U.S. DEPARTMENT OF THE INTERIOR
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Mineral-resource assessment maps of the Harrison 1°×2° quadrangle, Missouri and Arkansas

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Pamphlet to accompany
MISCELLANEOUS FIELD STUDIES
MAP MF-1994-D

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Mineral-resource assessment maps of the Harrison 1°×2° quadrangle, Missouri and Arkansas

FOLIO NOTE

This map is the fourth in a folio of maps of the Harrison 1°×2° quadrangle, Missouri and Arkansas, prepared under the Conterminous United States Mineral Assessment Program (CUSMAP). Previously published maps in this folio relate to the geochemistry of the subsurface carbonate rocks (Erickson and others, 1988), the geophysics of the basement terranes (McCafferty and others, 1989), and the mineralization and carbonate lithofacies in the Caulfield district in the eastern part of the Harrison quadrangle (Hayes and others, 1992). Additional maps showing other geologic aspects of the Harrison quadrangle will be published as U.S. Geological Survey Miscellaneous Field Studies Maps bearing the same serial number but with different letter suffixes (MF-1994-E, -F, and so on).

INTRODUCTION

by Walden P. Pratt, U.S. Geological Survey

This report and the accompanying maps present an assessment of the mineral-resource potential of the Harrison 1°×2° quadrangle, as appraised in September 1987. (All subsequent references to the Harrison quadrangle in this report are to the Harrison 1°×2° quadrangle.) The Harrison quadrangle is the third in a series of quadrangles in the southern Midcontinent whose mineral-resource potential is being evaluated under the Conterminous United States Mineral Assessment Program. The first in this series was the Rolla quadrangle, Missouri (Pratt, 1981, 1991; Pratt and others, 1984), and the second was the Springfield quadrangle, Missouri (Martin and Pratt, 1985, 1991). In each of these projects, various members of the CUSMAP team, composed of geologists from the U.S. Geological Survey and cooperating State geological surveys, have compiled a series of maps showing aspects of the geology, geochemistry, geophysics, and mineral occurrences of the quadrangle; finally, in each case the team has met as a group to review the available data and make an overall assessment of the resource potential.

The Harrison CUSMAP project was begun in October 1983 as a cooperative effort between the U.S. Geological Survey, the Arkansas Geological Commission, and the Missouri Department of Natural Resources, Division of Geology and Land Survey. After completion of the various map elements, the assessment meeting was held in Rolla, Missouri, September 29-30, 1987. Although specific authors are identified for the subsequent sections of this report, the first section in particular represents a team consensus, and it is appropriate to name here the members of the entire CUSMAP team:

U.S. Geological Survey—Walden P. Pratt, coordinator; Barbara Chazin, Marjorie S. Erickson, Ralph L. Erickson, Ernest E. Glick, Timothy S. Hayes, and Anne E. McCafferty.

Arkansas Geological Commission—William V. Bush, coordinator; George W. Colton, and John David McFarland III.

Missouri Geological Survey—James A. Martin, coordinator; Joy Lorraine Bostic, Eva B. Kisvarsanyi, Mark A. Marikos, Michael C. McFarland, Mark A. Middendorf, Laurence M. Nuelle, James P. Palmer, Charles E. Robertson, Ardel W. Rueff, Cheryl M. Seeger, Thomas L. Thompson, Heyward M. Wharton, and John W. Whitfield.

Also active in the project but not present at the assessment meeting were Lindrith Cordell, U.S. Geological Survey, and Ira R. Satterfield, Missouri Geological Survey.

Following a brief summary of the geology of the Harrison quadrangle, subsequent sections of this report discuss the potential for eight different categories of mineral resources:

(1) Mississippi Valley-type (MVT) lead-zinc deposits in Cambrian rocks,

(2) MVT deposits in Ordovician and Mississippian rocks (discussed in separate sections for Missouri and Arkansas),

(3) Residual brown iron-ore deposits in surficial materials,

(4) Lead-zinc deposits in sandstone,

(5) Red-bed-evaporite-associated stratabound copper deposits,

(6) Minor deposits of uranium, pyrite, manganese, coal, silver, arsenic, and cadmium in Arkansas,

(7) Industrial minerals, and

(8) Potential mineral deposits (Olympic Dam-type) in Precambrian basement rocks.

