responsible for setting the standards and procedures for reviewing and editing that were followed throughout the program. Weir, who had been assistant map editor for a number of years, did a particularly commendable job in processing the large number of maps submitted toward the end of the program.

The Branch of Technical Illustrations (subsequently the Branch of Cartography) of the Publications Division of the U.S. Geological Survey established a cartographic office (Kentucky Project Office) at the Lexington headquarters office to prepare the maps for publication. The cartographic office was, of course, administratively independent from the Branch of Kentucky Geology. J. T. Hopkins, Jr., Chief of the Kentucky Project Office from 1960 to 1969, was largely responsible for establishing the procedures for preparing the maps for publication. These procedures, described by Hopkins (1977), insured timely publication of a uniform, high-quality product. Hopkins was succeeded as chief by E. J. Gimpel, Jr., who served from 1969 to 1978. The location of the cartographic office at the Branch headquarters had many advantages, the chief of which was the direct communication possible between the draftsmen, the map editor, and the geologists.

The fieldwork was conducted from small offices established in various parts of the State. Each field office was headed by a Geologist-in-Charge, who served as liaison with the Branch Chief, assigned mapping priorities and assignments within his area, selected technical reviewers for maps submitted by the geologists in his office, and performed minor administrative chores. During the life of the project, there was a total of 18 field offices (fig. 2), though the most in operation at one time was 15 in 1962. When the area of easy access from a field office had been mapped, the office was closed and another was opened in an unmapped part of the State. By the late 1960's, the construction of toll roads and interstate highways made larger areas accessible to the field offices, and frequent moves were no longer required.

The size of the professional staff of the field offices averaged four or five geologists. Several offices early in the project headquartered seven



Field office	*Date opened*	*Date closed*
1. Ashland	November 1960	June 1964
2. Berea	July 1961	June 1971
3. Bowling Green	October 1960	June 1977
4. Columbia	November 1960	August 1965
5. Corbin	November 1960	November 1963
6. Elizabethtown	February 1961	June 1969
7. Erlanger	September 1966	June 1977
8. Flemingsburg	March 1962	July 1967
9. Hazard	September 1962	June 1964
10. Hopkinsville	October 1962	June 1966
11. Lexington	September 1961	September 1978
12. Madisonville	January 1962	June 1977
13. Middlesboro	September 1966	October 1974
14. Owensboro	October 1961	September 1978
15. Paducah	November 1960	June 1972
16. Pikeville	October 1960	July 1968
17. Princeton	August 1960	October 1972
18. Somerset	September 1965	June 1977

FIGURE 2.—Index map of Kentucky showing location of field offices.

geologists. The Lexington Field Office in the last few years housed 10 geologists. In addition to the professionals, two of the field offices employed part-time secretaries.

STAFFING

About 260 people, including more than 200 professionals, were assigned to the mapping program by the U.S. Geological Survey at one time or another (table 1). Twenty-four of the professionals were newly hired; the rest were transferred from other Branches in the Geologic Division. The professional manpower is listed by fiscal year in table 2.

TABLE 1.—*Number of U.S. Geological Survey employees, excluding cartographic personnel, that have been assigned to the cooperative mapping program*

Mapping personnel	
Professional:	
Full-time	94
Full-time, temporary duty	67
Part-time	35
Total	196
Subprofessional:	
Full-time	20
Part-time	19
Total	39
Nonmapping personnel	
Professional:	
Full-time	7
Part-time	2
Members of Paleontology and Stratigraphy Branch.	14
Total	23
Administrative and clerical:	
Full-time	13
Part-time	10
Total	23
Grand Total	281[1]

[1]Inasmuch as some people are included in two categories, the actual total is about 260.

For as many as half the years of the project, the full-time professional staff headquartered in Kentucky was less than that which could have been supported by the budget and less than that required to keep the mapping on schedule. It was, therefore, necessary to assign a number of geologists headquartered elsewhere to temporary duty in Kentucky. These men generally spent enough time in the State to complete the fieldwork on one quadrangle.

TABLE 2—*Professional manpower assigned to the cooperative mapping program by the U.S. Geological Survey, listed by fiscal year*

[Leaders (---) indicate not estimated]

Fiscal Year	Professional man-years: Original estimate	Professional man-years: Actual[1]
1961	30	30
1962	60	61
1963	70	61
1964	70	56
1965	70	41
1966	70	38
1967	70	38
1968	70	41
1969	60	37
1970	30	35
1971	---	33
1972	---	30
1973	---	30
1974	---	30
1975	---	32
1976	---	32
1977	---	25
1978	---	11
Total	600	661

[1]The differences between estimated and actual professional man-years resulted from a reduction of the State appropriation in FY-65 and the consequent lengthening of the program.

The use of faculty members from nearby universities as part-time mappers had several advantages. These men contributed significantly to the progress of the program, but more importantly they served as contacts with the various geology departments. The faculty members became more aware of the geologic problems in the State and were thus able to direct both their own research and that of their students into more fruitful areas. In turn, the results of the university research became available to the full-time members of the program.

Figure 3 summarizes the length of assignments of full-time professionals to Kentucky. About two-thirds of the geologists headquartered in the State were transferred elsewhere after an assignment of 4 years or less. However, about one-third of these transfers resulted from a reduction in the level of funding in the State biennium of fiscal years 1965 and 1966.

PROCEDURES

FIELD METHODS

Most of Kentucky is underlain by nearly horizontal sedimentary rocks of Paleozoic age, but the different parts of the State vary widely in the type and stratigraphic complexity of the bedrock,

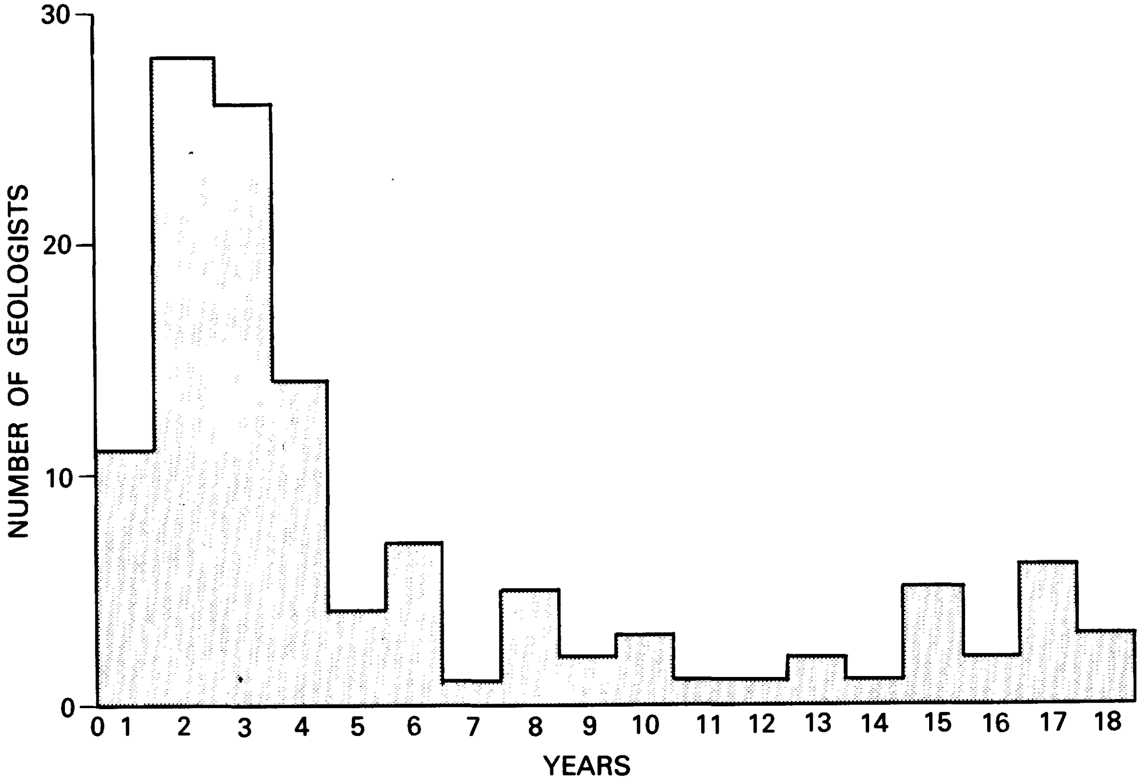


FIGURE 3.—Length of assignments to Kentucky Branch.

amount of faulting, degree of exposure, topography, and vegetation. Furthermore, each geologist assigned to the State came with a unique combination of temperament, education, and experience. Field methods, therefore, were varied. Nevertheless, the common map scale of 1:24,000, the constraints of the format of the geologic quadrangle maps, and the interchange of information and experience between geologists resulted in some common procedures.

