UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

THE MIDCONTINENT STRATEGIC AND CRITICAL MINERALS PROJECT--OBJECTIVES AND STATUS, OCTOBER 1985

Edited by
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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

[1]Denver, Colorado

THE MIDCONTINENT STRATEGIC AND CRITICAL MINERALS PROJECT

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INTRODUCTION

One hundred and eighty-one years ago, Meriwether Lewis and William Clark set out from St. Louis on their journey up the Missouri River. Their mission was to trace the river to its source in an effort to find a practicable commercial water route to the Pacific, but in doing so they had the opportunity to explore an immense tract of unknown territory, including much of what we now refer to as the Midcontinent.

The north-central region of the United States has long since been explored, claimed, settled, and developed, but in one respect -- detailed knowledge of its subsurface geology -- the area still is largely unknown territory. We believe the time has come to consider the potential for a secondary phase of exploration in this region. **The premise of the Midcontinent Strategic and Critical Minerals (SCM) Project is that the subsurface of the midcontinent region is one of the last great frontiers for mineral exploration in the United States.** Four world-class base-metal mining districts occur within this region: the Upper Mississippi Valley lead-zinc district, the Illinois-Kentucky fluorspar(-lead-barite) district, the Southeast Missouri lead-zinc(-silver-copper-nickel-cobalt) district, and the Tri-State (Missouri-Kansas-Oklahoma) lead-zinc district (see Fig. 1). Significantly, all four districts lie outside the areas of glacial cover (the Upper Mississippi Valley district is dominantly inside the perimeter of the "driftless area" of southern Wisconsin), and the original discoveries of all four districts were made at the surface. All four districts are hosted by Paleozoic platform carbonate rocks, and the same sedimentary succession continues north and northwest in the subsurface all the way through Canada, where the succession hosts the Pine Point lead-zinc district, and on through Alaska to the Arctic Ocean.

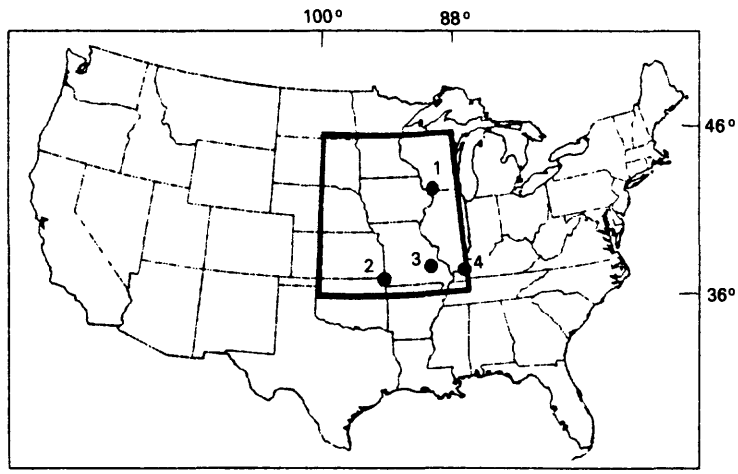

Figure 1.--Midcontinent Strategic and Critical Minerals Project--area of initial inventory, showing major mining districts. 1 - Upper Mississippi Valley district; 2 - Tri-State district; 3 - Southeast Missouri district; 4 - Illinois-Kentucky fluorspar district

A similar situation is true of the Precambrian basement rocks, but with the orientation reversed. The famous iron ores of the Lake Superior district, potentially valuable copper-nickel deposits in the Duluth Complex, and recently discovered zinc-copper massive-sulfide deposits in metamorphosed volcanic rocks in northern Wisconsin, are all in Precambrian terranes that are known at least partly from outcrops in the shield area, and that appear to extend southward beneath the Phanerozoic sedimentary cover. Drilling farther south has shown that the basement also contains many other Precambrian terranes, some of which have potential as host rocks for other kinds of mineral deposits. In sum, the subsurface terranes of the midcontinent region are believed to have some potential for undiscovered mineral deposits of the following types:

