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The Conterminous United States Mineral-Resource Assessment Program—Background Information to Accompany Folios of Geologic and Mineral-Resource Maps of the Harrison 1°×2° Quadrangle, Missouri and Arkansas, and the Joplin 1°×2° Quadrangle, Kansas and Missouri

Prepared in cooperation with the Missouri Division of Geology and Land Survey, the Kansas Geological Survey, and the Arkansas Geological Commission

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Edited by Walden P. Pratt

U.S. GEOLOGICAL SURVEY CIRCULAR 1140

Prepared in cooperation with the
Missouri Division of Geology and Land Survey, the
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Arkansas Geological Commission

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Edited by Walden P. Pratt

INTRODUCTION

The Harrison and Joplin 1°×2° quadrangles are the third and fourth, respectively, of five 1°×2° quadrangles in a tier across southern Missouri and adjoining states, that were selected for assessment of mineral-resource potential under the Conterminous United States Mineral-Resource Assessment Program (CUSMAP) (fig. 1). The first two quadrangles in this series were the Rolla and Springfield quadrangles, both in Missouri; results of those projects have been summarized by Pratt (1991) and by Martin and Pratt (1991), respectively. The Harrison and Joplin quadrangle projects were begun contemporaneously, as the Springfield project was being completed, and were followed later by the study of the Paducah quadrangle, Missouri-Illinois-Kentucky (Goldhaber and Eidel, 1992).

This report contains separate accounts of the operations and products of the Harrison and Joplin CUSMAP projects, as well as brief reviews of the scientific conclusions of the two projects, abridged from the published maps that make up the series informally known as the Harrison and Joplin CUSMAP folios. The full scientific products of the two projects are in the folios themselves. Inasmuch as the Harrison and Joplin quadrangles were studied in tandem and have much in common both geographically and topically, the summaries of the two projects are combined here into a single report. This coupling will avoid duplication, and, we hope, offer greater convenience to the user.

The final section of this report contains abstracts of several papers pertinent to the assessment of the two quadrangles that were presented at a symposium on the mineral-resource potential of the Midcontinent in St. Louis, Mo., April 11–12, 1989 (Pratt and Goldhaber, 1990).

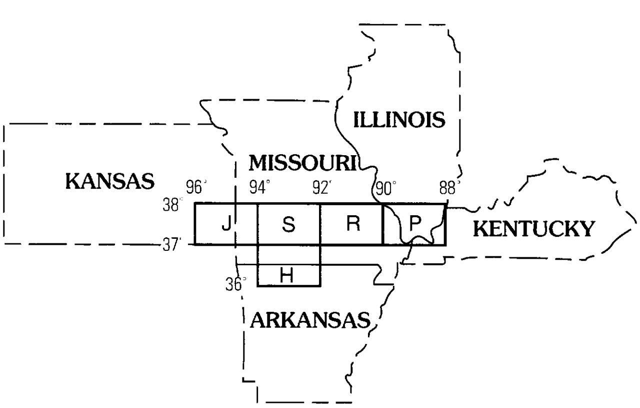

Figure 1. Index map showing location of Conterminous United States Mineral Resource Assessment Program quadrangles in the Midcontinent region. H, Harrison; J, Joplin; P, Paducah; R, Rolla; S, Springfield.

HARRISON 1°×2° QUADRANGLE, MISSOURI AND ARKANSAS

The Harrison 1°×2° quadrangle CUSMAP project was formally begun in October 1983 as a cooperative between the U.S. Geological Survey (USGS), the Missouri Geological Survey (MGS), and the Arkansas Geological Commission (AGC). Field work was completed by December 1986, and the assessment meeting was held in Rolla, Mo., September 29–30, 1987. The first formal publication to result from the project was a summary geochemical map of the quadrangle (Erickson and others, 1988); the last of the published reports are still in press. Results of most phases of the project were presented at a public meeting in St. Louis, Mo., in April 1989 (Pratt and Goldhaber, 1989, 1990). Directly involved in project operations at various times were 13 geoscientists of the USGS, 10 of the MGS, and 4 of the AGC.

The Harrison 1°×2° quadrangle CUSMAP folio is not a single entity but rather a set of maps and cross sections published individually, covering all or part of the Harrison 1°×2°

quadrangle and most bearing sequential numbers in the USGS Miscellaneous Field Studies Map (MF) series. These maps show the bedrock geology of the quadrangle, stratigraphy and depositional lithofacies of Upper Cambrian sedimentary rocks, subsurface geochemistry, geophysics and interpreted basement terranes, an assessment of the mineral-resource potential of the quadrangle, and detailed geology and mineralization of the Caulfield zinc district in the east-central part of the quadrangle. Summaries of the content of each of these maps follow, in order of publication; these summaries were prepared in part from the maps and in part from abstracts presented at the 1989 St. Louis meeting.

SUMMARY GEOCHEMICAL MAPS OF THE HARRISON 1°×2° QUADRANGLE

By R.L. Erickson, B. Chazin, *and* M.S. Erickson (USGS)

MAP MF–1994–A

Previous studies in the Ozark region have shown that insoluble residues of subsurface carbonate rocks are a useful and informative geochemical sample medium for characterizing trace-element suites and regional mineral trends (Erickson and others, 1978, 1979, 1985). Insoluble residue samples from 65 drill holes were selected for this study. All these holes penetrate at least some Ordovician rocks, 31 penetrate at least 100 ft into Cambrian rocks, and 16 penetrate to Precambrian basement or a basal Cambrian sandstone.

The subsurface geochemical studies reveal three principal areas of high metal concentrations in insoluble residues of Paleozoic carbonate rocks. The northeast anomalous area is part of a geochemical trend (Erickson and others, 1985) that extends from the southern border of Missouri northwestward across the adjacent Springfield 1°×2° quadrangle. This trend is hosted in dolomites of the post-Bonneterre Cambrian of Palmer (1991) and appears to follow a northwest structural grain bounded on the northeast by the Bolivar-Mansfield tectonic zone. The south-central anomalous trend is hosted in both Cambrian and Ordovician dolomites on the east flank of a Precambrian high and along the projection of the Chesapeake tectonic zone. The west-central anomalous area has no apparent relationship to known tectonic zones or buried Precambrian ridges and is considered to be less significant than the other two trends.

Paired geochemical maps compiled for Cambrian and Ordovician strata show that Pb, Ag, Cu, As, and Ni are most abundant in insoluble residues of Cambrian rocks and that zinc is most abundant in Ordovician rocks—a consistent pattern throughout the Ozark region.

Bar graphs in this report show the stratigraphic distributions of anomalous contents of selected metals in insoluble residue samples from each drill hole analyzed as part of the study. The complete analytical data for each hole are given in open-file reports by Erickson and Chazin (1987a-f) and Chazin and Erickson (1987a-c, 1988a-g).

GEOPHYSICAL MAPS AND INTERPRETATION OF BASEMENT TERRANE IN THE HARRISON 1°×2° QUADRANGLE

By A.E. McCafferty, Lindrith Cordell, *and* R.E. Bracken (USGS)

MAP MF–1994–B

The primary focus of this report is the Precambrian crystalline basement as expressed in geophysical data. Sparse drill-hole data and absence of outcrops provide little information on the buried basement. We applied two interpretive techniques to the geophysical data in an effort to extract additional information about the lithologies, depths, and structures of the Precambrian terrane. The overall objective was to provide insight into the basement geology and its possible indirect role in mineralization.

An analytical method called "terracing" (Cordell and McCafferty, 1989) is used in this study as a lithologic and structural mapping tool. The method uses gridded gravity or magnetic data to define inferred rock unit boundaries, based on the local curvature of the gravity or magnetic field. The terrace maps are physical-property models and, as such, their gravity or magnetic field can be calculated and compared with the observed gravity or magnetic field. The terrace maps have the value of theoretically outlining varying terranes and structure. They provide a useful geologic-like map, which can permit mapping with more confidence in areas where the rocks of interest are hidden from view.

The following observations correlate broad features identified in the terrace maps with their lithologic and structural implications.

(1) A northwest pattern of aeromagnetic anomalies pervades the quadrangle and follows the Precambrian rocks pattern of predominant northwest-southeast trends (McCracken, 1971). This regional pattern correlates with mapped faults such as the Bolivar-Mansfield fault system. From the magnetic terrace map we inferred that characteristic of that fault system are rocks with values of magnetic susceptibilties higher than the rocks directly southwest of the zone. These rocks with relatively high susceptibilities have been correlated with Middle Proterozoic granites and associated volcanics of the St. Francois terrane (Bickford and others, 1981).

(2) A 50-km-wide northwest-trending suite of rocks with relatively high susceptibilities strikes across the center of the quadrangle. The northeastern edge of this belt possibly coincides in part with the Chesapeake fault. The limited drill-hole data indicate that the rocks forming this upthrown belt may be correlated with epizonal granites and associated rhyolites of the Spavinaw terrane (Thomas and others, 1984).

The somewhat ragged southwestern edge of the belt may delimit another fault zone comparable in scale to the Chesapeake fault.

(3) Numerous other parallel and sub-parallel linear features are observed on the susceptibility model. In general, every lineament reflects a discontinuity in the Precambrian basement, but it is not known whether the discontinuities are associated strictly with faults.

(4) Superimposed on the regional northwest-southeast grain are arcuate features that are oval to circular in shape. These features seem to be younger than the rocks that define the regional geophysical grains because of their cross-cutting relationships. One such feature is a broad, circular gravity and magnetic anomaly in the eastern half of the quadrangle; we infer that it may be an intrusive pluton surrounded by a volcanic ring similar to those observed in the St. Francois terrane (Kisvarsanyi, 1980).