The base maps were, as previously described, U.S. Geological Survey 7½-minute topographic quadrangle maps, most with a contour interval of 10 or 20 ft, though in the more mountainous parts of eastern Kentucky the interval was 40 ft. Inasmuch as structure contours were to be shown, elevations of field stations were determined to within one-half of a contour interval. A wide variety of methods were used to locate the positions of field stations; but most geologists found the use of the surveying altimeter the most practical way of attaining the required accuracy. In areas where bench marks were sparse, the altimeter was used in conjunction with a barograph that was located at a base station. Where differences in elevation were small, many geologists obtained elevations by hand leveling from bench marks or other points of known elevation.

Correcting altimeter readings for diurnal pressure changes and for temperature is time-consuming. In an attempt to attain the required accuracy more expeditiously, one quadrangle was mapped on an orthophotographic base and another on rectified aerial photographs that have been corrected for the effects of tip and tilt—the deviation of the film from the true horizontal at the time of exposure. The field stations were located on the photographs and transferred by overlay to the topographic base map. Both methods were satisfactory in areas of gentle topography, but where topographic contours were closely spaced, locations could not be transferred from either type of photograph to the topographic base with sufficient accuracy to obtain elevations within the required one-half of a contour interval. The use of either orthophotographs or rectified photographs would have been appropriate in many other areas of gentle topography, but the cost of the photographs proved prohibitive.

The number of field stations occupied in a quadrangle ranged from a few hundred to a few thousand, depending on the abundance of exposures, the complexity of the geology, and the predilections of the geologist. For each quadrangle, there is an optimum number of field stations beyond which the increase in accuracy of the map is not commensurate with the additional effort; this optimum number can be determined only by experience.

Drill-hole information from published reports, logs on file at the Kentucky Geological Survey, and data made available from private sources, especially coal companies, were very useful in constructing the maps. The data were used in drawing structure contours, in determining thickness of poorly exposed strata, and in analyzing facies changes. Locations reported for many of the older holes were in error, and the data generally could be used with confidence only if the locations could be confirmed in the field.

Several dozen shallow diamond-drill holes were drilled to obtain cores in areas where rocks were poorly exposed and older data were few or unobtainable. These data proved extremely useful for the purposes just described. Gamma-ray logs made by members of the Water Resources Division of the U.S. Geological Survey of water wells in several parts of central Kentucky also proved useful for the same purposes.

In much of the western Kentucky coal field and adjacent parts of western Kentucky near the Ohio River, the bedrock is very poorly exposed and commonly mantled by Pleistocene lacustrine deposits and loess. Fortunately, many holes have been drilled in that area, and the geologists were able to supplement the meager surface data with the abundant subsurface information. Several geologists of the Kentucky Geological Survey were engaged nearly full-time in gathering and compiling all the available drill-hole data. The information supplied by these men was invaluable to the mappers.

Mapping in the Jackson Purchase region, that part of Kentucky west of the Tennessee River and within the Mississippi embayment, posed special problems. The strata there consist of Upper Cretaceous and Lower Tertiary sand and clay, surficial gravel of Miocene(?) to Pleistocene age, and a blanket of Pleistocene loess. A truck-mounted auger was used extensively to determine the configuration of the bedrock surface and the geology below the gravel deposits and loess mantle. The microflora and fauna were very useful in identifying the formations. Structure contours could not be shown because of the sparse data, but contours were drawn instead on the erosional surface cut on rocks of Eocene, Paleocene, Late Cretaceous, and Paleozoic age; that is, at the base of the surficial deposits. These contours are not only useful in interpreting late Cenozoic history, but also have been used by drilling companies in predicting drilling costs of water wells.

COMPILATION AND PREPARATION FOR PRINTING

Because exposures are sparse in much of Kentucky and because structure contours were to be shown on the published maps, it was generally impossible to draw contacts in the field in a manner that would subsequently permit construction of reasonable structure contours without considerably altering the projected contacts. The maps were, therefore, largely constructed in the office.

Plotted on a topographic base, a geologic map in an area of gently dipping rocks can easily be checked for internal consistency: The contoured horizon must agree at all intersecting points with the topographic contours, the attitudes shown on the map must also be consistent with the structure contours, and the thicknesses given for units in the columnar section must match the thicknesses shown on the geologic map. This concept of internal consistency might seem elementary and self-evident, but it was novel to a surprising number of geologists.

To insure internal consistency, structure-contour maps were commonly drawn of all contacts and isopach maps made of all intervals. Geologic contacts were then located by placing the topographic base over the structure-contour map of each horizon and drawing a line on the base map at the elevations indicated by the structure contours. Where the mapped units maintained a uniform thickness throughout the quadrangle, isopachous maps were, of course, not needed, and observed elevations could be projected from all contacts to the contoured horizon. In some areas, such as parts of the eastern Kentucky coal field, thicknesses of mapped units are too erratic to enable the construction of meaningful isopachous maps for an area the size of a 7½-minute quadrangle.

The format of the geologic quadrangle map had been decided in considerable detail in the discussions between the two Surveys before the program began. In order to insure both adherence to the format and an expeditious flow through the editorial mill, guidelines for map preparation and processing were worked out and distributed to all personnel. These were briefly described by Hopkins (1969).

A notable feature of the procedure was that nearly every geologist was required to scribe his own map. This had several advantages: Though few geologists enjoyed scribing, most agreed that it was faster and considerably more accurate than inking. The composite print made from the scribecoat and a negative of the base, when colored and labeled, made excellent, clear review copy. Finally, if the geologist's scribing was accepted by the Branch of Cartography as final copy, an average of 60 hours per map and one-fifth the cost of preparation for printing was saved. During the midyears of the project, about 65 percent of the authors' scribecoats were acceptable and the money saved thereby amounted to at least $25,000 a year. In the last few years, the acceptance rate dropped to less than 20 percent. This was largely because many of the maps were submitted by part-time employees or geologists, who were inexperienced scribers, on temporary duty from other Branches.

ROLE OF THE PALEONTOLOGY AND STRATIGRAPHY BRANCH

The rocks exposed in Kentucky are almost entirely sedimentary, and fossils are commonly abundant and conspicuous. The desirability of paleontologic support was, therefore, recognized from the beginning of the program. Accordingly, the program financed eight full-time and six part-time paleontologists and preparators of the Branch of Paleontology and Stratigraphy of the U.S. Geological Survey for a combined total of 30.7 man-years. Much more work on Kentucky fossils was supported entirely by the Branch of Paleontology and Stratigraphy. Age assignments and correlations suggested by reports on referred fossils were useful in all parts of the State. Mackenzie Gordon, Jr., was particularly helpful; he not only reported on a large number of referred fossil collections from Mississippian and Pennsylvanian rocks, but also visited the mappers in the field on several occasions. The paleontologic work was of particular value in the Cretaceous and Cenozoic of the Jackson Purchase region of westernmost Kentucky, the Ordovician in central and northern Kentucky, and the Pennsylvanian of the eastern and western coal fields.

In the Jackson Purchase region, the identifications of the Cretaceous and Tertiary formations were in large measure made possible by palynological studies by R. H. Tschudy that were conducted concurrently with mapping, under the leadership of W. W. Olive of the Branch of Kentucky Geology. This joint effort resulted in significant revisions of the stratigraphy and in revised dating of the initiation of the Mississippi embayment. Tschudy also provided much information indicative of the environment of deposition of the geologic units.

In addition to its purely scientific value, Tschudy's work, combined with stratigraphic and mineralogic investigations by Olive and Finch (1969), has economic application. The region is a source of ceramic-grade clay and, as indicated by pollen, most commercial clay deposits are in the middle and upper parts of the Claiborne Formation of Eocene age; clays in the other mapped formations contain too much montmorillonite to be of commercial value. Thus, the geologic maps showing the distribution of the Claiborne, made possible by the palynological studies, are extremely useful guides in prospecting for clays.