Precambrian rocks
- Sedimentary iron ores
- Layered gabbros and ultramafic rocks with chromium, copper-nickel sulfides, platinum-group metals, and gold
- Massive sulfide deposits of base and precious metals
- Olympic Dam-type deposits -- iron oxide with associated copper, cobalt, molybdenum, gold, silver, and uranium
- Algoma-type volcanogenic iron-titanium deposits
- Conglomeratic quartzites with potential for gold and uranium

Phanerozoic rocks
- Mississippi Valley-type (stratabound, carbonate-hosted) lead-zinc ores with silver, copper, nickel, and cobalt
- Zambian type (stratabound, sandstone-hosted) copper-silver ores
- Black shales containing a variety of metals (silver, vanadium, zinc, chromium, nickel, and molybdenum)
- Sedimentary manganese ores
- Diatremes of alkalic-ultramafic intrusive rocks with rare earths, fluorspar, base metals, and possibly diamonds

The Midcontinent SCM Project is a major integrated effort to more clearly define this varied mineral potential, with the following objectives:

1) To prepare an inventory of geologic data on the "core" area of the midcontinent -- a rectangle bounded by 36°-46° N. Lat. and 88°-100° W. Long. This area was selected as representative of the midcontinent geologic terrane. At the north it "anchors" onto the exposed Precambrian shield, and at the south it includes several contiguous $1^{\circ} \times 2^{\circ}$ quadrangles for which substantial data bases have been or are being accumulated through the Conterminous United States Mineral Assessment Program (CUSMAP). The product of this first-stage inventory will be a folio of 1:1,000,000 maps and cross sections to be published in the U.S. Geological Survey Miscellaneous Field Studies (MF) and Miscellaneous Investigations (MI) map series, giving a grossly accurate 3-dimensional picture of the major geologic and hydrologic terranes and known mineral systems in the region.

2) To develop and refine mineral-occurrence models for the types of mineral deposits likely to be associated with these terranes.

3) To define and pursue both regional and topical problems pertinent to the mineral-occurrence models.

4) On the basis of this research, to prepare 1:1,000,000 maps indicating mineral favorability of the basement and sedimentary terranes in the region.

The Midcontinent SCM Project was formally begun as a multi-state cooperative effort in January 1984. What follows in this report are summaries

of the objectives and status of each of several subprojects that have been started or proposed under the project. Readers wishing further information on any of these subprojects are invited to contact the project coordinator or the respective subproject leaders, whose names are given with the description of each subproject and whose names and addresses are listed in Appendix A. Names of the principal contacts for each of the state geological surveys are listed in Appendix B. General questions or comments on the program are invited at any time and may be directed to the Project Coordinator or to the Director, U.S. Geological Survey, Reston, VA 22092.

COMPLETED STUDIES

As of September 1985, several products have been essentially completed. They are summarized here.

Drill-hole map, compiled by Douglas N. Mugel

The midcontinent drill-hole map shows the location and other data for over 3,000 drill holes in the "initial inventory" area. Most of the drill holes shown are oil or mineral tests or water wells. The information shown for each hole consists of hole location, state drill-hole log number, bottom-hole elevation, age of rock at total depth, and types of samples, if any, that are available. The map is intended to show the availability of data and samples for representative deep drill holes in the northern midcontinent region. It was compiled from maps prepared by each of the state geological surveys to meet the following specifications: (1) basement penetration, or (2) other holes which in the judgment of the state contributor are deep enough to provide data and (or) samples for a significant part of the sedimentary section. Data obtained from these holes constitute an important data base for the project; many of the holes have been utilized in the cross sections and some of the maps of this folio. The map is also intended as a data base for other investigators involved in research into mineral potential in the midcontinent area.

Of the more than 3,000 drill holes shown on this map, most penetrate at least as deep as the Ordovician rocks, and about one-half penetrate the Precambrian basement. Drill-hole samples exist for approximately 2,000 of the drill holes, of which approximately 200 are core samples.