(5) A depth-to-magnetic source technique was applied to a part of the aeromagnetic data, to investigate a hypothesis proposed by E.E. Glick (this report) suggesting that there may be as much as 2000 m of topographic relief on the Precambrian basement surface. The quantitative depth anaylsis supports Glick's hypothesized relief having a generally north to northwest grain. Basement topographic highs show a widespread correlation with rock bodies of intermediate to high magnetic susceptibility, suggesting that the paleotopographic highs may be associated with rhyolitic volcanic rocks. Conversely, the paleotopographic lows are mostly associated with rocks that have low magnetic susceptibility, which may reflect intrusive rocks that tend to be less resistant to erosion than volcanic rocks.

CROSS SECTIONS OF LOWER ORDOVICIAN CARBONATE DEPOSITIONAL LITHOFACIES AND MISSISSIPPI VALLEY-TYPE ZINC- AND IRON-SULFIDE MINERALIZATION IN THE CAULFIELD DISTRICT, EAST-CENTRAL PART OF THE HARRISON 1°×2° QUADRANGLE

By Timothy S. Hayes (USGS), James R. Palmer (MGS), *and* Gary Krizanich (USGS)

MAP MF–1994–C

Logs of eight cores from the Caulfield zinc district have been compiled into two short cross sections. This detailed logging has (1) generated a model for Lower Ordovician cyclic peritidal carbonate sedimentation, (2) provided detailed correlation of the district's host rocks, (3) demonstrated that there was no lithofacies control on economically important Caulfield district mineralization, (4) confirmed that the Alice mine ores are hosted by a pipe-shaped zone of solution-collapse crackle breccia, (5) provided evidence that the host breccia pipe is connected to a subsurface stratal dissolution collapse breccia and that both breccias probably formed by pre-ore surficial karstification, and (6) correlated hydrothermal dolomite generations, demonstrating that the Caulfield district mineralization was part of a regionwide Mississippi Valley-type (MVT) hydrothermal system in the Ozark region.

If the Alice mine is typical of Caulfield district orebodies, the economic potential of the district is limited to orebodies of 500,000 tons or less; however, because of its simple structural control and paragenesis, the Alice mine is an excellent place for further scientific study. Two major hypotheses on the sources of metals and sulfur could be tested at the Alice mine. Currently, the data appear to indicate that both metals and sulfide sulfur were carried by a single solution that rose up the Alice mine breccia pipe, as proposed for other MVT systems in a study by Sverjensky (1984). The alternative two-solution model (Beales and Jackson, 1966; Anderson and Garven, 1987) appears possible only if the rising metals-bearing solution in the breccia pipe met a sulfur-bearing solution recharging laterally along the stratabound breccia.

MINERAL–RESOURCE ASSESSMENT MAPS OF THE HARRISON 1°×2° QUADRANGLE

By Walden P. Pratt, Timothy S. Hayes, Ralph L. Erickson (USGS), Eva B. Kisvarsanyi, Michael C. McFarland, Ardel Rueff (MGS), William V. Bush, George W. Colton, *and* John David McFarland III (AGC)

MAP MF–1994–D

The potential for the following types of undiscovered mineral resources in the Harrison 1°×2° quadrangle is discussed in this report: (1) Mississippi Valley-type deposits in Cambrian rocks, (2) other metallic mineral deposits in the Phanerozoic rocks, (3) metallic mineral deposits in the Precambrian basement, and (4) industrial minerals.

MISSISSIPPI VALLEY-TYPE DEPOSITS IN CAMBRIAN ROCKS

The assessment team used a simplified MVT deposit model consisting of six recognition criteria: (1) presence of a favorable host formation; (2) presence of a zone of abrupt changes in depositional lithofacies at ramp facies margins; (3) presence of anomalously high amounts of the typical MVT metal suite in insoluble residues of the carbonate rocks; (4) presence or proximity of a limestone-dolostone interface; (5) presence or proximity of faults; and (6) presence of knobs in the Precambrian surface. These criteria were applied separately to two sedimentary sequences—an upper sequence consisting of the post-Bonneterre Cambrian rocks and the upper part of the Bonneterre Formation, and a lower sequence comprising the lower and middle parts of the Bonneterre Formation. Using these criteria, the team identified three areas in the quadrangle considered to have a high or marginally high potential for undiscovered MVT deposits in Cambrian rocks. The level of potential is based on the amount and kinds of evidence suggesting a favorable geologic environment for mineralization; the degree of certainty reflects the availability of data. In the upper sequence, a northwest-trending band across the northeast quarter of the quadrangle (Douglas and Ozark Counties, Mo.) was assigned a high potential, with a moderate degree of certainty (fig. 2, area A). Also in the upper sequence, a northerly trending area at the south center of the quadrangle was assigned a high potential with a low degree of certainty (fig. 2, area B). In the lower sequence, a somewhat larger northerly trending area in the south-central part of the quadrangle was assigned a high-to-moderate potential with a moderate degree of certainty (fig. 2, area C).

OTHER METALLIC MINERAL DEPOSITS IN THE PHANEROZOIC ROCKS

The assessment team considered the potential for the following deposit types: MVT deposits in Ordovician and Mississippian rocks, residual brown iron-ore (limonite) deposits in surficial materials derived from Ordovician and Carboniferous rocks, lead-zinc deposits in Cambrian sandstone, red bed-evaporite-associated stratabound copper deposits, and minor deposits of uranium, pyrite, manganese, coal, silver, arsenic, and cadmium. The area outlined showing potential for lead-zinc deposits in Cambrian sandstone underlying the Bonneterre Formation is similar to the area outlined showing potential for MVT deposits in the Bonneterre itself (fig. 2, area C). The potential for significant undiscovered deposits of the other deposit types considered is low.

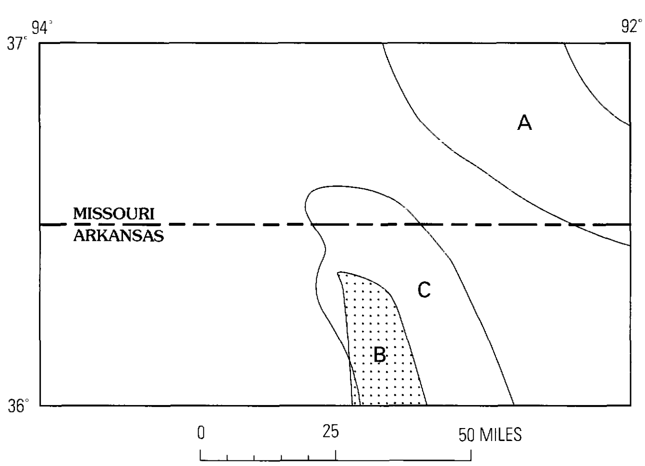

Figure 2. Map showing areas of high or marginally high potential for MVT deposits in the Harrison 1°×2° quadrangle. Letters A, B, and C refer to areas discussed in text.

METALLIC MINERAL DEPOSITS IN THE PRECAMBRIAN BASEMENT

No metallic mineral resources are known to exist in the Precambrian rocks in the Harrison 1°×2° quadrangle. Only six drill holes in the quadrangle penetrate the Precambrian basement; two are core holes, one in each state, and four are rotary holes, which provided cuttings. Samples from all of the drill holes, supplemented by interpretation of aeromagnetic anomalies and extrapolation of structures and basement terranes from adjoining quadrangles, permit tentative identification of two Middle Proterozoic epizonal terranes, the Spavinaw and the St. Francois. Within these terranes, nine areas in the quadrangle are identified that may be favorable for iron-rich complex metallic ore deposits of the Olympic Dam type, but drill-hole data are insufficient to assess their potential.

INDUSTRIAL MINERALS

Resources of crushed stone for use as aggregate and aglime are available throughout the quadrangle, and the Boone Formation in the southwestern part of the quadrangle could provide much high-calcium rock. Construction sand and gravel are widely available in ample quantities for local needs. Resources of dimension stone are sufficiently large and accessible to support a small industry, if one should develop. Several quartz sandstone units that have potential for industrial sand are present in the quadrangle, especially in Arkansas, but relatively little sandstone has been produced. The potential for economic deposits of clay and tripoli is very limited.

CROSS SECTIONS SHOWING STRATIGRAPHIC AND DEPOSITIONAL LITHOFACIES OF UPPER CAMBRIAN ROCKS AND THE RELATION OF LITHOFACIES TO POTENTIAL FOR MISSISSIPPI VALLEY–TYPE MINERALIZATION IN THE HARRISON 1°×2° QUADRANGLE

By Timothy S. Hayes (USGS),
James R. Palmer (MGS), Walden P. Pratt (USGS),
Gary W. Krizanich (USGS), John W. Whitfield (MGS),
and Cheryl M. Seeger (MGS)

MAP MF–1994–E

Upper Cambrian rocks in southern Missouri and northern Arkansas have significant potential for hosting MVT ore deposits (see, for example, Ohle, 1990; Pratt and others, 1993b). Each of the previous CUSMAP assessments in the Ozark region identified and mapped certain sedimentary host-rock criteria as diagnostic indicators of MVT deposit types (Pratt and others, 1984; Martin and Pratt, 1991). This report deals with sedimentary host-rock criteria for potential

MVT deposits in the Harrison quadrangle. Preliminary regional lithofacies analysis of proven and potential Cambrian MVT host rocks has resulted in a clearer understanding of stratigraphic relationships and problems (Howe, 1968; Palmer and Hayes, 1989; Palmer, 1990, 1991). We believe that host-rock studies in this region will be more useful if they show both the depositional lithofacies and the classical formations. The two sets of stratigraphic and lithofacies cross sections presented were prepared to show depositional lithofacies (Dunham, 1960) of the Upper Cambrian sedimentary rocks in the Harrison quadrangle, and to show the relation of these lithofacies to the classical regional stratigraphy. The practical application of this study is to permit comparison of the lithofacies mosaic of Cambrian rocks in the Harrison 1°×2° quadrangle with the lithofacies arrangement in the Southeast Missouri lead-zinc district, where the Upper Cambrian Bonneterre Formation is the host rock for major MVT lead-zinc sulfide deposits.