In the consensus opinion of the Harrison CUSMAP team, this list includes all the nonenergy minerals for which a reasonable potential exists in the Harrison quadrangle, on the basis of geologic information available in September 1987.

SUMMARY OF GEOLOGY OF THE HARRISON QUADRANGLE

(Modified from Middendorf and McFarland, 1990)

The Harrison 1°×2° quadrangle straddles the Missouri-Arkansas state line, lying in southwestern Missouri and northwestern Arkansas bounded by long. 92°-94° W. and lat. 36°-37° N. (fig. 1). It is immediately south of the Springfield quadrangle and southwest of the Rolla quadrangle, both covered by previous CUSMAP studies.

Basement rocks in the Harrison quadrangle consist of Proterozoic granite, rhyolite, and metamorphic rocks, as described by Kisvarsanyi in a separate section of this report. Overlying the basement in the subsurface is a thick rock sequence composed predominantly of dolostone of Late Cambrian age; from the base up, formations in the sequence are the Lamotte Sandstone and the Bonneterre, Davis, Derby-Doerun (as used by the Missouri Geological Survey and the Arkansas Geological Commission), Potosi, and Eminence Formations (fig. 2).

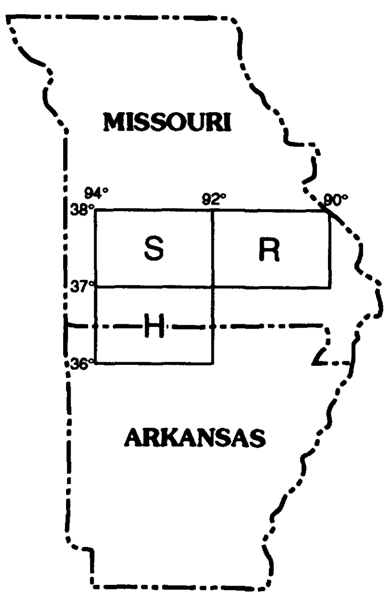

Figure 1. Location of Harrison 1°×2° quadrangle and relation to other CUSMAP quadrangles. H, Harrison; R, Rolla; S, Springfield.

Exposed rocks in the Harrison quadrangle are exclusively sedimentary. They range in age from Early Ordovician to Early Pennsylvanian and are represented principally by dolostone and limestone, although sandstone, and to a lesser degree shale, are also present.

The oldest exposed rocks in the quadrangle, Lower Ordovician dolostone, compose approximately 45 percent of the bedrock (fig. 3); from the base up, Ordovician units are the Gasconade Dolomite, Roubidoux Formation, Jefferson City Dolomite, Cotter Dolomite, and Powell Dolomite. Post-Cotter Ordovician units thin and pinch out to the north near the Missouri-Arkansas state line and to the west, because of erosion and nondeposition. In the lower Middle Ordovician 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 is represented in Arkansas by the Fernvale Formation and Cason Shale (in part); 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 (Middle Ordovician) and the Chattanooga Shale (Upper Devonian).

Mississippian rocks are predominantly variably cherty limestones, ranging from 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 shale and limestone beds compose the Pennsylvanian units and are found as channel to shallow marine deposits. In Arkansas the Hale and Bloyd 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 quadrangle is in the stable cratonic region on the southwest flank of the Ozark uplift. The area has been moderately faulted; high-angle normal faults and long, narrow grabens are dominant. A northwest trend of faults in the eastern three-quarters of the northern half of the quadrangle changes to east-west and northeast trends in the west (see fig. 8). Structures in Lower Ordovician post-Roubidoux units are difficult to discern because of the great thickness and 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 are northeast and east-west, and a minor west-northwest trend is apparent.