The drill-hole map is currently being processed for publication as the first map in the Midcontinent Folio, Miscellaneous Field Studies Map MF-1835-A.

Precambrian-basement map, compiled by Paul K. Sims

This map was compiled from 1:500,000-scale maps contributed by the respective state geological surveys showing basement drill holes, lithotypes or geologic map units, and basement topography, contoured at 200-foot intervals (500- and 1000-foot intervals in the Illinois Basin). In compiling the map, available aeromagnetic and gravity anomaly maps were used to help define the trend, extent, and boundaries of individual rock bodies. The completed map shows basement topography, structure, and principal lithologic terranes comprising over 50 individual units. The principal geologic contribution resulting from this compilation is the recognition and delineation of a major buried, northwest-trending Early Proterozoic orogen, named the Central Plains orogen (Sims and Peterman, in press). It extends from Nebraska through Kansas into Missouri, where it is overlapped by Middle

Proterozoic rhyolite-granite terranes, and it sharply truncates Archean rocks and an older Proterozoic orogenic (Penokean) belt in the inner part of the craton. A black and white version of the map is being processed for open-file release (USGS OF 85-0604), and a multicolored version is in preparation for publication in the Miscellaneous Investigations Series.

Precambrian-structure contour map, compiled by T. G. Hildenbrand

This map was digitized from the Precambrian basement map (see above) for the purpose of preparing an isopach map of the Phanerozoic rocks and sediments (see below), but will not be published separately.

Radiometric dates of basement rocks, compiled by R. F. Marvin

This product consists of two maps showing age ranges of available radiometric dates for basement rocks throughout the midcontinent, and accompanying tables listing pertinent data for the plotted samples. Map A shows sample localities for 111 samples giving 410 U-Pb zircon dates. These dates indicate that basement rocks in the northern reaches of the region are Archean, whereas those in the rest of the region are Proterozoic, probably dominantly Middle Proterozoic; in general, the ages of the basement rocks become younger from north to south. Map B, which shows sample localities for 560 samples giving 139 K-Ar and over 400 Rb-Sr dates, indicates the same general trend but with a much wider age span from oldest to youngest dates. Moreover, Proterozoic thermo-tectonic events in Wisconsin, Michigan, and probably the eastern Dakotas have affected the K-Ar and Rb-Sr isotopic systems to such an extent that Archean rocks generally have secondary (reset) Proterozoic ages. Much of the buried basement has not yet been dated radiometrically owing to the absence of samples.

These two maps are being prepared for publication in the MF map series. Accompanying tables will list locations (county, latitude and longitude), rock types, stratigraphic or plutonic names (if known), minerals or material dated, radiometric ages, and references.

Bouguer gravity anomaly map, compiled by T. G. Hildenbrand

Data from approximately 106,000 gravity stations abstracted from the Department of Defense data bank are being processed. Numerous errors in gravity values have been identified and corrected. Contour maps of the complete Bouguer anomaly are being sent to the states within the study area for their inspection for accuracy and completeness. When final editing has been completed, the gravity data will be filtered to enhance lithologic and structural boundaries. The 1:1,000,000-scale map will be published in color in the MI map series.

It is clearly evident from the preliminary compilation that the map conveys much information on the tectonic development of the midcontinent. Most conspicuous is the well-known Midcontinent Gravity Anomaly, a system of gravity highs that extends from western Lake Superior to central Oklahoma. Geologic and geophysical evidence indicates that these anomalies are expressions of a Keweenawan rift system containing layered mafic volcanic rocks. Northwest-trending features transect Missouri; in particular, a prominent gravity low extends from the St. Francois Mountains in southeastern Missouri to the Midcontinent Gravity Anomaly in southeastern Nebraska. The low has been interpreted as a low-density granitic terrane that developed during a late Precambrian rifting event (Guinness and others, 1982).