Detailed logging of drill cores and insoluble-residue samples of Upper Cambrian rocks from 11 drill holes in and near the quadrangle has permitted recognition of the following depositional lithofacies: basement-clast sedimentary breccia, fluvial sandstone, marine quartz sandstone, transitional grainstone, shallow ramp, deep ramp, basinal, ooid grainstone, digitate-thrombolite stromatolite boundstone, planar stromatolite boundstone and burrowed carbonate mudstone, and three varieties of crystalline carbonates. Major MVT sulfide deposits in the Southeast Missouri lead-zinc district are hosted by each of these depositional lithofacies, except for the undolomitized basinal and deep-ramp lithofacies and the fluvial-sandstone lithofacies. All other lithofacies are at least locally mineralized to ore grades somewhere in the greater Southeast Missouri district. Thus, on the basis of lithofacies alone—that is, independent of other factors that contribute to the formation of MVT deposits—these lithofacies are favorable as potential host rocks for MVT deposits.

A more important type of lithofacies control on MVT ore deposition pertains to the permeability of the underlying units. In both the Tri-State (Kansas-Oklahoma-Missouri) and Southeast Missouri districts, ores were found adjacent to and 100–400 ft upsection from the pinchouts of shaly, undolomitized rocks of the deep ramp and basinal lithofacies. Pinchouts of these aquitard units are inferred to be locations where laterally migrating ore fluids became unconfined above, allowing the ore fluids to move upward across stratigraphy and eventually to deposit the ores.

A hydrothermal crystalline carbonate facies containing growth-zoned dolomite crystals that are found in rocks throughout the region was also identified (Hayes and others, 1990). Where such zoned dolomite crystals are found in orebodies, they are interlayered with the ore sulfide minerals (Voss and others, 1989), indicating that the hydrothermal dolomites were deposited contemporaneously with the ore minerals.

Thus, three independent host-rock factors affecting MVT ore deposition in the Ozark region are recognized: (1) potentially favorable host rocks for MVT deposits include most of the carbonate lithofacies present, but not shales or shaly limestone aquitards; (2) favorable sites for ore deposition in carbonate host rocks were adjacent to and upsection from shale or shaly limestone pinchouts, or were above windows through the shales or impermeable carbonates; and (3) growth-zoned hydrothermal crystalline carbonates, that can be correlated by staining techniques with sparry dolomites in the orebodies, were probably deposited contemporaneously with the ores and are interpreted to indicate the presence of a component of ore fluids.

On the basis of these three host-rock factors, there are three separate zones of favorability in Cambrian rocks in the Harrison quadrangle. The first is a zone in the Davis Formation and the upper part of the Bonneterre Formation in the northeastern part of the quadrangle (Douglas and Ozark Cos.). The second is a north-south zone of rocks in the Davis Formation and Potosi Dolomite in the eastern part of the quadrangle (Ozark and Marion Cos.). The third is a zone of rocks in the upper part of the Bonneterre Formation in the southeastern part of the quadrangle (Marion, Baxter, and Fulton Cos.). Within each of these three favorable zones, rocks most likely to host MVT ores probably occur within several miles of the limestone pinchouts in map view, and 100–400 ft upsection from the respective pinchouts.

MAPS SHOWING LOCATIONS OF KNOWN MISSISSIPPI VALLEY–TYPE DEPOSITS AND OCCURRENCES OF THE OZARK MOUNTAINS REGION RELATIVE TO LATE CAMBRIAN SHALY LITHOFACIES AND OTHER SHALES

By James R. Palmer (MGS) *and*
Timothy S. Hayes (USGS)

MAP MF–1994–F

The maps and text correlate the synthesized Paleozoic rock stratigraphic and sedimentologic data collected in recent CUSMAP projects to known Mississippi Valley-type (MVT) deposits, as an aid to regional mineral assessment and prospecting. Although the maps cover an area larger than the Harrison 1°×2° quadrangle, they are included in the Harrison CUSMAP Folio because they all have the Harrison quadrangle in common.

Recent studies of the areal and stratigraphic distribution of MVT deposits in the Ozarks, particularly in connection with the CUSMAP program, have shown that deposits tend to be located selectively in limestone host rocks (or in dolostones that were limestone until just before ore fluids arrived), particularly where these host rocks are adjacent to and upsection from pinchouts of aquitards, specifically shale and shaly limestone (Hayes and others, 1990; Palmer and Hayes, 1989). This publication (MF–1994–F), particularly Map E, demonstrates this relationship for the part of the Ozark region that has been covered by the CUSMAP program.

Maps A–D of MF–1994–F show the sedimentation patterns of late Dresbachian through Trempealeauan rocks for the Rolla, Springfield, Harrison, and Joplin 1°×2° quadrangles and adjoining areas, using "slice maps" designed to approximate depositional time slices through the late Cambrian section. (A slice map (Palmer, 1986) shows the generalized distribution of lithofacies in a 10-ft interval located at a stated percent of the distance between two well-marked stratigraphic horizons—hence it illustrates depositional lithofacies along a somewhat irregular surface, projected to the map plane. With the assumption that depositional rates were relatively constant for each map location between the times of the bounding stratigraphic horizons, such slice maps approximate time slices through the sedimentary pile in order to present map views of depositional sedimentary environments at several successive times over the course of sedimentation.) Specifically, these four maps show distributions of basinal and deep-ramp lithofacies, particularly where the rocks are not dolomitized. These facies in the Ozark region were aquitards at the time of region-wide movement of MVT ore fluids (Hayes and others, 1990; Palmer and Hayes, 1989). Map E shows the known MVT occurrences in all ages of host rocks in the region relative to pinchouts of shale or shaly carbonate lithofacies of Cambrian through Mississippian age and relative to faults.

Map E shows that the large-tonnage MVT deposits of the region occur adjacent to pinchouts of shales and shaly limestone aquitards; most of these occur 100–400 ft upsection from the stratigraphically highest pinchouts. This map also shows that most deposits of the central Missouri barite district occur in an area where there are no underlying shaly aquitards.

Map E can be used to identify several additional prospective areas across the region. In the Springfield and, perhaps, Jefferson City 1°×2° quadrangles, about 20 mi east of Springfield and extending to the north, there is an eastward pinchout of undolomitized Davis Formation deep- and shallow-ramp lithofacies rocks (Palmer, 1991, fig. 8). The rocks adjacent to and upsection from this pinchout also contain strongly anomalous amounts of MVT-suite metals in carbonate-rock insoluble residues (Erickson and others, 1985). Palmer (1991) has pointed out that the facies tract along this pinchout in post-Bonneterre Cambrian rocks is very similar to that in the Bonneterre along the Viburnum Trend. On the basis of these assessment criteria, this shale edge appears to be highly prospective for large-tonnage, possibly lead-dominant, MVT deposits.

In the Rolla 1°×2° quadrangle, two extensions of the pinchout of undolomitized Bonneterre rocks appear prospective. The more obvious of the two extends southward and southwestward from the known ores along the Viburnum Trend. This is an area of currently active prospecting. The less obviously prospective area is the limestone-dolostone interface southeast of the "island" of dolomitized Bonneterre that encircles the St. Francois Mountains. The transition there is from whiterock dolostones of the Bonneterre (Lyle, 1977; Howe, 1968) to pink or red Taum Sauk limestones (Howe, 1968; Frank, 1981). Moreover, the limestone-dolostone interface in the Rolla 1°×2° quadrangle has areas of accompanying metal anomalies in carbonate-rock insoluble residues (Erickson and others, 1978).

BEDROCK GEOLOGIC MAP OF THE HARRISON 1°×2° QUADRANGLE

By Mark A. Middendorf (MGS),
Kenneth C. Thomson (Southwest Missouri State University),
Charles E. Robertson (MGS), John W. Whitfield (MGS),
Ernest E. Glick (USGS), William V. Bush (AGC),
Boyd R. Haley (USGS), *and*
John David McFarland III (AGC)

USGS OPEN-FILE REPORT 94–430

MAP I–2548

The rocks exposed in the Harrison 1°×2° quadrangle are exclusively sedimentary. They range in age from Early Ordovician to Middle Pennsylvanian and are represented principally by dolostone and limestone, although sandstone, and to a lesser degree shale, are also present (fig. 3). Bedrock outcrops are common, but of limited areal extent. The bedrock is usually covered by a relatively thin layer of surficial materials.

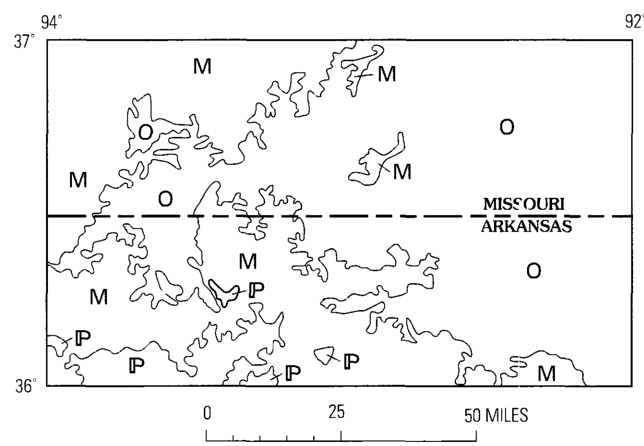

Figure 3. Generalized geologic map of the Harrison 1°×2° quadrangle. ℙ, Pennsylvanian rocks; M, Mississippian rocks; O, Ordovician rocks.