<table>
<tr><th rowspan="2">SYSTEM OR EONOTHEM</th><th colspan="2" rowspan="2">SERIES</th><th colspan="3">FORMATION</th></tr>
<tr><th>MISSOURI</th><th colspan="2">ARKANSAS</th></tr>
<tr><td rowspan="3">PENNSYL-VANIAN</td><td rowspan="2">Middle</td><td>Desmoinesian</td><td>Cherokee Group</td><td colspan="2"></td></tr>
<tr><td>Atokan</td><td></td><td colspan="2">Atoka Formation</td></tr>
<tr><td>Lower</td><td>Morrowan</td><td></td><td colspan="2">Bloyd Formation
Hale Formation</td></tr>
<tr><td rowspan="4">MISSISSIPPIAN</td><td rowspan="2">Upper</td><td>Chesterian</td><td>Fayetteville Fm.
Batesville Fm.
Hindsville Fm.</td><td colspan="2">Pitkin Limestone
Fayetteville Fm.
Batesville Fm.</td></tr>
<tr><td>Meramecian</td><td>Warsaw Formation</td><td colspan="2">Moorefield Fm.</td></tr>
<tr><td rowspan="2">Lower</td><td>Osagean</td><td>Keokuk Formation
Burlington Ls.
Elsey Formation
Reeds Spring Fm.
Pierson Limestone</td><td></td><td rowspan="2">Boone Formation</td></tr>
<tr><td>Kinderhookian</td><td>Northview Fm.
Compton Limestone
Bachelor Formation</td><td>St. Joe Limestone Member</td></tr>
<tr><td rowspan="2">DEVONIAN</td><td>Upper</td><td></td><td>Chattanooga Shale</td><td colspan="2">Chattanooga Shale</td></tr>
<tr><td>Middle</td><td></td><td>Fortune Formation</td><td colspan="2">Clifty Limestone</td></tr>
<tr><td>SILURIAN</td><td></td><td></td><td></td><td colspan="2">St. Clair Limestone</td></tr>
<tr><td rowspan="3">ORDOVICIAN</td><td>Upper</td><td>Cincinnatian</td><td></td><td colspan="2">Cason Shale
Fernvale Formation</td></tr>
<tr><td>Middle</td><td>Mohawkian</td><td></td><td colspan="2">Kimmswick Limestone
Plattin Limestone
Joachim Dolomite
St. Peter Sandstone
Everton Formation</td></tr>
<tr><td>Lower</td><td>Canadian</td><td colspan="3">Powell Dolomite
Cotter Dolomite
Jefferson City Dolomite
Roubidoux Formation
Gasconade Dolomite</td></tr>
<tr><td>CAMBRIAN[1]</td><td>Upper</td><td></td><td colspan="3">Eminence Dolomite
Potosi Dolomite
Derby-Doerun Dolomite[2]
Davis Formation
Bonneterre Formation
Lamotte Sandstone</td></tr>
<tr><td>PROTEROZOIC[1]</td><td></td><td></td><td colspan="3">Granite, rhyolite, metamorphic rocks</td></tr>
</table>

[1]Subsurface units
[2]As used by Missouri Geological Survey and Arkansas Geological Commission

Figure 2. Stratigraphic nomenclature for the Harrison 1°×2° quadrangle. Modified from Middendorf and McFarland (1990).

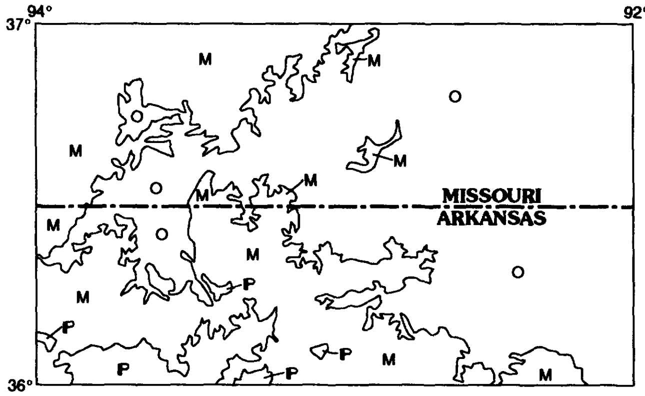

Figure 3. Generalized geologic map of the Harrison 1°×2° quadrangle. ℙ, Pennsylvanian rocks; M, Mississippian rocks; O, Ordovician rocks.