Terrain map, by T. G. Hildenbrand

A terrain map of the study area was generated from a U.S. Geological Survey digital data base created from a data base obtained from the National Geodetic Survey (Godson, 1981). Elevations were determined at horizontal intervals of 1.2 mi by using a minimum curvature gridding technique and then plotted on an Applicon color plotter. The map is in process of being published in color in the MI map series at a scale of 1:1,000,000 (contour/color interval of 125 ft).

Isopach map of Phanerozoic rocks and sediments, compiled by T. G. Hildenbrand

An isopach map of the Phanerozoic rocks and sediments within the study area was made by electronically subtracting the digitized Precambrian-structure-contour data from the digital terrain data to obtain thickness of the Phanerozoic cover. The structures of the Midcontinent Rift System are enhanced with unprecedented clarity on this color isopach map. The map also demonstrates that much of the potentially mineralized sedimentary section and even the basement in the project area are relatively shallow (i.e. less than 5,000 ft deep) and therefore within reasonable reach of the diamond drill. The map is in process of being published in color at 1:1,000,000 scale in the MI map series.

Sauk Sequence isopach and clastic-limestone-dolomite lithofacies map, compiled by Walden P. Pratt

This map was compiled from 1:500,000-scale isopach and lithofacies maps contributed by the states. It shows that Cambrian and Lower Ordovician sedimentary rocks of the midcontinent pinch out across Kansas, Nebraska, and Minnesota, and thicken south and east from the pinchout. Excluding the basal clastics, the rocks are overwhelmingly dolomite. Thicknesses of limestone that are locally significant within certain formations, such as the Bonneterre in southeast Missouri, are for the most part obscured by the preponderance of dolomite when the Sauk Sequence is considered in its entirety. The map is currently undergoing revision and will be submitted for publication in the MF map series.

Cross sections, compiled by Douglas N. Mugel

Thirteen cross sections along even-numbered lines of latitude and longitude of the study area were compiled from cross sections prepared by the states. The sections show major lithologies and stratigraphic-tectonic sequences and subsequences for the entire Phanerozoic. Major lithologies are limestone, dolomite, evaporite, sandstone and related clastics, shale, and organic shale. The sections also include important structural features such as major faults and the topography of the buried Precambrian surface.

The objective of these cross sections is to show at a usable scale the general stratigraphy and major structural features of the midcontinent region. When used in conjunction with data being compiled in other phases of the project, they will help to evaluate the potential of the region for sediment-hosted ore deposits.

Originals of the cross sections contributed by the state geological surveys are at 1:500,000 horizontal scale (vertical scale 1 inch = 500 ft). Composites are being prepared for publication in two complete sets, both with a vertical exaggeration of 83X. One set will be at 1:1,000,000 horizontal scale (vertical scale 1 inch = 1,000 ft) and will be published in the MF map series; the other will be at 1:2,500,000 horizontal scale (vertical scale 1 inch = 2,500 ft) and will be published in color in the MI map series.

Alkaline igneous rocks, carbonatites, and peridotites,
compiled by F. A. Hills, R. W. Scott, Jr.,
and T. J. Armbrustmacher

This map, prepared by the USGS from all available data, shows the locations of alkaline and ultramafic igneous rocks, including carbonatites and kimberlites, and of structural domes and diatremes known or thought to be associated with similar igneous rocks. Also shown are other structures and geophysical anomalies of uncertain origin that may be related to buried igneous intrusions. These include cryptoexplosion structures, some of which have been interpreted as astroblemes, and gravity and magnetic anomalies that have been interpreted as indicating buried mafic plutons. The 1:1,000,000-scale map is being prepared for publication in the MF map series. A pamphlet that will accompany the map includes (1) tables summarizing what is known of the petrography, age, and structural setting of each occurrence; (2) a list of the principal references for each occurrence; and (3) larger-scale maps of areas in which occurrences of igneous rocks and related features such as diatremes are too dense to show clearly at 1:1,000,000 scale.