The Lower Ordovician Canadian Series—Gasconade Dolomite, Roubidoux Formation, Jefferson City Dolomite, Cotter Dolomite, and Powell Dolomite—comprises the bedrock of approximately 45 percent of the quadrangle. The lithologies of these formations identify a series of shallowing upward sequences from intertidal to subtidal and supratidal environments on a regional carbonate shelf. Post-Cotter Ordovician units thin and pinch out to the north near the Missouri-Arkansas State line and to the west, owing to modern erosional truncation and stratigraphic diminishment. In the lower Middle Ordovician (Whiterockian and lower Mohawkian) of Arkansas, sandstone is the dominant lithology of the Everton Formation and St. Peter Sandstone. Above the St. Peter Sandstone, the Joachim Dolomite, Plattin Limestone, and Kimmswick Limestone are shallow carbonate platform deposits. The Upper Ordovician Cincinnatian Series is represented in Arkansas by the Fernvale Formation and Cason Shale; the Cason spans the Ordovician-Silurian boundary.

The Silurian of Arkansas is areally limited, represented by the Cason Shale (in part) and the St. Clair Limestone. In both states the Devonian is of limited mappable exposure, comprising the Fortune Formation or Clifty Limestone of the Middle Series and the Chattanooga Shale of the Upper Series.

Mississippian rocks predominantly are variably cherty limestones, very finely to coarsely crystalline, and fossiliferous (abundant crinoid debris and brachiopods); sandstone and shale are subordinate. The general depositional setting for these rocks is shelf margin to platform and shallow basin. Sandstone and interbedded thin shales and limestones compose the Pennsylvanian units and are found as channel to shallow marine deposits. In Arkansas the Bloyd and Hale Formations of the Morrowan Series are overlain by the Atoka Formation of the Atokan Series. In Missouri, the Pennsylvanian units are assigned to the Cherokee Group of the Desmoinesian Series.

The Harrison 1°×2° quadrangle is located in a stable cratonic region on the southwest flank of the Ozark uplift and contains more than 100 mapped faults, the longest of which is about 35 mi long. High-angle normal faults and long, narrow grabens are dominant. A northwest trend in the eastern three-quarters of the northern half of the quadrangle changes to east-west and northeast in the western part. In the northeastern part of the quadrangle, discontinuous faults are located along the trend of the Bolivar-Mansfield tectonic zone, which extends into this quadrangle from the Springfield 1°×2° quadrangle to the north (see Middendorf and others, 1991, and Kisvarsanyi, 1991). Similarly, in the west-central part of the quadrangle, a northwest-trending sinuous fault is located approximately along the trend of the Chesapeake tectonic zone in the Springfield quadrangle. Structures in Canadian post-Roubidoux Formation units are difficult to discern because of the great thickness of the units and the lack of good marker beds. In the southern half of the quadrangle, two major faults and at least one minor fault are discernible; major structural trends in the southern half are northeast and east-west, and a minor west-northwest trend is apparent.

SPECTROGRAPHIC ANALYTICAL DATA

Spectrographic analytical data on insoluble-residue samples from 54 regionally spaced drill holes in the Harrison 1°×2° quadrangle, analyzed for trace-element signatures of the regional stratigraphic units, are available in the U.S. Geological Survey Open-File Reports listed below. Drill-hole numbers are those used on map MF–1994–A (Erickson and others, 1988).

Drill-hole no.	Reference
A7, 13, 44	Erickson and Chazin, 1987a
21, 23, 24	Erickson and Chazin, 1987b
11, 12, 14	Erickson and Chazin, 1987c
7, 9, 10	Erickson and Chazin, 1987d
4, 5, 6	Erickson and Chazin, 1987e
26, 27, 28	Erickson and Chazin, 1987f
1, 2, 3	Chazin and Erickson, 1987a
16, 17, 20	Chazin and Erickson, 1987b
38, 43	Chazin and Erickson, 1987c
31, 32, 34	Chazin and Erickson, 1988a
15, 18, 19	Chazin and Erickson, 1988b
50, 51, 52, 53, 54	Chazin and Erickson, 1988c
59, 60, 61, 63	Chazin and Erickson, 1988d
45, 46, 47, 48, 49	Chazin and Erickson, 1988e
55, 56, 57, 58	Chazin and Erickson, 1988f
64, 65, 66, 67	Chazin and Erickson, 1988g

JOPLIN 1°×2° QUADRANGLE, KANSAS AND MISSOURI

The Joplin 1°×2° quadrangle CUSMAP project was formally begun in October 1983 as a cooperative between the U.S. Geological Survey (USGS), the Kansas Geological Survey (KGS), and the Missouri Geological Survey (MGS). Field work was completed by late 1988, and the assessment meeting was held in Nevada, Missouri, February 14–15, 1989. The first formal publication to result from the project was a summary geochemical map of the quadrangle (Erickson and others, 1990); the last publication, the geologic map, is still in press at this date. Results of most phases of the project were presented at a public meeting in St. Louis, Mo., in April 1989 (Pratt and Goldhaber, 1989, 1990). Directly involved in project operations at various times were 10 geoscientists of the USGS, 8 of the KGS, and 12 of the MGS.

The Joplin CUSMAP folio is not a single entity but rather a set of maps published individually, all covering the

Joplin 1°×2° quadrangle and most bearing sequential numbers in the USGS Miscellaneous Field Studies Map (MF) series. These maps show the bedrock geology of the quadrangle, subsurface structural contours on top of the Mississippian carbonates and the Cambrian-Ordovician Arbuckle Group, subsurface geochemistry, geophysics and interpreted basement terranes, an assessment of the resource potential of the quadrangle for Mississippi Valley-type deposits and other minerals, and coal resources and industrial minerals of the quadrangle. Summaries of the content of each of the maps follow, in order of publication; these summaries were prepared in part from the maps and in part from abstracts presented at the St. Louis meeting.

SUMMARY GEOCHEMICAL MAPS OF THE JOPLIN 1°×2° QUADRANGLE

By R.L. Erickson, E.L. Mosier, H.W. Folger, J.H. Bullock, Jr. (USGS), Pieter Berendsen, *and* Mary Daly [Daily] (KGS)

MAP MF–2125–A

Subsurface geochemical studies in the Joplin 1°×2° quadrangle indicate that the abundance of ore-related elements in insoluble residue samples of Paleozoic carbonate rocks is much less than the abundances obtained in the adjacent Springfield and Harrison 1°×2° quadrangles. The geochemical maps show broad low-level anomalous patterns approximately parallel with the regional strike of the sedimentary units in the quadrangle. The patterns show no clear association, however, with known structural or geophysical trends. The summary geochemical map, compiled on a generalized geologic, structure, and aeromagnetic base, shows two broad geochemically anomalous areas. A western area is defined chiefly by anomalous amounts of zinc in Pennsylvanian strata and by anomalous amounts of Cu, Pb, Zn, Ag, Ni, As, and Mo in Cambrian-Ordovician strata. A southeast anomalous area reflects the Tri-State zinc-lead district and is caused by anomalous amounts of zinc in Mississippian strata and by a zinc-lead-rich base-metal suite of elements in Cambrian-Ordovician strata.

Surprisingly, all drill holes in the northeast quadrant of the Joplin quadrangle show anomalous amounts of zinc in Mississippian strata. Most Mississippian-hosted zinc deposits and occurrences are structurally controlled and commonly do not exhibit large lateral halos. This broad consistent pattern suggests that significant potential exists for discovery of concealed zinc deposits beneath relatively thin Pennsylvanian cover in the area, particularly in areas of faulting or brecciation.

Bar graphs in this report show the stratigraphic distributions of anomalous contents of selected metals in insoluble residue samples from each drill hole analyzed as part of the study. The complete analytical data for each hole are given in open-file reports by Bullock and Whitney (1989a-t) and Bullock and Folger (1989a-e, 1990a-k).

INDUSTRIAL MINERALS OF THE JOPLIN 1°×2° QUADRANGLE

By D.A. Grisafe (KGS) *and* A.W. Rueff (MGS)

MAP MF–2125–B

The known industrial mineral resources of the Joplin 1°×2° quadrangle are crushed stone, clay and shale, construction sand and gravel, asphaltic sandstone, and dimension stone. The production value of these resources in 1987, the latest year of complete data as supplied by the U.S. Bureau of Mines, was almost $25,600,000. If finished products such as cement and ceramic products are included, the value is many times that amount.

Crushed stone is the most important of the industrial minerals in the quadrangle, and the resources are large, of high quality, and generally well distributed. Limestone from several formations is the basis of a highly developed cement industry in the western part of the quadrangle and is used extensively throughout the quadrangle for the production of aggregate and aglime. Chert from mine-mill tailing piles associated with the now depleted zinc mines and from a bedrock quarry is used for railroad ballast, aggregate, roofing granules, and abrasives. Clay and shale resources are large and are used in the manufacture of cement, brick, sewer pipe, tile, pottery, and animal feed supplement. Alluvial deposits of sand and gravel are locally important as aggregate but have no significance outside the quadrangle. Small quantities of sandstone and limestone are produced in Kansas for use as dimension stone, and resources are large. As of 1997 there has been no production of asphaltic sandstone for several years, although there are large resources and a record of major past production. Hypothetical resources of industrial sand are available, but there has been no production.