RESOURCE POTENTIAL FOR MISSISSIPPI VALLEY-TYPE DEPOSITS IN CAMBRIAN ROCKS

by Walden P. Pratt, Timothy S. Hayes, and Ralph L. Erickson,
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for the Harrison CUSMAP Team

INTRODUCTION

Mississippi Valley-type (MVT) deposits are defined as predominantly sphalerite-galena replacement and vein deposits (including vug and breccia fillings) occurring in shallow-water carbonate host rocks, generally restricted to certain formations but not restricted to specific beds, and peneconformable but clearly crosscutting—that is, the deposits are epigenetic and strata*bound* but not strati*form*.

The Harrison quadrangle includes parts of several Mississippi Valley-type zinc-lead districts of historic importance, notably the Aurora and Caulfield districts in Missouri (Kiilsgaard and others, 1967, p. 56-61) and the Northern Arkansas district (McKnight, 1935) (fig. 4). The quadrangle also includes part of an area recently reported to have potential for undiscovered MVT deposits, on the basis of geochemical and stratigraphic studies made as a sequel to the CUSMAP studies of the nearby Rolla quadrangle (Erickson and others, 1981). Therefore a systematic assessment of the potential for undiscovered MVT deposits was the first priority in this CUSMAP assessment. This section of the report deals with the resource potential for MVT deposits in Cambrian rocks; the potential for MVT deposits in Ordovician and Mississippian rocks is discussed in the next two sections of the report.

The assessment for MVT deposits consisted of four steps. First, the team agreed on a descriptive model for MVT deposits, on the basis of the known characteristics of MVT deposits in the mining districts elsewhere in this region (Northern Arkansas, Tri-State, and Southeast Missouri). We defined this descriptive model in terms of six geologic "recognition criteria" believed to be required or at least favorable for the presence of a MVT deposit. (Because all the Cambrian formations in the quadrangle are in the subsurface, it was implicit in the selection of these criteria that at least some data on their presence or absence in the quadrangle were available from drill logs and drill samples. The locations of the drill holes used are shown on maps A and B.) Second, we superimposed maps of the quadrangle showing the areal extent of these favorable criteria. Inspection of the stacked overlays

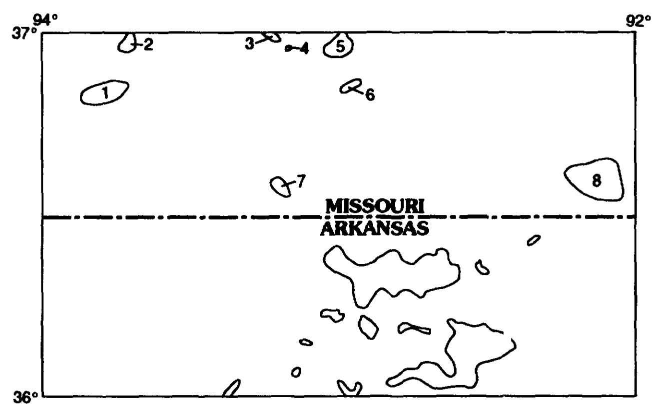

Figure 4. Index map showing zinc-lead mining areas in the Harrison 1°×2° quadrangle (after Erickson and others, 1988). 1, Purdy; 2, Aurora mines; 3, Elk Valley mines; 4, Mary Arnold; 5, Swan Creek; 6, Turkey Creek; 7, Melva; 8 Caulfield mines. All areas in Arkansas are part of the Northern Arkansas zinc district.