The Ordovician of central and northern Kentucky and of adjacent parts of Ohio and Indiana has been considered classic since the latter part of the 19th century, and the Upper Ordovician section of the Cincinnati region has long been the standard for North America. Most of the stratigraphic units recognized in these rocks had been defined largely on the basis of their fauna, in accord with the common practice of the time. However, few fossil collections described in the literature were gathered from carefully measured sections, the taxonomy was mostly that of the turn of the century, and biostratigraphic zones had never been established; thus, the section was a rather frail standard. Using these considerations, Branch Chief P. W. Richards recognized that the mapping should be accompanied by paleontologic and stratigraphic studies. Accordingly, R. J. Ross, Jr., John Pojeta, Jr., R. B. Neuman, O. L. Karklins, E. L. Yochelson, J. M. Berdan, and W. A. Oliver, Jr., all of the Paleontology and Stratigraphy Branch, and W. C. Sweet and Stig Bergstrom of Ohio State University visited the State on a number of occasions and collected rocks from sections measured by the fieldmen. Approximately 12 tons of rock containing silicified fossils were collected from the Lexington Limestone of Middle and Late Ordovician age, and a large number of collections of unsilicified material were made from the Upper Ordovician rocks throughout their outcrop belt in

Kentucky. On the published geologic quadrangle maps, the locations of the collections were shown on the map, the stratigraphic position was given on the column, and the identifications were given in the text. As a result of close communication and cooperation between the paleontologists and the field mappers, the fossil collections were firmly keyed to a lithostratigraphic framework that was based on measured sections tied together by mapping. (See Cressman, 1973, pl. 1-6, for an example.)

As of this writing, studies of the collections from the Ordovician made by more than a dozen specialists are still in progress; seven such studies are in U.S. Geological Survey Professional paper 1066 (published as Alberstadt, 1979; Ball, 1979; Branstrator, 1979; Howe, 1979; Pojeta, 1979; Ross, 1979; Sweet, 1979). When completed, these studies will modernize the taxonomy and will establish a zonal scheme that will provide a vastly improved basis for comparison with other areas. Both the improved taxonomy and the zonation, when combined with the lithostratigraphic data, will serve as a basis for paleoecological interpretations. We emphasize that the close collaboration between the paleontologists and the mappers has proven invaluable to both.

The correlation of coal beds in the Pennsylvanian of eastern Kentucky, important for both economic and scientific purposes, is difficult because of poor exposures, the large number of thin coal beds, the discontinuity of some, and the splitting of others. Beginning in 1963 and extending throughout the life of the program, R. H. Kosanke of the Paleontology and Stratigraphy Branch processed a large number of coal samples for spores, and his reports have been of much assistance in correlating the beds. R. C. Douglass, also of the Paleontology and Stratigraphy Branch, has dated a number of limestone units from both the eastern and western Kentucky coal fields on the basis of their fusulinids. As a result of Douglass' investigations in the western coal field where the rocks are poorly exposed, some limestone units as mapped in the field have been found to be miscorrelated; the revised correlations will be most helpful in the summary report on that area. Douglass' work has also resulted in a more refined correlation between the two coal fields.

CONTRIBUTIONS BY THE KENTUCKY GEOLOGICAL SURVEY

In addition to the conception, initiation, and continuing financial support of the program, the Kentucky Geological Survey provided economic data, stratigraphic support, and drill-hole records to field offices. Geologists of the State Survey supervised core-drilling and augering projects, constructed bedrock-topography maps, made subsurface structural interpretations, mapped several quadrangles, prepared county economic reports, microfilmed field notes, and collected maps showing the locations of field stations.

At the start of the program, data on known economically important units and potential undeveloped mineral resources of the Commonwealth were supplied to each field office. Drill-hole records were also supplied to field offices for use in projecting mapped contacts and faults and in collating oil and gas data. In the early stages of the program, field conferences were held to acquaint newly assigned geologists with the nomenclature and stratigraphic framework, and throughout the program stratigraphic information was provided from detailed studies being conducted by Kentucky Geological Survey geologists.

Several times during the program, diamond-core drilling and augering projects were conducted to obtain subsurface information for use in constructing the geologic maps. Kentucky Geological Survey personnel contracted and supervised the core-drilling operations and assisted in some of the augering and logging of holes in the Jackson Purchase and Owensboro areas of western Kentucky. The Water Resources Division of the U.S. Geological Survey supplied wire-line logging equipment, and its personnel assisted in obtaining logs of some of the core holes.

In the Owensboro field office, Kentucky Geological Survey geologists and geologic assistants prepared maps showing the bedrock topography in areas where the bedrock was concealed by large areas of surficial deposits. Where sufficient data were available, the location of selected coal beds beneath alluvial deposits were shown. They also made the subsurface structural interpretations for some geologic maps. The bedrock maps were constructed at a scale of 1:24,000 and were printed on transparent material so they could be overlain on the geologic maps. The maps were printed by the U.S. Geological Survey as part of its Miscellaneous Geologic Investigation Series. Indexes of test holes and maps at a scale of 1:24,000 showing their locations were prepared from the data used in the subsurface interpretations and are open-filed at the Henderson office of the Kentucky Geological Survey. Also available from the State

Survey is a map at a scale of 1:48,000 showing locations of drill holes in the southern part of Ohio County.

During the latter part of the program, geologists of the State Survey mapped some quadrangles in eastern Kentucky.

Kentucky Geological Survey personnel have prepared or have in progress a new series of county economic reports based in part on data gathered as part of the mapping program. Reports have been published for Allen, Calloway, Hancock, Marshall, and Warren Counties (Branson, 1966; McGrain, 1968; McGrain and others, 1970; McGrain, 1970; McGrain and Sutton, 1973). The McCracken County report was published in 1979 (McGrain, 1979).

Kentucky Geological Survey personnel have microfilmed original field notes. These microfilms and the maps showing the locations of field stations are on file and available for inspection at the office of the Kentucky Geological Survey in Lexington.

The following Kentucky Geological Survey personnel were at one time or another assigned primarily to the mapping program: E. R. Branson, M. O. Smith, and M. C. Noger, Program Coordinators; J. M. Poteet, L. R. Ponsetto, W. E. Jackson, R. G. Ping, G. J. Grabowski, R. E. Sergeant, Geologists; and J. C. Kerns, D. K. Tully, and J. L. Kenkler, Geologic Assistants, Lexington; and A. S. Smith and R. N. Norris, Geologists, and G. E. Carpenter and T. Ball, Geologic Assistants, Owensboro.

PRODUCTIVITY

Figure 4 illustrates the cumulative number of geologic quadrangle reports and the cumulative professional man-years for the life of the mapping program. A comparison of the two curves shows that the rate of production varied only slightly from the average of 1.1 geologic quadrangle reports per man-year for the entire program (excluding 11 man-years in fiscal year 1978 that were devoted largely to the preparation of summary reports). Figure 4 indicates an increasing productivity in the first few years; a fall in productivity, stabilizing at one report per man-year in the middle years; and an increase in the years following 1972 as the planned data of completion approached.

The productivity for different individuals ranged from one quadrangle every 4 years to two quadrangles a year. The rate of mapping might have been expected to differ with the complexity of geology, but in fact the variation between geologists in the same field office was greater than the variation between field offices.

PROBLEMS

No large program is entirely free of problems, and the Kentucky Cooperative Mapping program was no exception. Now that the work is complete, most of the problems encountered, even those that appeared severe at the time seem minor. Nevertheless, we will discuss some of these problems and indicate actions that we believe might have ameliorated them, with the hope that others might benefit from our experience.

Inasmuch as a cooperative program of this scope was unprecedented, it was inevitable that some friction should develop between personnel of the U.S. Geological Survey and of the Kentucky Geological Survey. On the administrative level, some conflicts arose over the scope of authority and responsibility of the Chief of the Branch of Kentucky Geology and the Program Coordinator for the Kentucky Geological Survey. The contract between the two organizations was short and general, allowing considerable room for interpretation, and many details had to be hammered out through experience. We doubt that these conflicts could have been entirely avoided, but we can assure others that such problems can be overcome and that close and effective cooperation can be established.

Some antagonism developed in the early years of the program between members of the two Surveys at the field level. Some members of the Branch of Kentucky Geology, most of whom were experienced geologists, resented what they considered to be interference by some members of the State Survey, whereas some members of the State Survey felt that their opinions, based on their longer experience in the State, were not adequately considered by members of the Federal Survey. As members of the two organizations became more familiar with the capabilities, personalities, and methods of operation of members of the other, the friction subsided, and close working relations developed. These close relations might have been established earlier, if some members of the State Survey could have been assigned at least part-time to actual field mapping along with the U.S. Geological Survey personnel.