SUBSURFACE STRUCTURAL CONTOUR MAPS ON TOP OF THE MISSISSIPPIAN CARBONATES AND THE CAMBRIAN–ORDOVICIAN ARBUCKLE GROUP IN THE JOPLIN 1°×2° QUADRANGLE

By K.P. Blair, Pieter Berendsen (KGS), *and* C.M. Seeger (MGS)

MAP MF–2125–C

Formation tops from approximately 3,250 wells in the Joplin 1°×2° quadrangle were used to draw structure contour maps on the tops of carbonate rocks of Mississippian age and rocks of the Arbuckle Group of Early Ordovician and

Cambrian age. Preliminary maps for each county in the Kansas part of the quadrangle were drawn to a scale of 1:100,000 with a contour interval of 20 ft, then synthesized along with the Missouri data into a 1:250,000-scale compilation using a 50-ft contour interval.

The subsurface structural geology of the quadrangle is dominated by a number of through-going, northwest-trending fold-fault systems of variable width (Fall River, Chesapeake, and Bolivar-Mansfield tectonic zones). Discontinuous patterns of horsts and grabens along strike suggest wrench motion along these trends. Northeast-trending faults and folds, subordinate to the primary northwest-trending structures, occur throughout the quadrangle. Individual domal culminations and small downwarped depressions occur in patterns suggestive of the interference of two trends of folding.

This report indicates that economically important structures commonly occur at intersections between these two structural trends. For example, the Fredonia anticline is a major horstlike structure situated at the junction of the Fall River tectonic zone (FRTZ) and a prominent, unnamed northeast-trending fold-fault system. Lead-zinc mineralization near Oswego in eastern Labette County, Kans., appears to be located at the intersection of a zone of northeast-trending folds and the FRTZ. Similarly, the Picher lead-zinc field, in the Tri-State district, occurs at the junction of the FRTZ and the major northeast-trending Miami trough. Minor structures also occur along the length of the Chesapeake tectonic zone. The prominent Bolivar-Mansfield tectonic zone may be traced through the quadrangle west into Kansas and east into the Springfield 1°×2° quadrangle. Lead-zinc mineralization associated with the Big Jumbo and Prescott areas in Kansas occurs in this zone.

Many of these major tectonic zones can be recognized on geophysical maps of the Precambrian basement. On the basis of structural analysis elsewhere, we believe that many structures mapped in the Paleozoic carbonate rocks in the Joplin 1°×2° quadrangle are reactivated basement structures.

GEOPHYSICALLY INFERRED STRUCTURAL AND LITHOLOGIC MAP OF THE PRECAMBRIAN BASEMENT IN THE JOPLIN 1°×2° QUADRANGLE

By A.E. McCafferty *and* L.E. Cordell (USGS)

MAP MF–2125–D

This publication contains five different 1:500,000-scale geophysical maps of the Joplin 1°×2° quadrangle: a complete Bouguer gravity-anomaly map, an aeromagnetic-anomaly map, a terrace-density map, a terrace-magnetization map, and a geophysically inferred structural and lithologic map of the Precambrian basement.

Terracing (Cordell and McCafferty, 1989) is a data-processing technique that recasts gridded gravity or magnetic data (transformed to pseudogravity) into inferred physical-property maps. The resulting maps emphasize large, sharply bounded domains of rock density or magnetization. The inferred physical-property boundaries often delineate known geologic features, such as faults, contacts, and intrusive igneous bodies. In this study, the terracing technique was used to define physical-property domains and (or) geologic structures in the Precambrian basement and to infer rock types based on the density or magnetization values within the domain boundaries.

The inferred structural and lithologic map is an interpretation from the synthesis of terrace maps, the aeromagnetic image, and the gravity- and pseudogravity-gradient maxima. Basement lithologies encountered in drill holes can be grouped into three categories: granitic, volcanic (predominantly rhyolite, minor trachyte and andesite), and low-grade metamorphic rocks. The terranes shown on this map are divided into the same general lithologic units. A fourth category, labeled "mafic," is defined on the basis of coincident high density and magnetization values. The traces of the gradient maxima and terrace-domain boundaries were used as convenient boundaries to indicate changes from one lithologic terrane to another.

This study found that an older metamorphic terrane can be fairly confidently mapped on the basis of the distinct magnetic texture seen in the magnetic image, and this terrane extends farther south than previously supposed (Sims, 1990).

Approximately 30 new probable granite plutons were identified, as were 7 major possible mafic bodies. However, because the mafic bodies are identified primarily by their high density, an alternate hypothesis for the dense sources is a thinner body of ultramafic rock, or, locally, an even thinner massive hematitic body similar to that in the Olympic Dam Cu-U-Au-Fe deposit in Australia (Roberts and Hudson, 1983; Hauck, 1990).

An alternative interpretation of the aeromagnetic map of the Joplin 1°×2° quadrangle, based on work done as part of the CUSMAP project, was published by the Kansas Geological Survey (Berendsen and Blair, 1991) but is not a part of the CUSMAP folio.

ASSESSMENT OF THE JOPLIN 1°×2° QUADRANGLE FOR MISSISSIPPI VALLEY–TYPE DEPOSITS AND OTHER MINERALS

By W.P. Pratt, T.S. Hayes, R.L. Erickson (USGS), Pieter Berendsen (KGS), *and* E.B. Kisvarsanyi (MGS)

MAP MF–2125–E

The Joplin CUSMAP assessment, completed early in 1989, incorporated a major change in philosophy of the model for Mississippi Valley-type (MVT) lead-zinc deposits from the previous CUSMAP assessments in this region. Continuing studies of carbonate facies indicate that the critical lithologic factor for MVT deposits is not the favorability of a particular carbonate facies, but rather the unfavorability of shaly ramp and basinal facies aquitards; all other lithofacies are favorable for MVT deposits, particularly where they are adjacent to and upsection from a shale pinchout. Applying these criteria to the Joplin quadrangle, the CUSMAP assessment team identified two areas, one in the east-central and one in the southwest part of the quadrangle (fig. 4, areas A, B), considered to have moderate potential for undiscovered MVT deposits in Cambrian-Ordovician rocks. In Mississippian rocks, the assessment criteria confirm a high potential for the area of the Tri-State district and a high potential for an area of known mineralization north of Oswego, Kans. (fig. 4, area C). Of greater interest, the criteria also indicate, with a moderate level of certainty, an area of high potential in the northeastern part of the quadrangle (fig. 4, area D) and another area of high potential north of Coffeyville, Kans. (fig. 4, area E). The potential for significant MVT deposits in the Pennsylvanian rocks is extremely low.

Alkalic and ultrapotassic lamproite dikes and sills intrude Pennsylvanian rocks at Rose dome and Silver City dome (fig. 4, points R, S). Lamproite of the same composition as these is the host rock in the Argyle mine, one of the richest diamond mines in Australia; consequently some potential for diamonds may exist at Rose and Silver City domes. The lamproite sill at Silver City dome has been considered as a possible source for vermiculite, bauxite, chromite, and road ballast since the 1940s. A mining and processing operation produced insulating material from 1961 to about 1966. Soft weathered lamproite has been mined continually since 1982; 98 percent of the material is used as an animal feed additive and pellet binder, and the remainder in specialty applications.

In the Precambrian basement, two areas in the Joplin 1°×2° quadrangle are judged favorable for the occurrence of undiscovered Olympic Dam-type deposits (iron oxide-rich deposits containing anomalous concentrations of copper, uranium, gold, silver, and rare-earth elements) (Hauck, 1990). One is an area of volcanic rock in Cherokee Co., Kans., in the south-central part of the quadrangle (fig. 4, area F); the other is a sequence of red clastic rocks in the graben defined by the Bolivar-Mansfield and Chesapeake tectonic zones, in the northeast part of the quadrangle (fig. 4, area G).

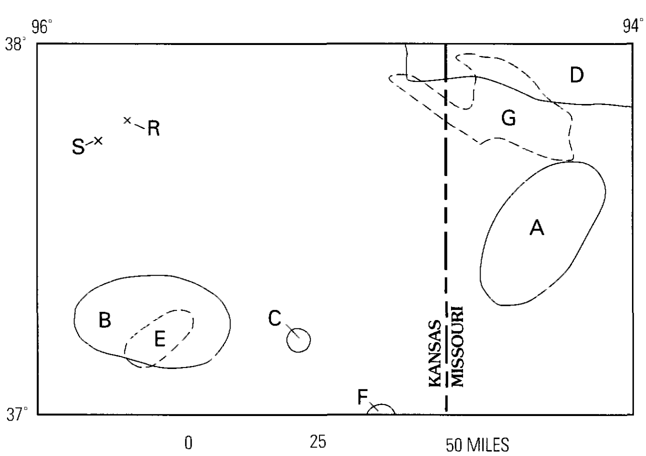

Figure 4. Map showing areas of potential for Mississippi Valley-type (MVT) deposits and other minerals in the Joplin 1°×2° quadrangle. Letters A–G refer to text; R, Rose dome; S, Silver City dome.