Equivalent-freshwater head and dissolved-solids concentration
of water in rocks of Cambrian and Ordovician age
and in rocks of Mississippian age (two maps),
compiled by D. G. Jorgensen, J. O. Helgesen, R. B. Leonard,
and D. C. Signor

These two 1:1,000,000-scale maps show preliminary interpretations of predevelopment hydrogeologic conditions of water in the two aquifer systems named, and can be used in a manner described by Signor and others (1980) to develop conceptual and predictive models of hydrologic and geochemical aspects of the regional flow systems.

The maps indicate that each of the two aquifers contains three major regional ground-water flow systems, and that the regional extent and dissolved-solids concentration (salinity) of the three systems are similar in both aquifers. The flow systems in each aquifer in the Ozark area in southwestern Missouri and northwestern Arkansas makes a pair, each containing fresh water with less than 1,000 milligrams per liter (mg/l) dissolved solids. A similar pair of flow systems is in northeastern Oklahoma and southeastern Kansas and contains water with a salinity ranging from about 20,000 to more than 200,000 mg/l. In each aquifer, these two flow systems merge in a narrow zone of mixed waters about 40 km wide, which trends southward through southeast Kansas and northeast Oklahoma.

The third pair of major flow systems is generally similar in areal extent but less so in the patterns of salinity. Water in the aquifer in the Cambrian and Ordovician rocks flows southeastward (or locally to the Mississippi River) from recharge areas in northeastern Nebraska, northwestern Iowa, southeastern Minnesota, and southern Wisconsin, and the salinity ranges from less than 500

mg/l in eastern Iowa to more than 1,000 mg/l in western Iowa. This concentration gradient implies that water has flowed from east to west under different geologic and hydrologic conditions than at present. In particular the concentration gradient is believed to reflect the paleoflow direction from east to west during the Pleistocene. Water in the aquifer in the Mississippian rocks in this third system flows southeast from east-central Nebraska and west-central Iowa, and salinity decreases from 5,000 mg/l in western Iowa to less than 500 mg/l in central Iowa. This distribution of dissolved solids may result from mixing of meteoric water with formation water.

The two maps are in press for publication in the MF map series as maps MF-1835-B (Cambrian and Ordovician) and MF-1835-C (Mississippian).

STUDIES IN PROGRESS

Subprojects currently in progress, including several which have just been started, are of two types, compilations of maps and cross sections for the entire inventory region, and topical studies restricted to only parts of the 12-state region.

Regional Studies

Magnetic anomaly map, compiled by T. G. Hildenbrand

Approximately 100 individual magnetic surveys have been processed to grid form and are being merged into a consistent data set (all data reduced to 1,000 ft above ground). The first regional magnetic anomaly map will encompass Missouri, central and eastern Kansas and Nebraska, Iowa, northern Arkansas, and Illinois, and is now being reviewed. Minnesota, Wisconsin, and South Dakota will be added during calendar 1986, and a map of the entire project area at 1:1,000,000 scale will be submitted for review by about June 1986.

Mines, prospects, and mineral occurrences, compiled by Mary H. Miller

Compiled from USGS files and supplemented by data contributed by the states, this map shows all known districts, isolated individual deposits, and minor surface occurrences in the study area. Types of deposits shown include major Mississippi Valley-type lead-zinc deposits with associated silver, copper, nickel, and cobalt; iron; barite; manganese; fluorspar and rare-earth minerals; and sedimentary copper.

Because review of the first draft of this map revealed many inaccuracies in references and locations -- most of which had accumulated through repeated iterations of incorrect or incomplete data over the years -- the data are being verified and digitized for publication, first on a state-by-state basis and later to be combined into a single map of the entire project area. The state of Iowa was selected for the pilot study, and a 1:1,000,000-scale map of Iowa is now in preparation for publication in the MF series. Other states will follow, but the number of unknown factors precludes setting a compilation schedule at this time.