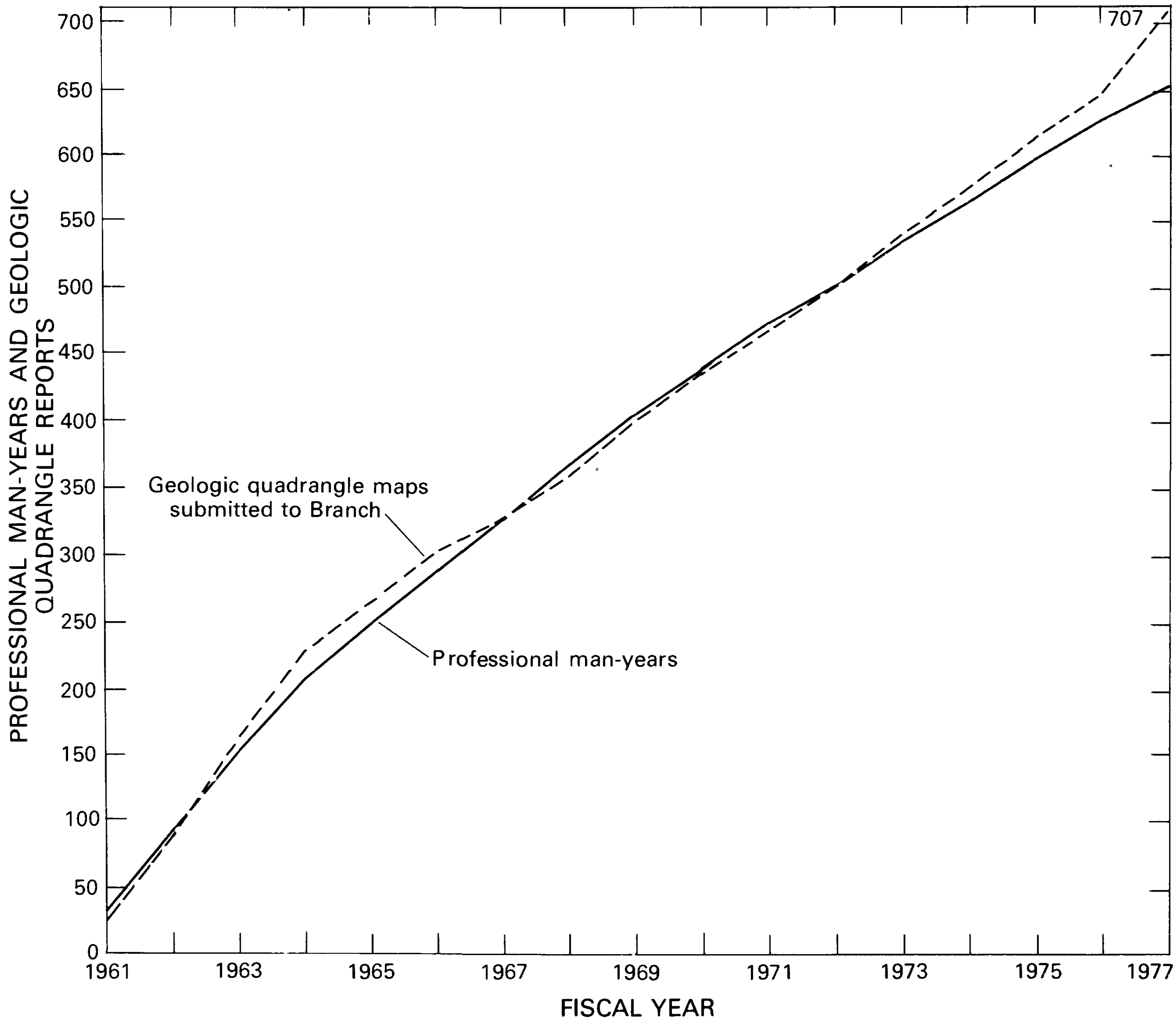


FIGURE 4.—Graph illustrating relationship between production of maps and size of professional staff.

Problems of stratigraphic nomenclature caused many disputes in the early years and at one time seemed to threaten the existence of the program. Much of the existing nomenclature had been established early in the century, generally on the basis of stratigraphic studies that had a strong paleontologic component, and the formational units had never been tested by mapping at more than a reconnaissance scale. It was inevitable that parts of this nomenclature would prove inadequate for the type and scale of mapping planned for the program, and, indeed, the field geologists were soon proposing major revisions. Some of those geologists who had been educated in Kentucky and had most of their experience in the State, but who were not directly involved in the mapping, opposed changes with a fervor that is commonly evoked by tinkering with an old and familiar nomenclature. The conflict between the field mappers and those attached to the existing nomenclature was finally resolved by revising the nomenclature when clearly required, but showing the older nomenclature by a separate column on the geologic quadrangle map.

The older stratigraphic nomenclature may have needed major overhaul, but no arrangements had been made for stratigraphic studies in advance of the mapping, possibly because it was assumed that the stratigraphy was already well known. Thus, a geologist mapping his quadrangle might find that none of the units he could map were formally named. If his assignment was to map one or two 7½-minute quadrangles, he was not able to judge the extent or regional significance of his individual map units. Furthermore, strata of the same age might be mapped from two or more field offices, but the stratigraphic relations between the areas might not be known. Coordinators were eventually designated for parts of the section where problems became especially severe, but the coordinators had no formal authority and their principal responsibilities remained geologic mapping. In hindsight, we believe that many problems could have been anticipated and avoided and much additional significant information generated if regional stratigraphy had been considered an integral part of the program from the beginning and if some geologists had been given stratigraphic studies as their principal assignment.

Rather strangely, the necessity for significant changes in stratigraphic nomenclature does not seem to have been anticipated in the negotiations that led to the program. It should have been obvious that the much more detailed scale of the mapping and advances in stratigraphic science would make many changes inevitable.

Geologic mapping involves a large amount of interpretation and, as noted by Harrison (1963, p. 225), a good geologic map is the result of research of a high order. Not all geologists are equally capable, and, naturally, the quality of maps produced by different geologists varies. The overall quality of the Kentucky maps is very high, but a few maps are definitely inadequate. In the following paragraphs, we will discuss a few procedures that we believe would have improved quality.

Like most other specialties in the profession, geologic mapping requires aptitudes that are not possessed by all, and those with the aptitude must develop proficiency through training and experience. Considering the varied backgrounds of men assigned to the program, we believe that the quality of the maps could have been improved and time saved in the long run by requiring training of all geologists in techniques of both mapping and compilation. We strongly recommend that such training be an integral part of any similar program initiated in the future.

The review and editorial system was admirably devised and conducted to insure internal consistency, but a map can be internally consistent and largely wrong. The only way to insure accuracy is close field supervision and field checking, but the organization of the Kentucky program was such that only the Branch Chief had supervisory authority, and the demands on his time were such that he could not have actually supervised the fieldwork. In retrospect, we believe that formal supervisory authority should have been delegated to the Geologists-in-Charge of the field offices and that field checking should have been an integral part of the program.

The Federal and State Surveys had different, sometimes conflicting, viewpoints. For example, the U.S. Geological Survey prefers not to maintain small field offices and, if such offices are unavoidable, tries to rotate personnel frequently because a variety of assignments is considered essential to professional advancement. The State Survey, on the other hand, felt that geologists should remain in field offices for longer terms to benefit from the experience gained in the area. The matter was compromised, but for a variety of reasons no regular, consistent plan of rotation was developed. As predicted, long-term assignments did indeed have an adverse effect on the professional development of some of those who remained in Kentucky for many years, especially those headquartered in the smaller field offices. The lack of an easily accessible library, of laboratory facilities, and particularly of contact with geologists of different backgrounds and interests made it extremely difficult to keep informed on new developments in the science. Undoubtedly, both the mapping project and the careers of the men would have benefited from a regular, planned rotation. In the absence of rotation, the adverse effects could have been ameliorated by temporary duty assignments to projects in other States and by participation in short courses and other means of continuing education; but during much of the project, money was not available for such alternatives.

COST

The original estimate and the actual expenditures for the mapping program are listed in table 3. The overmatching by Federal funds from fiscal years 1973–1977 resulted from a change in the methods of assessment for administrative overhead by the U.S. Geological Survey.