COAL RESOURCES OF THE JOPLIN 1°×2° QUADRANGLE

By L.L. Brady (KGS), L.M. Nuelle (MGS), D.B. Haug (KGS), D.C. Smith, J.L. Bostic, *and* J.C. Jaquess (MGS),

MAP I–2426–A

Coal beds are widespread in the Joplin 1°×2° quadrangle in the Pennsylvanian Cherokee Group everywhere but in the southeastern part of the quadrangle where rocks older than Pennsylvanian are exposed. A calculated 5,090 million short tons of coal resources are present at depths less than 100 ft and having a bed thickness of 14 in. or more. The Mineral, Weir-Pittsburg, Rowe, Bevier, and Croweburg coal beds contain the largest amounts of strippable resources. Thirteen additional coal beds also have strippable resources in the quadrangle.

Deep coal resources, those deeper than 100 ft and generally lying west of the outcrop belt of the Cherokee Group, represent more than 22 billion short tons of coal resources. Twenty-nine different coal beds were recognized that are thicker than 14 in. The coal beds with the largest resources include the Bevier, Riverton, Mineral, Weir-Pittsburg, and the Croweburg coals. Deep coal resources that exceed 42 in. in thickness total approximately 800 million short tons.

Mining of coal at seven mines in the quadrangle amounted to 1.032 million tons in 1988, with coal strip mined from the Rowe, Drywood, Weir-Pittsburg, Mineral, Croweburg, and Bevier coal beds. The coal is mainly used for power generation, but large tonnages are also used for cement manufacture. Most of the coal is high-volatile A or B bituminous (HvAb or HvBb) in rank. Generally, the coals are considered to be medium to high sulfur, but a low-to-medium sulfur (0.82–2.43 percent S), unnamed coal bed is present in Missouri.

BEDROCK GEOLOGIC MAP OF THE JOPLIN 1°×2° QUADRANGLE

By J.R. McCauley (KGS), D.C. Smith, *and* C.E. Robertson (MGS)

MAP I–2426–B

The Joplin 1°×2° quadrangle straddles the Kansas-Missouri boundary. West-to-northwest dips in the bedrock reflect the quadrangle's location on the Prairie-Plains homocline of the northwest flank of the Ozark dome, the area's dominant structural feature.

The oldest rocks, exposed only in the northeast corner of the quadrangle, are Canadian (Lower Ordovician) dolomites of the Jefferson City and Cotter Formations (fig. 5). These are overlain unconformably by limestones and shales of Mississippian (Kinderhookian) age. Osagean limestones of the Burlington and Keokuk Limestones overlie Kinderhookian strata and crop out in isolated patches in the southeast corner of the quadrangle. Meramecian limestones belonging predominantly to the Warsaw Formation overlie the Osagean limestones and crop out in a wide band trending to the northeast from the southeastern corner of Kansas. Chesterian rocks are limited to scattered exposures in the Joplin area. Pennsylvanian shales and sandstones of the Atokan and Desmoinesian Cherokee Group and minor limestones and economically important coal beds form a broad outcrop belt from the south-central part to the northeast corner of the quadrangle.

West of the Cherokee Group outcrops are alternating limestones and shales and scattered channel sandstones of the Desmoinesian Marmaton Group; Missourian Pleasanton, Kansas City, and Lansing Groups; and Virgilian Douglas and Shawnee Groups of Pennsylvanian age. These rocks form a series of subparallel northeast-trending outcrop bands that are progressively younger to the northwest and culminate with the Deer Creek Limestone, the youngest Paleozoic formation in the quadrangle. Outcrops are characterized by gently dipping east-facing cuestas formed on the erosionally resistant limestones.

Two major northwest-trending fault zones cross the quadrangle. The Bolivar-Mansfield fault system crosses the extreme northeast corner, and the Chesapeake diagonally bisects the Missouri portion of the quadrangle. Many minor structures, including the Dederick-Eldorado Springs dome in the northeast, also occur in the quadrangle. The Rose and Silver City domes are laccoliths; outcrops of Cretaceous lamproite at the latter dome are the youngest bedrock and the only igneous rock exposed in the quadrangle.

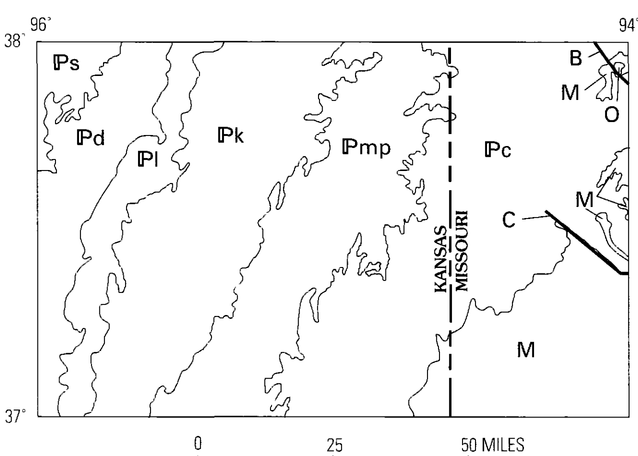

Figure 5. Generalized geologic map of the Joplin 1°×2° quadrangle, Kansas and Missouri. B, Bolivar-Mansfield fault system; C, Chesapeake fault system. O, Ordovician rocks. M, Mississippian rocks. IP, Pennsylvanian rocks: IPc, Cherokee Group; IPmp, Marmaton and Pleasanton Groups; IPk, Kansas City Group; IPl, Lansing Group; IPd, Douglas Group; IPs, Shawnee Group.

SPECTROGRAPHIC ANALYTICAL DATA

Spectrographic analytical data on insoluble-residue samples from 112 regionally spaced drill holes in the Joplin 1°×2° quadrangle, analyzed for trace-element signatures of the regional stratigraphic units, are available in the U.S. Geological Survey Open-File Reports listed below. Drill-hole numbers are those used on map MF–2125–A (Erickson and others, 1990).

Drill-hole no.	Reference
1, 2, 3	Bullock and Whitney, 1989a
4, 5, 6	Bullock and Whitney, 1989b
7, 8, 9	Bullock and Whitney, 1989c
10, 11, 12	Bullock and Whitney, 1989d
16, 17, 18	Bullock and Whitney, 1989e
33, 34, 35	Bullock and Whitney, 1989f
13, 14, 15	Bullock and Whitney, 1989g
19, 20, 21	Bullock and Whitney, 1989h
22, 23, 24, 25, 26	Bullock and Whitney, 1989i
27, 28, 29	Bullock and Whitney, 1989j
30, 31, 32	Bullock and Whitney, 1989k
39, 40, 41, 42	Bullock and Whitney, 1989l
43, 44, 45	Bullock and Whitney, 1989m
36, 37, 38	Bullock and Whitney, 1989n
53, 54, 55	Bullock and Whitney, 1989o
56, 57, 58	Bullock and Whitney, 1989p
49, 51	Bullock and Whitney, 1989q
59, 60, 61	Bullock and Whitney, 1989r
62, 63, 64	Bullock and Whitney, 1989s
46, 47, 48	Bullock and Whitney, 1989t
71, 72, 73, 74	Bullock and Folger, 1989a
75, 76, 77, 78, 79	Bullock and Folger, 1989b
125, 126, 127	Bullock and Folger, 1989c
128, 129, 130	Bullock and Folger, 1989d
131, 132, 133	Bullock and Folger, 1989e
103, 104, 105	Bullock and Folger, 1990a
106, 107, 108	Bullock and Folger, 1990b
109, 110, 111	Bullock and Folger, 1990c
112, 113, 114, 115	Bullock and Folger, 1990d
116, 117, 118	Bullock and Folger, 1990e
119, 120, 121	Bullock and Folger, 1990f
122, 123, 124	Bullock and Folger, 1990g
68, 69, 70	Bullock and Folger, 1990h
65, 66, 67	Bullock and Folger, 1990i
100, 101, 102	Bullock and Folger, 1990j
134, 135, 136	Bullock and Folger, 1990k

ABSTRACTS PERTAINING TO THE HARRISON AND JOPLIN 1°×2° QUADRANGLES (Excluding topics discussed in the preceding summaries) reprinted from Pratt and Goldhaber, 1990, listed alphabetically by first author

TECTONIC AND STRATIGRAPHIC CONTROL OF SUBSURFACE GEOCHEMICAL PATTERNS IN THE OZARK REGION

By R.L. Erickson, Barbara Chazin, M.S. Erickson, E.L. Mosier, *and* Helen Whitney (USGS)

Subsurface geochemical studies in four contiguous 1°×2° quadrangles in parts of Missouri, Arkansas, and Kansas and along a north-south transect of drill holes in western Illinois reveal surprisingly consistent regional patterns of distribution and abundance of metals that have important implications for the genesis of Mississippi Valley-type (MVT) deposits. Insoluble residues of "barren" carbonate rocks of Cambrian age throughout this broad area commonly are lead rich and contain an extensive suite of other metals (Zn, Cu, Ni, Co, Mo, Ag, As). This lead-rich metal suite is characteristic of Cambrian-hosted ore deposits in the Southeast Missouri lead-zinc district. Residues of carbonate strata of Ordovician, Mississippian and Pennsylvanian age tend to be zinc rich with respect to lead, and anomalous concentrations of other metals (Cu, Ni, Co, Mo, Ag, and As) are rare.