At our request, the states have also supplied maps showing locations and depths of occurrences of visible sulfide minerals in drill samples, in an attempt to determine whether vertical zones of trace mineralization exist in

the region, and if so, whether they have any recognizable regional or stratigraphic pattern. At present this compilation is on "hold", pending design and implementation of a data-base system adequate to hold and process the large amounts of data that were supplied.

Regional tectonic map, compiled by Raymond R. Anderson, Iowa Geological Survey

The purpose of this 1:1,000,000-scale map is to show the principal tectonic features affecting Phanerozoic rocks in the study area, and in particular their relations to basement structures. The map is now in process of being compiled from maps contributed by the states.

Isopach and limestone/dolomite lithofacies map and detailed east-west cross sections of "Mississippian limestones"

These two compilations are being undertaken in an attempt to define in greater detail the regional and stratigraphic distribution of lithologies that are likely to be favorable hosts for Mississippi Valley-type mineral deposits. The isopach and lithofacies map will be compiled at a scale of 1:1,000,000; the cross sections initially will be at a horizontal scale of 1:500,000 and vertical scale of 1:1200 (1 inch = 100 ft). At present both products are at the stage of compilation by the individual states, for submittal in the fall of 1985.

Topical Studies

Fluid-inclusion, petrographic, and geochemical studies, by D. L. Leach, J. G. Viets, and E. L. Rowan

Fluid-inclusion, petrographic, and geochemical studies of Mississippi Valley-type lead-zinc deposits in Missouri, Arkansas, and eastern Kansas and Oklahoma are being conducted to develop a genetic model for deposits in the region. The model will take into account the source, temperature, and chemical evolution of the mineralizing fluids, and should provide insight into factors controlling transport and deposition of the ore. Results to date suggest that world-class districts (Tri-State and Southeast Missouri), smaller districts (Central Missouri and Northern Arkansas), and the widespread trace occurrences of sulfides, are all genetically related to a single, regional, thermal-hydrologic event.

Homogenization temperatures for fluid inclusions in hydrothermal, vug-lining dolomite in Cambrian through Pennsylvanian formations record the passage of highly saline fluids at temperatures significantly hotter than consistent with "normal" heat flow from the basement. Data from the dolomite combined with data from earlier studies provide evidence for broad-scale heating of the Paleozoic rocks to temperatures of 90°-160°C. Hot, advecting brines of deep basin origin may have been responsible for regional heating as well as localized mineralization. On a broad scale, higher homogenization temperatures to the south suggest a southern fluid source, while on a smaller scale, no localized or steep thermal gradients from major ore districts into barren host rock have been observed. Thermal equilibrium between fluid and host rock is implied, suggesting a major, regional thermal event rather than localized thermal anomalies.

Preliminary observations suggest that a cathodoluminescence "microstratigraphy," defined in hydrothermal dolomite from the Viburnum Trend (Voss and Hagni, 1984), can be correlated with the zonation in dolomites from the Northern Arkansas zinc district. Work is currently in progress to verify the correlation between cathodoluminescent microstratigraphies, and to trace the regional extent of the fluid ultimately responsible for mineralization in the Viburnum Trend. In addition, dissolution textures in the dolomite observed with cathodoluminescence may reflect pH changes in the fluid, and may be linked to precipitation of sulfides.

"Bulk extractions" of inclusion fluids from sphalerite, galena, and dolomite are being performed, and the fluids analyzed by ion and gas chromatography, atomic absorption, and mass spectrometry. Ratios of cation and anion species indicate that inclusion fluids within the study area are similar to many basinal brines, and have remarkably similar compositions considering that the samples are hosted by Cambrian through Pennsylvanian rocks and are separated by hundreds of kilometers. Regionally, the calcium concentration of inclusion fluids decreases from south to north, whereas the potassium concentration increases. Although the inorganic species in the inclusion fluids are similar to those of formation waters, preliminary results of gas analyses show surprisingly large amounts of CO_2 and very scarce hydrocarbon. The abundance of CO_2 with only small amounts of C_1 to C_3 hydrocarbons suggests that the mineralizing fluids may have originated in a distant, deep basin, perhaps in an environment of low-grade metamorphism ($300^{\circ}C$), but at temperatures well in excess of those recorded by fluid inclusions in the ore deposits.