The actual cost of the program in terms of 1960 dollars was one-third greater than the original estimate. This resulted from the following factors: (1) The program required 661 professional

TABLE 3.—*Cost of the Kentucky Geological Survey—U.S. Geological Survey Cooperative Mapping Program*

[Leaders (___) indicate not estimated]

Kentucky fiscal year	Original estimate	Authorization		Total	Total in[1] 1960 dollars
		State	Federal		
1961	600,000	300,000	300,000	600,000	600,000
1962	1,200,000	600,000	600,000	1,200,000	1,188,000
1963	1,400,000	600,000	600,000	1,200,000	1,176,000
1964	1,400,000	600,000	600,000	1,200,000	1,162,000
1965	1,400,000	450,000	450,000	900,000	859,000
1966	1,400,000	450,000	450,000	900,000	845,000
1967	1,400,000	500,000	500,000	1,000,000	913,000
1968	1,400,000	500,000	500,000	1,000,000	887,000
1969	1,200,000	510,000	510,000	1,020,000	869,000
1970	600,000	510,000	510,000	1,020,000	824,000
1971	--	550,000	550,000	1,100,000	839,000
1972	--	575,000	575,000	1,150,000	841,000
1973	--	600,000	664,900	1,264,900	897,000
1974	--	630,000	814,200	1,444,200	963,000
1975	--	675,300	923,500	1,598,800	961,000
1976	--	718,000	924,600	1,642,600	899,000
1977	--	718,000	890,000	1,608,000	806,000
1978	--	539,500	539,500	1,079,000	506,000
Total	12,000,000	10,025,800	10,901,700	20,927,500	16,035,000

[1] Based on the Consumer Price Index.

man-years to complete rather than the original estimate of 600; (2) salaries of full-time professionals increased due to promotions, ingrade raises, and government-wide pay increases that more than compensated for inflation; and (3) increased assessments were made by the U.S. Geological Survey in 1973 and subsequent years.

ECONOMIC BENEFITS

The main impetus behind the mapping was the expected stimulus the maps would provide to the economic development of Kentucky. Although scientific and educational benefits are and will continue to be considerable, the success of the program should be evaluated in terms of its principal goal of economic development. The geologic maps are widely used in mineral exploration, for engineering purposes, and for land-use planning, but the monetary value of these uses is extremely difficult to determine. Most of the information is anecdotal, and a value can seldom be placed on a single use.

In the following pages, we list data on geologic quadrangle map sales to demonstrate that the maps are widely used and then analyze the sales figures for indications as to the types of uses. We then present examples in order to document actual economic benefits accruing from specific uses of the maps. The examples, which are by no means exhaustive, have been selected mostly from information in the files of the Branch of Kentucky Geology, but several have been described by McGrain (1971).

MAP SALES

Sales are an indication of the extent to which the geologic quadrangle maps are used. The maps are available for purchase from the Kentucky Geological Survey, the Kentucky Department of Commerce, and the U.S. Geological Survey. The U.S. Geological Survey does not keep a separate record of the sales of geologic quadrangle maps of Kentucky, but sales in recent years by the first two organizations are listed in the table below. The sales show that the maps are used extensively, but they give no hint as to purpose or user.

Year	Kentucky Geological Survey	Kentucky Department of Commerce	Total
1972	4,519	--[1]	--[1]
1973	6,319	--[1]	--[1]
1974	10,109	5,000	15,109
1975	14,062	5,207	19,269
1976	13,220	6,011[2]	19,231
1977	14,688	--[1]	--[1]

[1] Information not available.

[2] Does not include sales for last 3 months of year.

Total sales figures for individual quadrangles are not available; however, the Kentucky Geological Survey receives a stock of 180 maps from the

U.S. Geological Survey when they are published and reorders maps as their stocks are depleted. The number of copies reordered can be used as an indication of the relative demand for the various quadrangles. Figure 5 shows the number of copies reordered for each quadrangle in the fiscal years 1972 through 1977. The demand has been greatest for maps in the eastern Kentucky coal field. Maps in the western Kentucky coal field are next in demand, followed by those in the western Kentucky fluorspar district. Several individual geologic quadrangle maps are in particular demand—Mammoth Cave for recreational purposes, Ford quadrangle for use by students at the University of Kentucky, Morehead quadrangle for use by students at Morehead University, and Lawrenceburg (Indiana-Kentucky) quadrangle for use in studying landslides that have caused problems along the banks of the Ohio River. Sales are also greater for maps of areas near urban centers than for those of the surrounding open countryside.

MINERAL COMMODITIES

COAL

Figure 6 compares coal production in the eastern Kentucky coal field with production in the neighboring States of West Virginia, Ohio, and Tennessee from 1960 to 1974. Coal production in eastern Kentucky has continued to increase, whereas production in the adjacent States has either remained relatively constant or has declined in recent years. The reasons for the greater increases in production in Kentucky are complex; but, as shown below, the geologic quadrangle maps are undoubtedly used widely in the area and may be a contributing factor.

The following paragraphs present several examples of uses of the geologic maps from many that have been reported.

In eastern Kentucky, the geologic quadrangle maps are used extensively to block out coal properties for leasing and to plan detailed drilling for precise evaluation. One operator stated that exploration tends to be deferred until maps are available. Certainly, in recent years, the Lexington office has received requests to open-file quadrangle maps in eastern Kentucky as soon as announcements have been made that the fieldwork has been completed.

Mapping has demonstrated persistence of beds containing steam and coking coal and has thus led to exploration in areas not previously thought by operators to be worthy of exploration. The geologic quadrangle reports are providing landowners and operators a better basis on which to estimate both quantity and quality of the coal reserves, making possible more reliable decisions on sale of land and on mineral development. The general tendency of individual coal seams to have the same quality over wide areas is an important factor in estimating the value of coal reserves; so the correlation of coal beds is an economically valuable product of the geologic mapping.

Coal operators and geologists who have not recognized geologic structure have miscorrelated coal beds, and the geologic mapping has led to changes in operators' exploration programs. In one instance, plans to acquire land were changed when the operator realized that the coal bed on the land he planned to lease was not the coal bed he sought. In another instance, an operator's drilling program was changed when he learned that the failure to recognize the dip of the strata had led to plans to drill a stratigraphically higher coal bed than the commercially valuable bed he wanted.

In the western Kentucky coal field, as in eastern Kentucky, the geologic maps have been instrumental in the opening of a number of mines. The maps are also used widely in property evaluation. According to McGrain (1971, p. 6), more than one-half million tons of coal have been recovered from outliers of the No. 9 and No. 11 coal beds, near Madisonville, which were unknown to coal companies before geologic maps (Kehn, 1963, 1964) were published on the area.

The No. 4 coal bed of western Kentucky contains a high-quality stoker and coking coal, known reserves of which were nearly depleted by the time the mapping program began. Mapping and correlation of coal beds in the southwestern part of the western Kentucky coal field have shown that the No. 4 had been miscorrelated with a stratigraphically higher bed (Kehn and others, 1967). As a result, many test holes for coal in the area had not been drilled deep enough to encounter the No. 4. An independent engineer has estimated that the revised correlation may double the coal reserves of that area, and McGrain (1971, p. 6) stated that further exploration based on the new correlation will probably add several million tons to the reserves.

The maps in the western coal field have been of use not only in locating coal, but also in planning mining operations. The geologic map of the Saint Charles quadrangle (Palmer, 1967) was useful in determining the direction and the amount of offset