The widespread occurrence of ore-related metals in insoluble residues of Paleozoic carbonate rocks attests to the passage of metal-bearing fluids through vast areas of the Ozark region. Leach and Rowan (1986) provided compelling evidence that MVT deposits in the Ozark region formed from a single hydrologic system related to fluid migration northward out of the Arkoma basin in response to Ouachita tectonism. Our geochemical data generally support their model, but recently acquired data from drill holes along the west margin of the Mississippi embayment and the Illinois basin suggest that fluids migrating from the Illinois basin and (or) the New Madrid rift zone may have played a significant role in the genesis of the Southeast Missouri lead-zinc district. All of our data, however, suggest that Cambrian strata were the major regional aquifers in the Ozark region for transport of an extensive suite of metals, regardless of which sedimentary basin is favored as a metal/brine source. Further, the geochemical data suggest an explanation for the differences in ore composition (that is, zinc-rich versus lead-rich) between vertically stacked host rocks and between MVT mineral districts in the Ozark region. If we accept the premise that Cambrian strata were the major regional aquifers for fluids, then mineral districts hosted by post-Cambrian rocks could form where geologic structures intersect and tap the Cambrian aquifers. Fluids released up these structures would selectively deposit metal sulfides according to their relative solubility in the presence of reduced sulfur ($Ag<Cu<Pb<Co<Ni<Zn$). Zinc, the most mobile metal in the suite, should travel farther and thus become enriched upward relative to the other metals as the fluid is selectively depleted in the less mobile metals. This process could result in formation of structurally controlled, zinc-rich districts in post-Cambrian carbonate strata (Mississippian-hosted Tri-State and Ordovician-hosted Northern Arkansas zinc districts). Fluids remaining in the Cambrian aquifers would retain their full complement of metals and continue to migrate in Cambrian strata in search of a "depository" for their metal burden. The Cambrian-hosted Southeast Missouri lead-zinc district with its extensive suite of other metals may be such a depository. The implications of the subsurface geochemical patterns are that Cambrian aquifers provided the plumbing system for all Ozark MVT districts, and that the Illinois basin and New Madrid rift zone, as well as the Arkoma basin, may have served as metal/brine sources in the Ozark region.

INFLUENCE OF PRECAMBRIAN TOPOGRAPHY ON LONG-TERM SOLUTION LETDOWN OF OVERLYING CARBONATE SEQUENCES IN THE HARRISON 1°×2° QUADRANGLE

By Ernest E. Glick (USGS)

Maps showing structure contours on the top or bottom of the Boone Formation (Mississippian) in the Harrison 1°×2° quadrangle (Purdue and Miser, 1916; McKnight, 1935; E.E. Glick, unpub. data) indicate the presence of apparently randomly scattered domes and basins that generally cannot be attributed to any known tectonic event. These features range in size from about 1 mi^2 square mile to more than 10 mi^2. Dip of the Boone generally is less than 2°, but persistence of dip results in several hundred feet of structural relief. Some of these structures are faulted on at least one side.

E.L. Ohle, formerly of Hanna Mining Co., suggested that each Boone high probably is underlain by a Precambrian basement high. This proposed cause-and-effect relationship assumes that structural relief can result from differential deposition, compaction, or solution. Boone structural anomalies, however, could not have been caused by differential deposition and compaction that was completed in pre-Boone time. Consequently, differential solution is my favored hypothesis.

Two fundamentally different processes must be considered in looking for the cause of this carbonate solution: (1) hot brine invaded the area during the time of mineralization (shown by fluid inclusions in crystals), and (2) the original marine salt, as well as the brine of mineralizing solutions, has been flushed out during the past 250 m.y. (million years).

J.R. Palmer has observed (Missouri Geological Survey, oral commun., 1989) that essentially all of the dissolution noted in rock core from this area predates the lead-zinc mineralization. Block faulting during Late Mississippian time (Glick, this report) and extension faulting during Middle Pennsylvanian time also predate mineralization. Some basins and domes may have begun to form by differential solution during mineralization, and the process may have continued slowly during the following 250 m.y. of erosion. At least shallow solution is still in progress.

If the basins and domes are indeed indicative of Precambrian topography, this concept offers access to a key factor in mineral deposition. One hole drilled on the side of a Boone high 12 mi southeast of Harrison reveals Lower Ordovician rocks on Precambrian basement in an area where several hundred feet of Cambrian rocks would be expected.

LATE MISSISSIPPIAN HIGH-ANGLE REVERSE FAULTING IN THE SOUTHWESTERN HARRISON 1°×2° QUADRANGLE—IMPLICATIONS FOR UNDERGROUND GAS STORAGE

By Ernest E. Glick (USGS)

Purdue and Miser (1916) described thinning of the Fayetteville Shale (Chesterian) across three antiformal structures in the southwestern quarter of the Harrison 1°×2° quadrangle. Contours drawn on top of the underlying Boone Formation (Mississippian) clearly reflect more structural closure than do contours drawn on horizons within the overlying Pennsylvanian sequence.

One of these structures, the Carrollton dome, was selected as a potential gas-storage site by the Arkansas Western Gas Company. In the early 1960's gas was injected into the Gunter Sandstone Member of the Gasconade Dolomite, which is at the base of the Ordovician sequence—here at a depth greater than 2,000 ft. The initial bubble of gas escaped the injection area, and J.M. Clark, a geologist with the Arkansas Western Gas Company, began an appraisal of the site to determine whether gas could be stored there. He found (oral commun., 1966) that the structure is complicated by a largely concealed pre-Morrowan fault. One fortuitously located drill hole cut duplicate sections of the Boone Formation (one on each side of the fault) that indicate high-angle reverse displacement. The eastern block, containing the prospective gas reservoir, overrides the western one.

As shown by Purdue and Miser, the area was tectonically active during Chesterian deposition; that is, selected areas were arched and uplifted several hundred feet, producing structures without a common trend. This suggests simultaneous regional marine deposition and local block-faulting at depth. Near-surface layers were broken locally but generally were only flexed; however, no blocks overlain by anomalously thick Fayetteville sequences have been specifically identified.

Even though the structures and reservoir rocks of this area appear appropriate for gas storage, an apparently connected fresh-water column from the surface to the basement—well below sea level—suggests an intercommunicative hydraulic system. Scattered artesian flows, however, indicate that some aquifers are confined, even in sequences without shale beds.

Other local structures may offer promise for gas storage; possible deeper reservoirs may have a Cambrian shale cap or may be in closed structures capped by younger shales. If the Carrollton dome gas bubble can be located, it will define a storage reservoir in an unexpectedly complex structure that has no convincing shale cap.

CORRELATION OF HYDROTHERMAL DOLOMITE GENERATIONS ACROSS THE MISSISSIPPI VALLEY-TYPE MINERALIZING SYSTEM OF THE OZARK REGION

By Timothy S. Hayes (USGS), James R. Palmer (MGS), *and* E. Lanier Rowan (USGS)

Hydrothermal dolomite generations, correlatable between Mississippi Valley-type (MVT) districts and barren sections elsewhere across the Ozarks, provide important constraints on theories of Ozark region MVT ore genesis. MVT sulfide mineralization in the Ozark region is accompanied by a series of fracture- and vug-crusting or limestone-replacing, coarse, hydrothermal saddle dolomites, which at many places have the color sequence (1) gray to tan, (2) white, (3) limpid, and (4) pink. These color zones generally correlate (by potassium ferricyanide staining) with zone I, tan and white; zones II and III, limpid; and zone IV, pink, of the cathodoluminescent microstratigraphy of Voss and Hagni (1985) and Rowan (1986). Interlayering of the paragenetically late dolomite crusts and ore sulfides in orebodies of the Southeast Missouri, Northern Arkansas, and Tri-State districts allows correlation of sulfide stages between districts and demonstrates that a single, interconnected mineralizing system existed across the region at all stages. The dolomite crusts also occur remote from ore, across the region and throughout the stratigraphy, interlayered with trace-metals-anomalous pyrite, marcasite, and pyrobitumens (Erickson and others, 1978, 1985). The abundance of the hydrothermal dolomite is directly proportional to the trace-metals content of the insoluble residues. Hydrothermal dolomite is relatively scarce within and above shaly aquitards, but is much more abundant above shale-free depositional paleohighs. The regionally ubiquitous hydrothermal dolomites, combined with differences in detail within the paragenetic sequence (such as, near versus remote from ore), indicate that chemical reactions unique to the orebodies occurred at a time when the connected secondary porosity of the entire carbonate section over the whole region was being saturated by ore solutions.

Ozark region MVT host breccias include fault breccias, paleokarst breccias, sedimentary breccias, compactional breccias, and probably other types. Recognition of hydrothermal dolomite allows pre-ore events to be distinguished from ore-stage events and indicates that minerals deposited by the ore fluids and those deposited when local meteoric recharge cooled and diluted the ore fluids are the latest minerals in all rocks of the region. Hydrothermal dolomite correlation demonstrates that the ore stage of every MVT deposit of the Ozarks occurred since Early Pennsylvanian time and probably since 310 m.y. ago (Missourian Series of Upper Pennsylvanian).

MVT ore deposits of the Ozark region formed where ore solutions could, or had to, escape upward, probably under artesian pressure. The same clear relation to fluid movement upward is not everywhere true of the regional insoluble-residue-metals and hydrothermal dolomite anomalies. Both major districts of the Ozark region occur adjacent to and upsection from the pinchout of one or more shaly units. Other Ozark region MVT ores are found where aquitards were structurally breached by faulting or paleokarst collapse, and the ore fluids were allowed to climb section.