The Ouachita-Arkoma Basin is regarded as a plausible source for the mineralizing fluids. Deformation of the basin during the Late Pennsylvanian-Early Permian Ouachita orogeny may have contributed to expulsion of brines from the depths of the basin and subsequent migration onto the southern margin of the craton.

Sulfur isotope studies, by M. B. Goldhaber

Measurement of sulfur isotopes in unmineralized Cambrian and Ordovician carbonate rocks across southern Missouri shows a marked trend toward increasing values of the sulfur isotopic ratio ($\delta^{34}S$) with depth in the section. The largest (most positive) values occur in the Bonneterre Formation and represent early diagenetic pyrite. Early galena and marcasite from Bonneterre-hosted lead-zinc deposits in southeast Missouri also show large positive $\delta^{34}S$ values, whereas other deposits in Missouri and adjacent states, all located in younger strata, contain sulfur with smaller positive $\delta^{34}S$ values. These relations suggest that sulfur in southeast Missouri ore deposits was in part derived locally from diagenetic Bonneterre sulfur, and that sulfur in other deposits in Missouri and adjacent states could also have had local sources.

Midcontinent basal sandstones and Precambrian geochemistry, by E. L. Mosier

The ultimate objective of this project is to determine whether basal sandstones constitute a valid geochemical medium for investigating the mineral-resource potential of the Precambrian basement. As a necessary step, the project will first attempt to develop analytical techniques that (1) have sufficient sensitivity to overcome the massive diluent effect of the basal

sandstones, (2) will differentiate element contribution from basal sandstone and Precambrian detritus and/or secondary minerals derived from leaching of the Precambrian rocks (because some of the sandstones may have been derived from great distances and therefore will have no bearing on the local geochemistry), and (3) will have sufficient precision to study alteration (where applicable) of the Precambrian basement.

Paleo-hydrodynamics of metal-bearing fluids, by L. H. Filipek

This project involves research into paleoflow and heat transport modeling as a tool to aid in the understanding of Mississippi Valley-type mineral deposits. The theory of groundwater flow in mature basins is being applied to the Ouachita orogeny and Ozark Uplift in the late Paleozoic to put constraints on the timing of mineralization of the Southeast Missouri, Northern Arkansas, and Tri-State Mississippi Valley-type deposits, assuming they were formed by gravity flow from the Arkoma Basin. There is an approximately 20-million-year span during the Middle to Late Pennsylvanian and Early Permian in which significant flow could have occurred from south to north out of the Arkoma Basin to Missouri, based on present knowledge of the relative topographies of the Ozark dome and the Ouachita Mountains during the Pennsylvanian and Permian. A two-dimensional numerical model is being developed to test this hypothesis, using a USGS modeling program.

In addition, the same program will be used to test the hypothesis of flow northeastward out of the Anadarko Basin during late Paleozoic time. This work will be in collaboration with D. G. Jorgensen of the USGS, Water Resources Division, who is supplying present-day vertical hydrologic cross sections and paleo-reconstructions to use with the program, as well as valuable hydrologic insight.

Manganese potential of the Zuni strandline, by D. L. Southwick, Minnesota Geological Survey

The objective of this new project is to assemble as complete a picture as possible of the distribution, thickness, and lithostratigraphy of Upper Cretaceous marine sedimentary rocks along the high-stand "Zuni" shoreline in Iowa, Nebraska, South Dakota, and Minnesota. These data will be analyzed to identify paleogeographic and stratigraphic environments that appear favorable for manganese accumulation. The project is predicated on the Cannon-Force model (Cannon and Force, 1985), which interprets the world-class sedimentary manganese deposits as having accumulated in marine-transgressive sedimentary sequences on stable cratonic platforms; manganese deposition is favored during high sea-level stands when the oceans tend to become stratified, stagnant, and anoxic. In terms of this model, the high sea-level stand represented by the Late Cretaceous transgression into the northern midcontinent may have been a favorable scenario for manganese deposition, as suggested by the subeconomic Chamberlain deposit in South Dakota. This project is currently in the planning stage.