showed some areas where all or some of the criteria were present (in varying degrees), and other areas where only a few or none of the criteria were present. Third, we drew outlines around areas containing similar combinations of criteria. This process divided the quadrangle into a number of assessment areas or blocks. Fourth, to each assessment block we assigned levels of potential and certainty for the occurrence of MVT deposits, based on a subjective "gut level" consensus, and using the resource classification developed by Taylor and others (1984). This classification assigns resource categories on the basis of two independent factors: (1) the amount and kinds of evidence suggesting a favorable geologic environment for resource occurrence (the level of mineral potential), and (2) the availability of data (the level of certainty). These factors are combined in a simple matrix (fig. 5) which indicates the class of resource potential and certainty. The Harrison CUSMAP team used this matrix as a guide to assign assessment levels to each outlined area; the assignments are *qualitative* and reflect a team consensus.

Following the approach used in the assessment of MVT deposits in the Springfield quadrangle (Erickson and Chazin, 1991), this part of the Harrison assessment was done separately for two sedimentary "packages"—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.

THE MODEL

A simplified MVT assessment model was used for both the upper and lower sequences, and it consisted of six criteria:

1. **Presence of favorable host formation** (respectively, the upper and lower sequences). This is simplistic but essential. For the upper sequence to have potential for MVT deposits, the upper sequence rocks must be present; likewise for the lower sequence. Source of data: J.R. Palmer, Missouri Geological Survey, and T.S. Hayes, U.S. Geological Survey (unpub. mapping, 1986-87).

2. **Presence of a zone of abrupt changes in depositional lithofacies at ramp facies margins—specifically, a change from any permeable facies to impermeable shaly ramp and basinal facies.** This is believed to be favorable for MVT deposits because the shaly ramp and basinal facies probably retarded the movement of metal-bearing fluids and diverted upward-moving ore fluids to their margins. Thus the permeable rocks on one side of the zone of change are considered favorable and the impermeable rocks on the other side are unfavorable. Source of data: J.R. Palmer and T.S. Hayes (unpub. mapping, 1986-87).

3. **Presence of "favorable geochemistry" (that is, anomalously high amounts of the typical MVT metal suite (Pb-Zn-Ag-Cu-Ni-Co-As-Mo) in insoluble residues of the carbonate rocks).** The use of geochemical analyses of insoluble residues in the Rolla, Springfield, and Harrison CUSMAP studies has been fully documented in Erickson and others (1978, 1981, 1985, 1988; Erickson and Chazin, 1991); the method can be described briefly as follows. Hydrochloric acid-insoluble residues from thousands of drill samples of the carbonate rocks of the region have been analyzed by a semiquantitative six-step spectrographic method. These analyses have revealed, even in rocks that appear to be barren of sulfide ores, a suite of metals (Pb-Zn-Ag-Cu-Ni-Co-As-Mo), characteristic of MVT deposits, whose abundances vary across the region. For the purposes of this study, the results of the analyses were plotted on the maps (Erickson and others, 1988) in anomalous metal feet (AMF). (AMF is a reporting unit derived by normalizing the ratio of a reported anomalous metal content to the threshold of anomalous metal content, multiplied by the length of the sample interval in feet. The thresholds of anomalous metal contents of insoluble residues, in parts per million (ppm), were established by inspection of the data: As, 200; Zn, 200; Pb, 100; Cu, 100; Ni, 70; Co, 30; Mo, 10; and Ag, 1. Thus, reported values of 500 ppm Pb and 3 ppm Ag for a 10-foot interval normalize to 50 AMF of Pb and 30 AMF of Ag.) The AMF can be summed for an entire drill hole, for each formation, or for individual metals. After the AMF values have been plotted on the quadrangle map, form lines (not contours) are drawn on the map to call attention to clusters of similar AMF values. The geochemical patterns thus generated permit comparison and integration with lithologic, structural, and geophysical trends. They are integral to the resource assessment because anomalous amounts of the metal suite are believed to record the presence, at some time, of metal-bearing fluids, which are essential to the formation of MVT deposits.