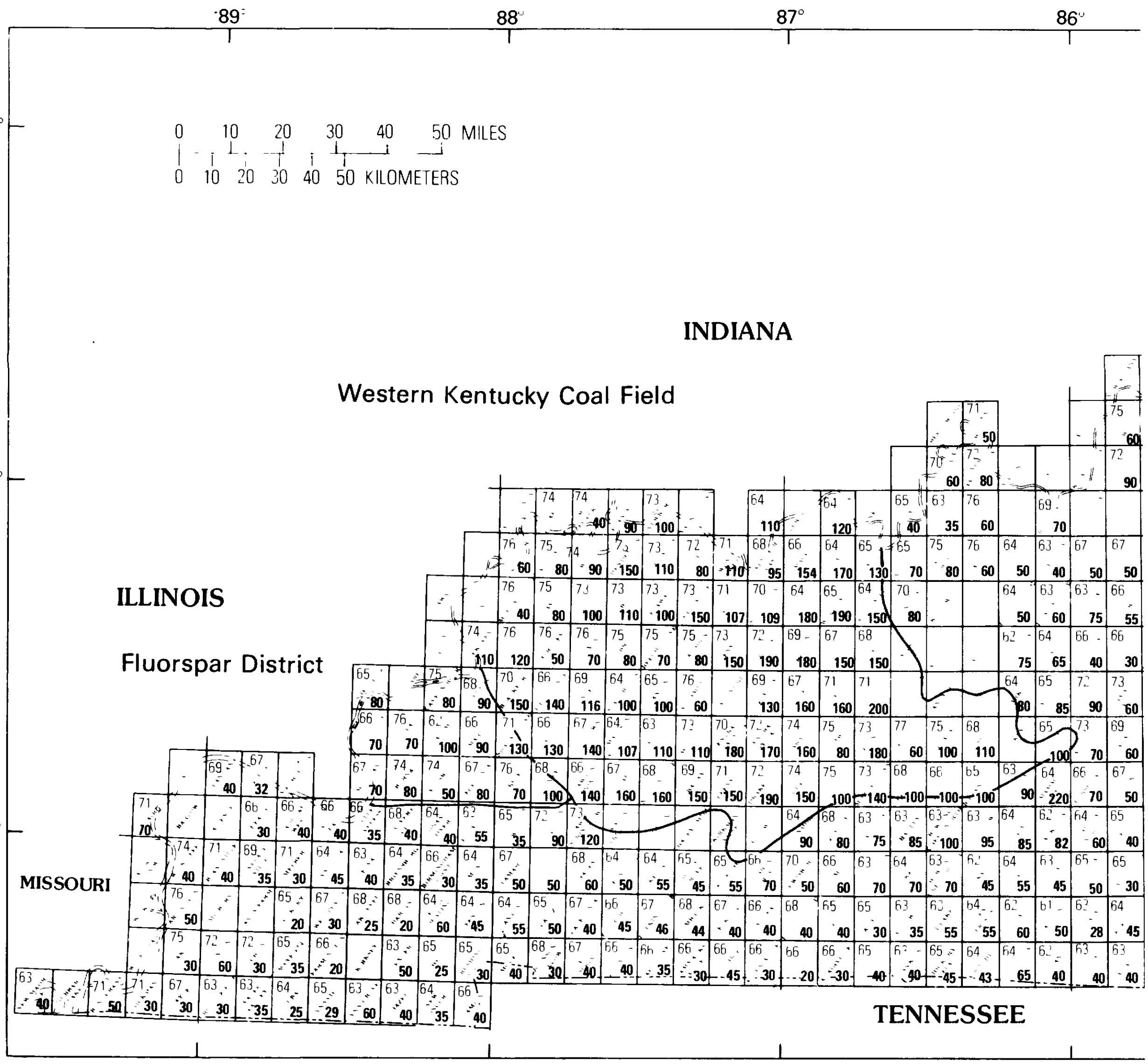
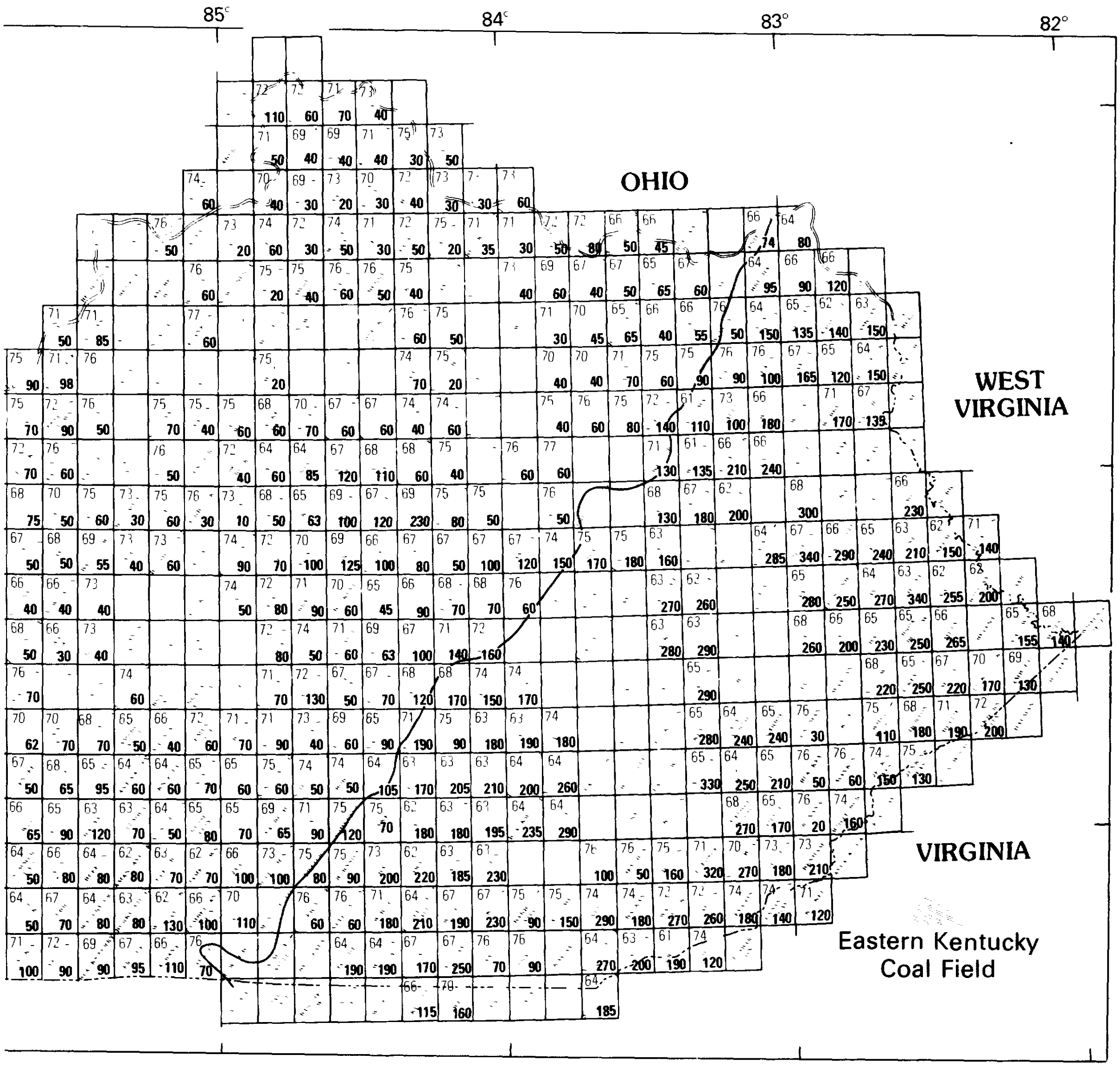


FIGURE 5.—Geologic quadrangle maps reordered by the Kentucky Geological Survey in fiscal years 1972 through 1977. Number
Survey between July 1, 1972, and June 30, 1977. Number in upper left corner of each quadrangle is last two digits of year
June 30, 1977, or original stock had not been depleted. The fluorspar district and the eastern and western Kentucky coal fields

that was needed in order to alleviate roof-rock and ventilation problems caused by faulting in two underground coal mines. Using this map, a U.S. Bureau of Mines inspector was instrumental in getting the operating companies to offset the main mine entries, both of which followed faults. Structure contours on the No. 9 coal bed in two quadrangles were used by an engineer of another company in planning mining operations.

An interesting unanticipated use of the maps was reported by the Peabody Coal Company. State law requires that coal cannot be mined within a 15-ft radius of a drill hole, if the location can be recovered or within a 150-ft radius, if the location cannot be recovered. The locations of drill holes used for structural control are shown on the published geologic maps of the Robards and Delaware quadrangles, Henderson County, Ky. (Fairer, 1973; Johnson, 1973). Using the quadrangle maps and information collected during the mapping, the 15-ft radius can be used. The additional recoverable coal has an estimated value of $150,000.

Perhaps the most striking example of using the maps in the coal fields was reported by Knight (1976, p. 8). A 70- to 80-million-ton coal field with a gross value at 1974 prices of $1,127,000,000 was



in lower right corner of each quadrangle is quantity of geologic quadrangle maps reordered by Kentucky Geological of original publication of geologic quadrangle map. Quadrangles with no numbers had either not been published by are the principal mineral-producing areas of the State.

found by use of the maps. Knight did not identify the location of the deposit.

OIL AND GAS

It is more difficult to evaluate the impact of the geologic maps on oil and gas exploration than on coal mining, partly because it is difficult to evaluate the relative contribution of surface geology, subsurface geology, and geophysics in the discovery of new fields. It is certain, though, that the maps are widely used by the oil and gas industry, as shown by a quotation from E. J. Combs of the Sun Oil Company (written commun., 1967).