Keweenawan clastic rocks of the Midcontinent Rift System, by R. R. Anderson, Iowa Geological Survey

Keweenawan clastic rocks are exposed in parts of the northern midcontinent and are known to extend farther south in the subsurface along the

Midcontinent Rift System, but detailed information is lacking. They are believed to have potential for undiscovered deposits of copper and silver as well as for oil and gas. A series of three field expeditions will be conducted this fall (1985) by investigators from the Iowa, Minnesota, Wisconsin, Nebraska, and Kansas Geological Surveys to examine, describe, and sample these formations in exposures and from reposited core and rock bit materials. These investigators will prepare a report containing tentative conclusions as to the extent, nature, and resource potential of these rocks, and recommendations for additional research to be done as a later phase of this project.

Southern Extension of the Churchill Province, by R. R. Anderson, Iowa Geological Survey

Rocks of the Churchill Province in Canada include greenstone belts that host the massive base-metal sulfide deposits of the Flin Flon district, as well as mafic and ultramafic igneous rocks that contain the nickel sulfide deposits of the Thompson district. Presumably, a potential for similar deposits exists in the southern extension of the Churchill Province in the north-central United States. The ultimate purpose of this project is to obtain information about the subsurface extent and nature and mineral-resource potential of rocks of the Churchill southern extension. The first year of the project is limited to a workshop, to be held in December 1985, of key investigators currently engaged in research on geologic problems related to the extension. The information obtained in this workshop will be used in planning an integrated program of research toward the objective of characterizing the resource potential. A report will be prepared outlining some of the theories discussed at the workshop, including the geologic history and geometry of the southern extension of the province, and suggesting topics for future research on these theories.

PROPOSED STUDIES

Early in February 1985, representatives from all twelve state geological surveys involved in the project met with the USGS team for a two-day seminar to review the work of the first year and to take part in workshops on future regional and topical studies to be recommended. Following is a list of the projects that were proposed, excluding some that have already been started and are described above. Scheduling of these projects will depend on estimated costs and future budgets.

I. Regional Studies -- State Cooperatives

1. Isopach and lithofacies maps and detailed east-west cross sections of the "Upper Ordovician limestones"
2. Paleotectonic maps for selected age intervals
3. Regional subsurface geochemical data base of carbonate rocks
4. Regional distribution of black shales

II. Topical Studies -- Cooperatives involving selected states

1. Zambian-type copper-silver mineralization in Permian rocks (Oklahoma-Kansas)
2. Test of southwestern and southern extensions of Wisconsin magmatic terrane and associated Archean gneiss (Wisconsin-Iowa)

III. Regional Studies -- primarily within USGS

1. Assess mineral-resource potential of inferred Precambrian basement tectonostratigraphic terranes
2. Prepare 1:2,500,000 derivative maps from 1:1,000,000 gravity and aeromagnetic maps and model interesting target areas
3. Accelerate collection, cataloguing, and interpretation of lithochemistry of basement rocks
4. Construct paleohydrologic maps for selected intervals in the Phanerozoic
5. Display relative sediment permeabilities in each basin

IV. Topical Studies -- primarily within USGS

1. Continue studies of alkaline rocks and kimberlites
2. Improve isotopic age data base
3. Begin analyses of brines from oil and water wells (proposed as a combined effort of Water Resources Division, Branch of Oil and Gas Resources, and Branch of Exploration Geochemistry)
4. Determine age of Mississippi Valley-type deposits
5. Develop geophysical method for finding buried knobs
6. Undertake detailed carbonate petrologic studies of Mississippi Valley-type orebodies and their host rocks
7. Fill in gaps in aeromagnetic mapping
8. Study correlations between organic materials in fluid inclusions and those in nearby basins

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