The "favorable geochemistry" used here for the upper sequence was taken from the map of Erickson and others (1988), and it has been modified slightly to reflect the definition of the upper sequence in use at the time of the assessment (see below under "Upper Sequence"). The "favorable geochemistry" for the lower sequence was taken from unpublished working maps by the same authors. On both maps, subjective formlines were drawn to enclose clusters of drill holes that have higher metal anomalies, independent of other geologic factors such as structural or sedimentary trends. These formlines do not, however,

LEVEL OF RESOURCE POTENTIAL ↑					
	HIGH	U UNKNOWN POTENTIAL	H/L HIGH POTENTIAL	H/M HIGH POTENTIAL	H/H HIGH POTENTIAL
	MODERATE		M/L MODERATE POTENTIAL	M/M MODERATE POTENTIAL	M/H MODERATE POTENTIAL
	LOW		L/L LOW POTENTIAL	L/M LOW POTENTIAL	L/H LOW POTENTIAL N NO POTENTIAL
		LOWEST	LOW	MODERATE	HIGH

LEVEL OF CERTAINTY →

<u>Definitions of levels of mineral resource potential</u>

Low potential: Assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment where the existence of resources is unlikely.

Moderate potential: Characteristics indicate a geologic environment favorable for resource occurrence, interpretation of data indicate a reasonable chance for resource accumulation, and an application of models indicates favorable ground.

High potential: Characteristics indicate a geologic environment favorable for resource occurrence, interpretations of data indicate a high likelihood for resource accumulation, data support models indicating presence of resources, and evidence indicates that mineral concentration has taken place. Assignment of high resource potential requires positive knowledge that resource-forming processes have been active in at least part of the area; it does not require that occurrences or deposits be identified.

Unknown potential: The level of knowledge is so inadequate that classification of the area as high, moderate, or low would be misleading.

<u>Definitions of levels of certainty</u>

Lowest certainty: The available data are not adequate to determine the level of mineral resource potential.

Low certainty: Available data are adequate to suggest the geologic environment and the level of mineral resource potential, but the evidence is insufficient to establish precisely the likelihood of resource occurrence.

Moderate certainty: Available data give a good indication of the geologic environment and the level of mineral resource potential, but additional evidence is needed to establish precisely the likelihood of resource occurrence or the activity of resource-forming processes.

High certainty: Available data clearly define the geologic environment and the level of mineral resource potential, and indicate the activity of resource-forming processes.

Figure 5. Classification diagram for mineral-resource potential and certainty (after Taylor and others, 1984, p. 40-42).

imply a continuum of metal anomaly values. Therefore, in these assessments, the importance of the "favorable geochemistry" in any given area should be considered in relation to the number and locations of drill holes in that area, which are shown on maps A and B. In some areas, as will be discussed in this report, little or no geochemical data are available and the assessment is made without knowledge of the presence or absence of metal anomalies.

4. **Presence or proximity of a limestone/dolostone interface.** This has been a principal prospecting guide in Cambrian-hosted MVT districts in this region—nearly all known deposits are hosted in dolostone, but are close to the limestone interface. It is believed to be equally valid as a criterion for assessment of resource potential. Source of data: J.R. Palmer and T.S. Hayes (unpub. mapping, 1986-87).

5. **Presence or proximity of faults.** This was considered to be a favorable factor in previous models in this region, on the assumption that faults and fractures provide channelways for upward movement of metal-bearing fluids. This criterion was interpreted rather subjectively, without regard to length or orientation of faults; the simple factor considered was the presence or absence of faults, with increasing weight given (qualitatively) for a greater number of faults present in the assessment block under consideration. Source of data: M.A. Middendorf, Missouri Geological Survey, and J.D. McFarland III, Arkansas Geological Commission (unpub. mapping, 1987). (This source includes inferred subsurface faults as well as those mapped at the surface.)