The usage of geologic maps is so varied and carries so many facets that it is hard to describe or express the value in specific terms.

The oil industry uses these maps for elevation control, outcrop positions and data on subsurface rock units that enable geologists to help plan drilling programs. The value of this data is difficult to express in monetary terms but for every drilling location made, money can be saved by prior usage of the geologic maps. Geologic maps are considered a basic tool in planning seismic and core drilling programs. Knowledge of mined out areas, alluvium and bedrock is very pertinent in planning such programs. Thousands of dollars can be saved in good planning as compared to going into an area blind.

A few specific examples are listed below:

Information on geologic quadrangle maps was

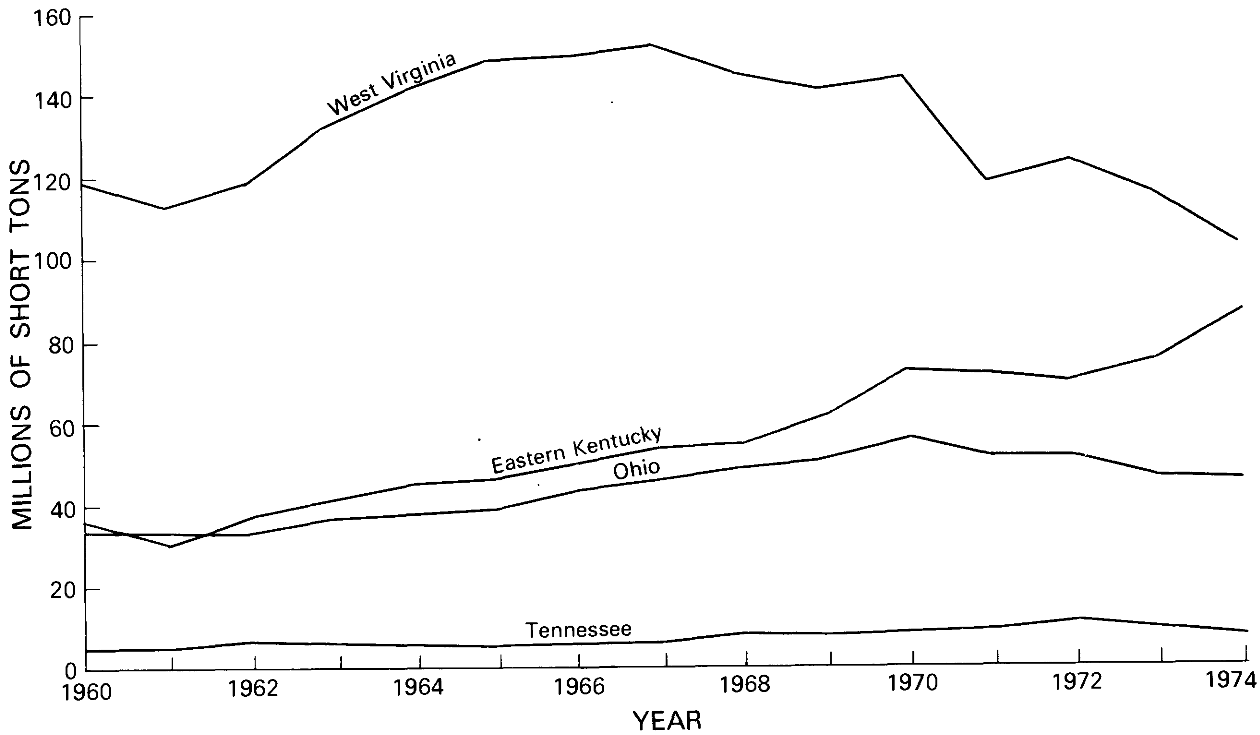


FIGURE 6.—Comparison of coal production in eastern Kentucky with that of adjacent States of the Appalachian coal field since the beginning of the mapping program. Data from U.S. Bureau of Mines (1960–1974).

used in conjunction with subsurface and geophysical data from other sources in locating the Cecelia gas storage field for the city of Elizabethtown and in defining the limits of the East Gradyville oil and gas field near Somerset, Ky. The maps were also used to define the trend and extent of an oil-producing reef of Mississippian age in south-central Kentucky.

The Gradyville East field was discovered in July 1969 in Adair County. The discovery well was located, probably prior to the mapping, on a large plunging anticline, and oil was discovered in the Knox Dolomite (Cambrian and Ordovician). Subsequent drilling followed the trend of a large plunging anticline shown on the Gradyville and Columbia geologic quadrangle maps (Taylor, 1963; Lewis and Thaden, 1963). By early 1970, at least 17 oil wells had been completed. Although other factors contributed to the oil entrapment, the significant geologic fact is that drilling on the anticline, which is shown on the geologic maps, reveals structurally high Ordovician rocks 1,500 ft below the Mississippian strata at the surface.

In western Kentucky, the locations of folds, faults, and sandstone channels shown on geologic quadrangle maps have been widely used in exploring for oil and gas. Maps of the St. Charles and Nortonville quadrangles (Palmer, 1967, 1968) were used by one oil company to find new and to extend known oil and gas reserves along faults. Fault trends of the Reineke fault system in the Madisonville East quadrangle (Kehn, 1963) continue to serve as a guide in prospecting for oil and gas reserves.

The following quotation is from a letter to the Kentucky State Survey from an independent oil company:

> This letter is to inform you that the lease and oil discovery in Southern Logan County is a direct result of the Geological mapping program in the state of Kentucky, being conducted by you and the USGS.
>
> The procuring of a lease block and the drilling of a test well were a direct result of a structural feature contained on your Homer Quadrangle. The surface structure was borne out, in depth, as indicated by the results of our well. In my opinion, a significant discovery of oil and gas reserves have been a direct result of your mapping program. I feel that the industry, and our company in particular, owes a debt of gratitude to your organization for pushing the economic mapping series for the state of Kentucky.

The Homer quadrangle had been mapped by Gildersleeve (1966). Many examples could be added, but those given above are adequate to demonstrate that the maps are valuable to the industry.

FLUORSPAR

The Illinois-Kentucky fluorspar district has produced more than three-fourths of the fluorspar mined in the United States. Though the area has been in production for many years, Trace (1974, p. 74) estimated that reserves were adequate for at least 15 to 20 years, and Pinckney (1976) stated that reasonable projections indicate that the area of potential production is more than twice as large as the area of known production.

Fluorspar is localized either as veins along a series of complex, northeast-trending, steeply dipping normal fault zones or as bedding replacement deposits along three horizons in rocks of Mississippian age. Most of the Kentucky deposits are of the first type. The geologic quadrangle maps show the faulting more accurately than previously available maps and can be used to predict the positions of horizons favorable for mineralization at depth. Industry uses them to help determine favorable areas for the core drilling required to determine the presence, size, and shape of orebodies. An indication of the potential value of the maps is the statement by W. W. Weigel, a geologic consultant (oral commun., 1968), that if similar maps had been available in southeastern Missouri, $25,000,000 could have been saved on a $750,000,000 exploration program.

Mapping in Livingston and Crittenden Counties (Trace, 1962) revealed the presence of a fault that had not been known previously. After the geologic map was published, exploration along the fault by a company resulted in the discovery of a fluorspar body of more than 100,000 tons (McGrain, 1971, p. 7). At the 1977 price of about $90 a ton, this one deposit is valued at more than $9,000,000.

CLAY

The Jackson Purchase region of westernmost Kentucky is a major source of ball clay, which is produced from rocks of Eocene age. Mineralogic and ceramic analyses reported by Olive and Finch (1969) have shown that the composition of the clays is closely related to stratigraphy. Clays of the Wilcox and Claiborne Formations of early and middle Eocene age are highly kaolinitic and are suitable for use in ceramics; on the other hand, clays in the Jackson Formation of late Eocene age are generally montmorillonitic and are suitable for use as animal bedding. The distribution of exposed clay deposits in these formations is shown on the geologic quadrangle maps. Although only a few new clay pits have been opened as a result of the mapping, there has been extensive and continued leasing of clay deposits as the maps have been published. Many of these leases will undoubtedly be brought into production in the future.

ENGINEERING GEOLOGY

To geologists, a somewhat unexpected result of the project was the varied and extensive use of the maps for engineering purposes; they are used more in this manner than for any other single purpose except coal exploration. Many engineering firms are aware of the program and routinely use the maps in evaluating foundation and excavation conditions and in preparing Environmental Impact Statements. The following quotation is from a request received from Fuller, Mossbarger and Scott, Civil Engineers, Inc., for the open-filing of an unpublished map:

> We routinely utilize published geologic quadrangle maps in planning and executing subsurface investigations for engineering projects. In that we are experiencing the need for such data for a specific site within the limits of the Monticello quadrangle, we would appreciate the benefit of related information your branch may now possess. Indeed, the U.S.G.S. information might well have a major influence on the overall feasibility of the project.