METALLIC MINES AND PROSPECTS OF THE HARRISON AND JOPLIN 1°×2° QUADRANGLES

By Michael C. McFarland (MGS), George W. Colton (AGC), *and* James R. McCauley (KGS)

An important element in the appraisal of the mineral resource potential of the Harrison and Joplin 1°×2° quadrangles was the determination of the number and types of known metallic mineral deposits, including their location, character, and significance. This information was compiled from records on file at the individual State surveys. Commodities and ore minerals, modes of occurrence, host-rock lithologies, ore controls, periods of mining activity, and production statistics were summarized for each known or reported mine, prospect, and occurrence. The information was then entered into GS-MODS (Mineral Occurrence Database System), a computerized system developed in the U.S. Geological Survey, expressly for the purpose of organizing, analyzing, and displaying mineral occurrence data. Output included individual site record forms, county summary listings, and map displays at 1:250,000 scale. Map displays were made by merging GS-MODS data with the plot capabilities of GS-MAP and GS-DRAW, which are USGS-developed software used to generate maps and illustrations (Selner and Taylor, 1989a, b). From these record and map sets, a realistic basis was established for determining the type and size of possible undiscovered metallic mineral deposits that might be present in the study areas.

The Harrison 1°×2° quadrangle includes parts of southwestern Missouri and northwestern Arkansas. A total of 983 mines, prospects, and occurrences were inventoried: 642 in Missouri, 341 in Arkansas. Zinc, lead, and copper deposits make up 85 percent of the deposits; sphalerite, galena, and chalcopyrite are the most significant ore minerals. Iron deposits are 15 percent of the total; pyrite, marcasite, limonite, and hematite are the ore minerals. Major mining areas include the Aurora zinc-lead district (Missouri), the Northern Arkansas zinc-lead district (Arkansas), and the West Plains brown iron-ore (limonite) district (Missouri). Mineral deposit types identified in the quadrangle include (1) MVT zinc-lead deposits in cherty Mississippian limestones and cherty Ordovician dolostones and (2) residual brown iron-ore deposits in Ordovician residuum.

The Joplin 1°×2° quadrangle includes parts of southwestern Missouri and southeastern Kansas. A total of 2,850 mines, prospects, and occurrences were inventoried: 2,067 in Missouri, 783 in Kansas. Zinc and lead deposits make up 99 percent of the deposits; the dominant ore minerals are sphalerite, hemimorphite, smithsonite, galena, and cerussite. A few deposits consist of the iron minerals limonite and hematite. The world-class Tri-State zinc-lead district (Oklahoma, Kansas, and Missouri) is in the southeast corner of the quadrangle. Mineral deposit types identified in the quadrangle include (1) MVT zinc-lead deposits in cherty Mississippian limestones and (2) residual brown iron ore deposits in Pennsylvanian and Mississippian residuums.

HEAVY-OIL RESOURCE POTENTIAL OF THE JOPLIN 1°×2° QUADRANGLES

By Bruce W. Netzler (MGS)

Previous heavy-oil studies in Missouri have focused in the Joplin 1°×2° quadrangle where heavy-oil-bearing sandstones are present, although they pinch out westward into Kansas. Heavy oil occurs in sandstones of the Pennsylvanian Cherokee Group, which crops out in the southeasternmost part of the quadrangle and is 100–120 ft below the surface in the northwestern part of the quadrangle. The Cherokee contains four potential reservoir intervals: (1) lower part of the Warner Formation, (2) upper part of the Warner Formation, (3) lower part of the Bluejacket Formation, and (4) upper part of the Bluejacket Formation. The lower part of the Bluejacket and the upper part of the Warner contain most of the potential heavy-oil reserves. The gravity of this oil ranges from 25 to 8 °API, and in the lower ranges the oil is very viscous to nearly solid.

Previous realistic estimates of reserves range from 1.4 to 8.3 billion barrels of oil in place (J.S. Wells, Missouri Geological Survey, unpub. mapping, 1974; Wells and Heath, 1979). The economic cutoff for production of heavy oil in

Missouri is about $20/barrel. Using this amount and a proven recovery rate of as much as 50 percent of oil in place with existing methods, this resource is worth $14–85 billion as of 1989.

A total of 715,000 barrels of oil has been produced in the Missouri portion of the Joplin quadrangle from the beginning of production records in late 1966 through 1988. From 1983 to 1985, more than half of Missouri's total oil production came from heavy-oil deposits in this area.

ORE DISTRIBUTION IN THE MISSOURI AND KANSAS PORTIONS OF THE TRI-STATE DISTRICT OF MISSOURI, KANSAS, AND OKLAHOMA

By Laurence M. Nuelle *and* Michael C. McFarland (MGS)

As part of the Joplin CUSMAP mineral assessment, the Missouri and Kansas portions of the Tri-State district were evaluated for potential ore deposits. The assessment consisted of outlining favorable blocks of ground defined by a set of criteria (Pratt and others, 1993a), plotting mines and prospects (McFarland, Colton, and McCauley, this report), and reviewing ore distribution.

Tri-State district ore bodies are in Mississippian rocks, mostly in the Keokuk Limestone (Osagean) and Warsaw Formation (Meramecian); minor deposits are in the Osagean Reeds Spring Formation and in Chesterian rocks. Beds were assigned letter designations during district exploitation; the lettered beds alphabetically increase in age downward through the stratigraphic succession. Important productive beds were the E, G, H, K (Warsaw Formation), and M and N (Keokuk Limestone), all consisting of cherty limestone or alternating beds of chert and limestone (Brockie and others, 1968).

Ore bodies have three basic geometries: (1) Circle deposits, associated with paleosinkholes, fill curved fracture patterns around the structure's margin, giving a circular appearance in plan view and a truncated cone appearance in cross section. (2) Run deposits occupy narrow shear zones having a long linear appearance; a minority of runs occupy sinuous fracture zones resembling the shape of a meandering channel. (3) Sheet-ground deposits are extensive flat-lying ore bodies having grades that generally do not exceed much over 3 percent combined lead and zinc, about half the grade of other deposits. Sheet-ground mines are irregularly shaped areas mined by the room-and-pillar method.

Most ore bodies are zoned; a central dolomitic core is surrounded by the main ore run, which in turn is surrounded by jasperoid, and finally by unaltered limestone. Sphalerite and galena, the only ore minerals recovered, are present in a ratio of about 5:1. The association of mineralization to jasperoid and dolomite is well documented (for Missouri deposits) by six maps compiled by Thiel (1922). The maps, large and cumbersome, were digitized into a computer file using GSMAP (a U.S. Geological Survey computer drafting program, Selner and Taylor, 1989a, b) so they can be plotted on scales more useful for field work.

Ideas about ore genesis have not changed greatly since the turn of the century. Much current thought is that ore-bearing fluids were transported by aquifers in Cambrian and Ordovician rocks, with overlying shales acting as aquitards; peripheral pinchout of the various shales causes the district to be in a "shale window". The lack of aquitards in the "window" coupled with extensive fracturing allowed ore-bearing fluids to rise and deposit ore minerals upon a decrease in pressure. Much of this was described as early as 1894. The importance of the shale pinchouts was known as early as 1907. The ore deposits are thought to be post-Pennsylvanian because some ore occurs in fractured Pennsylvanian shales that covered the entire district during ore deposition.

REGIONAL UPPER CAMBRIAN LITHOFACIES FRAMEWORK OF SOUTHERN MISSOURI

By James R. Palmer (MGS)

Upper Cambrian rocks in southern Missouri have significant potential for hosting Mississippi Valley-type (MVT) ore deposits. Preliminary regional lithofacies analysis of proven and potential Cambrian MVT host rocks has resulted in a clearer understanding of stratigraphic relationships and problems.

Upper Cambrian rocks are at least 4,700 ft thick near the Reelfoot graben in southeast Missouri and thin gradually toward western Missouri, where they are 700 ft thick. The nature of pre-upper Lamotte Sandstone rocks near and in the Reelfoot graben in Missouri remains largely unknown.

Above the fluvial, alluvial, and marine sandstones of the Upper Cambrian Lamotte Sandstone, the Upper Cambrian sequence comprises a series of transgressive-regressive cycles within a regional carbonate shelf. The regional shelf margin is at the Reelfoot graben. North and northwestward from the graben, facies transitions between intrashelf basinal shales and platform carbonate rocks are characteristic of homoclinal ramps. Some local facies variations indicate, however, that ramps were, at places, distally steepened and that fringing banks existed at places along some ramps.

There are two basic types of Cambrian transgressive-regressive sequences. Type I sequences within the intrashelf basinal areas consist of shallowing-upward cycles, 60–200 ft thick, composed of (1) basinal shale and lime mudstone, wackestone and packstone, grading upward to (2) carbonate mudstone, wackestone, packstone, and grainstone of the ramp and shoal, and locally overlain by (3) platform-peritidal cycles dominated by bedded cryptalgal boundstone. The middle to upper parts of these cycles are mostly dolostone. In contrast, platform core areas have Type II brown to "whiterock" dolostone cycles 20-300 ft or more thick. These have (1) abrupt transgressive bases of packstone or grainstone, (2) ramp or subtidal platform mudstone and wackestone, (3) either a packstone-grainstone shoal or a fringing bank of cyclically bedded cryptalgal boundstone, and (4) emergent-platform cryptalgal laminated to coarsely crystalline and locally brecciated "whiterock" dolostone. In CUSMAP assessments only intrashelf basin shales and ramp shaly limestones have been consistently assigned a low potential for MVT deposits. All other facies, in some geographic and stratigraphic setting, have been rated potentially favorable for MVT deposits.

Because most Cambrian formations were named where the Davis Formation is present and is composed mostly of intrashelf basinal shale and limestone, formation names outside of that intrashelf basin setting, where the sequences are Type I, have little application in the platform core areas, where sequences are Type II. Paleohydrologic studies, and MVT assessments and exploration models, are dependent upon an accurate representation of that regional stratigraphic and sedimentational framework. The first step in understanding the framework is recognition of the relationships between lithofacies and formational type section terms already in use.

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