6. **Presence of knobs on the Precambrian surface,** either known from drilling data or, in most cases, inferred from local high-amplitude positive anomalies on the aeromagnetic map. Precambrian knobs are considered to be favorable for the formation of MVT deposits in the Southeast Missouri district because pinchouts of the Lamotte Sandstone against basement knobs helped to localize many ore bodies in the overlying carbonate rocks. As with faults, this criterion was applied qualitatively. Source of data: U.S. Geological Survey, unpublished aeromagnetic mapping (1987), as interpreted by E.B. Kisvarsanyi.

Maps A and B show the distribution of these six criteria through the quadrangle in the upper and lower sequences, respectively. Figures 6-10 show the same information diagrammatically, in a less cluttered form, at a smaller scale (1:2,000,000). Figures 6 and 9 show lithofacies criteria, figures 7 and 9 show geochemical criteria, and figures 8 and 10, structural criteria.

UPPER SEQUENCE—MAP A

The upper sequence consists of all rocks overlying the basal erosional contact of the Sullivan Siltstone Member of the Bonneterre Formation and underlying the basal erosional contact of the Gunter Sandstone Member of the Gasconade Dolomite. It thus includes the upper part of the Bonneterre Formation (the Sullivan Siltstone and Whetstone Creek Members of local usage) as well as the Davis, Derby-Doerun, Potosi, and Eminence Formations. [At the time this assessment was done and in a previous report on this assessment (Pratt and others, 1990), the upper sequence was referred to as "post-Bonneterre Cambrian," which created the paradox of "post-Bonneterre" rocks including the upper part of the Bonneterre Formation itself. That paradox was a part of the puzzle of regional Upper Cambrian lithostratigraphy, which has since been resolved (see Palmer, 1991).] The upper sequence is believed to be a single, uninterrupted depositional sequence of rocks between two erosional diastems or disconformities. Where the Sullivan Siltstone Member is absent, we have interpreted that it has changed facies to marine sandstone, and that an erosional surface separating marine sandstone from underlying fluvial sandstone is the continuation of the Sullivan's basal erosional contact. The upper sequence is present in the subsurface throughout the quadrangle, except for a small area along the central southern edge of the quadrangle (area marked "N" on map A), where it was not deposited in an area of high-standing Precambrian-rock hills. Hence this area has no potential for MVT deposits in the upper sequence.

By inspection of the map data, the quadrangle was divided into nine assessment blocks, as follows (see map A).

Area 1—This area is locally traversed by an extensive limestone/dolostone interface in the Davis and Derby-Doerun part of the upper sequence, and also is part of a zone extending south into Area 2 that contains the most highly anomalous geochemical signature in the quadrangle. It contains only minor faults, and only two inferred Precambrian knobs. It is assigned an assessment level of moderate potential and low certainty (M/L as defined on figure 5).

Area 2—Area 2 is coincident with a zone of abrupt lithofacies changes, specifically changes from deep ramp to cryptalgalaminates and mottled-fabric dolostone in the lower half of the upper sequence. It also includes the continuation of the zone of highly favorable geochemistry

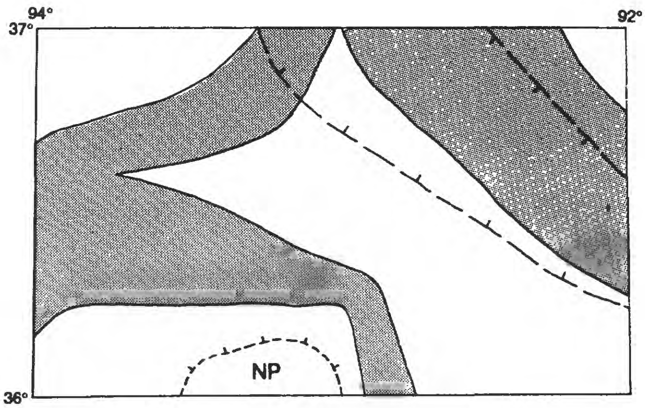

Figure 6. Distribution of lithofacies criteria for MVT deposits in the upper sequence. **Short dashed line**, upper sequence rocks present on hachured side; **NP**, upper sequence rocks not present; **shaded area**, extent of favorable lithofacies, delineated by abrupt lithofacies changes at ramp margins; **long dashed line**, limestone-dolostone interface, hachures on dolostone side.