Only a few specific uses by such firms have come to our attention, and it is impossible to estimate the economic impact of the maps, even in these examples.

The Kentucky Department of Highways has regularly used the maps during studies of new routes, and in several instances project geologists were able to forewarn of potential problems while the geologic mapping was in progress. McGrain (1971, p. 3) wrote the following:

> Field geologists working in the Jackson Purchase region of western Kentucky recognized certain situations where porous, water-bearing gravels or sands resting on relatively impervious clays could produce unstable slope and foundation conditions. The proposed route of the Purchase Parkway was through an area where this situation was common. Engineers of the Kentucky Department of Highways were alerted. As the result of conferences with mapping project geologists and further engineering studies, three to four miles of the proposed route of the Parkway were relocated. Assuming the average of a minimum of one slide per mile on the first proposed route and corrective measures costing an estimated $200,000 to $500,000 per slide, it is easy to calculate the implications of geologic mapping to this construction project.

This is not the only instance of highway relocation based on information from the geologic mapping, nor will it be the last.

Relocation during the late 1960's of State Highway 119 in southeastern Kentucky was disrupted by a series of landslides which caused considerable property damage and abandonment of portions of the new roadway. The slides, some new and others reactivated, were a surprise to Highway Department personnel who had been advised by a consultant that the landslide potential of the route was low. A. J. Froelich of the U.S. Geological Survey, who had recently started mapping a nearby area, examined the slide areas for the geologic factors involved.

Froelich (1970) showed that a unique set of conditions in the area had been disturbed by the highway construction, resulting in the slides. Route 119 runs along the Cumberland River on the south side of and parallel with Pine Mountain, which trends northeasterly 100 miles across southeastern Kentucky. Interbedded shale, siltstone, sandstone, coal, and associated underclay forming the south slope of Pine Mountain dip toward the Cumberland River. Landslides had repeatedly occurred where these dipping strata had been undercut by the Cumberland River. Old slides had been reactivated and new slides initiated by the road construction. Parts of Highway 119 were then redesigned and relocated on the basis of Froelich's study. The savings cannot be determined, but the construction of one stretch of highway that was built before Froelich's study and largely destroyed by a major slide cost $4,000,000.

In 1968, the Kentucky Department of Highways and the Louisville and Nashville Railroad requested that priority be given to mapping several quadrangles along Pine Mountain in order to aid planning for a tunnel through Pine Mountain. Pine Mountain is on the leading edge of the Pine Mountain overthrust sheet, and the mapping (Froelich and others, 1970) revealed that the route originally chosen for the tunnel, located on the basis of a report by a consultant, would be through crushed and broken rock of the overthrust zone. The plans for the tunnel were eventually abandoned.

John S. Stokely (oral commun., 1968), a consulting geological engineer, a major part of whose business is contract drilling for the Kentucky Department of Highways, has estimated that the availability of a geologic map saves the State 10 percent of the cost of highway investigations. A District Engineer of the Highway Department stated that the geologic maps saved the Department millions of dollars in the planning and the letting of contracts for two parkways in southern and southeastern Kentucky. An example, contributed by another engineer of the Department of Highways, was a savings of about $80,000 in core drilling costs in 1967 along Kentucky Highway 15 between Jackson and Hazard in eastern Kentucky through using the maps to predict the depth of coals under the highway right-of-way.

In the Paducah area of western Kentucky, unconsolidated sediments and earthquakes cause many foundation probelms. Engineering geology studies of parts of the area were published by Nichols (1968) and Finch (1968) as byproducts of the mapping program. According to Paul Moore, Building Inspector for Paducah, these publications have been particularly useful in providing answers to queries as to engineering properties of rock units, foundation requirements, and seismic zoning for structures such as a high-rise apartment, a control tower at the local airport, and a large shopping mall. The report by Nichols was also used by the Corps of Engineers in determining foundation requirements for a post office building. As the Paducah area expands in population, the usefulness of these reports and the geologic maps on which they are based will undoubtedly increase, though no monetary value can be placed on the savings.

The geologic quadrangles are used extensively by the Soil Conservation Service in Kentucky in Watershed Protection and Flood Prevention Programs. In watershed development, the maps are used during field examinations and preliminary investigations, and in watershed planning and operations for the proper selection and placement of structure sites, which are the key to flood control. Factors influencing the selection of sites include structural stability; availability of borrow materials; the presence or absence of mineral resources, especially coal; and, in some cases, the ability of a structure to maintain permanent water storage. The maps are effectively used to help identify problem areas. According to J. M. Burns and B. J. Hines (written commun., 1968) of the Soil Conservation Service, the availability of a good geologic map during structure site evaluations eliminates from 2 to 3 days of investigation. Expenses for a day's operation were estimated by Burns and Hines to range from $200 to $400, so savings would range from $400 to $800 per site. About 25 sites are investigated annually, with a yearly savings of about $15,000.

ENVIRONMENTAL GEOLOGY AND LAND-USE PLANNING

The major use of the geologic quadrangle maps as basic data for environmental geology studies and land-use planning lies in the future. The Kentucky Geological Survey and the U.S. Geological Survey plan a future cooperative study in a three-county area of northern Kentucky that will be a pilot program for other environmental geology studies elsewhere in the State. Municipal and county officials in other areas in the State have already expressed interest. Land planning in Kentucky is generally done on a countywide basis, and planners generally find that scales of 1:48,000 or 1:50,000 are the most useful for their needs and that smaller scales are nearly useless.

Although environmental geology studies are in their infancy in Kentucky, the geologic maps have already proven useful. In Fayette County, which includes Lexington, engineering geologic maps compiled from the quadrangle maps by C. G. Johnson of the U.S. Geological Survey were instrumental in convincing officials that a site proposed for a new sanitary landfill was unsuited because it would contribute to ground-water pollution. A landfill-site map prepared by M. C. Noger and others of the Kentucky Geological Survey based on data on the quadrangle maps and some additional fieldwork was used in determining a suitable site, which is now in operation.

Other examples in which the geologic maps have proven useful are: (1) The Corps of Engineers reviews and approves all applications for mining permits and for other activities that might affect water quality in the Cumberland River basin. In evaluating the permits, they use the geologic quadrangle maps extensively to determine the location of coal beds, the stability of slopes, and the most suitable locations for holding ponds. (2) Project geologists have supplied information and assistance to the U.S. Forest Service in the preparation and review of management plans for the Beaver Creek Wilderness Area in the Daniel Boone National Forest. (3) The National Park Service has used the geologic maps to determine local geologic conditions and land and mineral values in the Big Smith Fork Public Reservation Area in southern Kentucky.

INDUSTRIAL LOCATION

The State of Kentucky and local Chambers of Commerce have found the geologic maps of value in attracting industry. McGrain (1971) wrote the following:

> Data derived from geologic mapping have been used by the Kentucky Department of Commerce, local chambers of commerce, and consulting engineers for the evaluation of industrial sites which have resulted in new plants at Bowling Green, Hickman, Murray, Princeton, Richmond, Russellville, and South Portsmouth. One Chamber of Commerce official reported that the geologic maps allow his office to be acquainted with the potential of all sections of his county and to document their evaluation of the foundation conditions at possible plantsites. Further, these available geological data permit industrial developers to speak with a degree of authority which generates confidence in and prestige for their office.

The Executive Secretary of the Murray Chamber of Commerce, Murray, Ky., wrote the following in a letter to the President of the University of Kentucky after two major companies had selected Murray as the site for plants:

> Through the efforts of the Kentucky Geological Survey, a complete mapping program in Calloway County has been a major factor in the attraction of these two fine industries.

The mapping program referred to is, of course, the cooperative Kentucky Geological Survey-U.S. Geological Survey program.

CONCLUSION

We have been able to estimate a monetary value for only a few of the uses described in the preceding pages, but we have not been able, in this report, to quantify most of the benefit. The information which we have provided, however, does support the thesis that geologic mapping has a positive benefit on economic development and can result in saving taxpayer money on the application of government services. Though all geologic maps eventually become obsolete, those of Kentucky will continue to be used beyond the turn of the century and will continue to return benefits to citizens of the State and Nation.

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