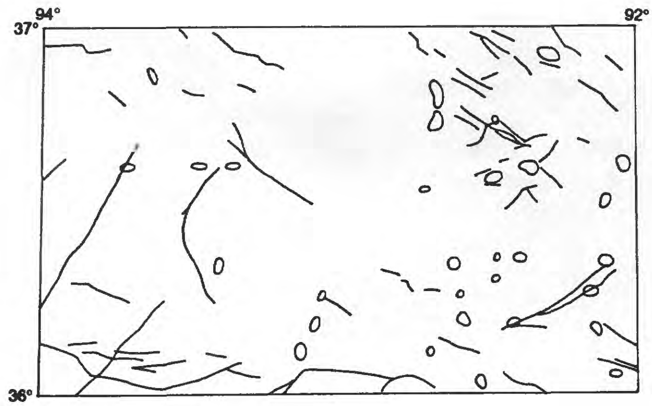

Figure 8. Distribution of structural criteria for MVT deposits in the upper sequence. **Line**, fault; **enclosed area**, Precambrian basement high inferred from aeromagnetic map.

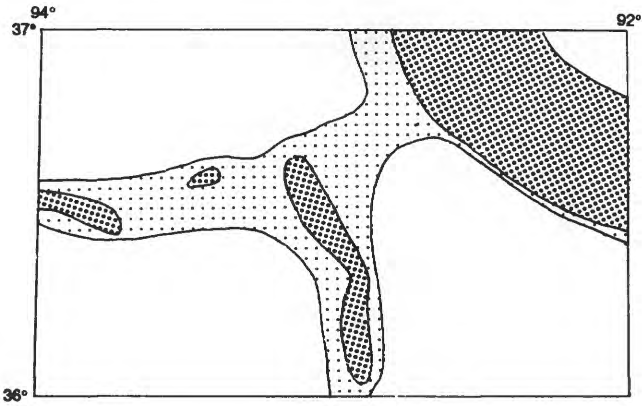

Figure 7. Distribution of geochemical criteria for MVT deposits in the upper sequence. **Heavy stipple**, area of strong geochemical anomalies; **light stipple**, area of moderate geochemical anomalies.

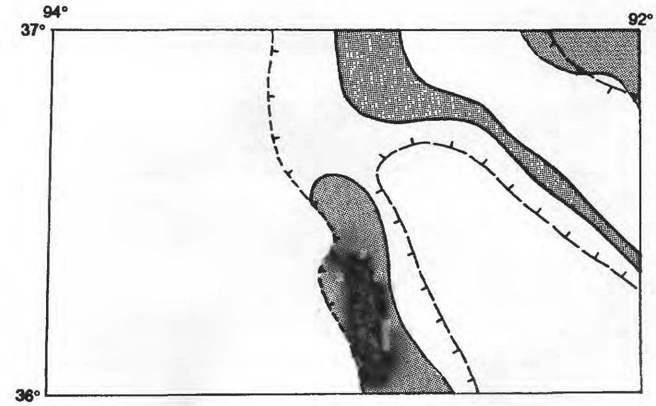

Figure 9. Distribution of lithofacies and geochemical criteria for MVT deposits in the lower sequence. **Short dashed line**, lower sequence rocks present on hachured side; **shaded area**, extent of favorable lithofacies, delineated by abrupt lithofacies changes at ramp margins; **long dashed line**, limestone-dolostone interface, hachures on dolostone side; **stipple**, area of moderate geochemical anomalies.

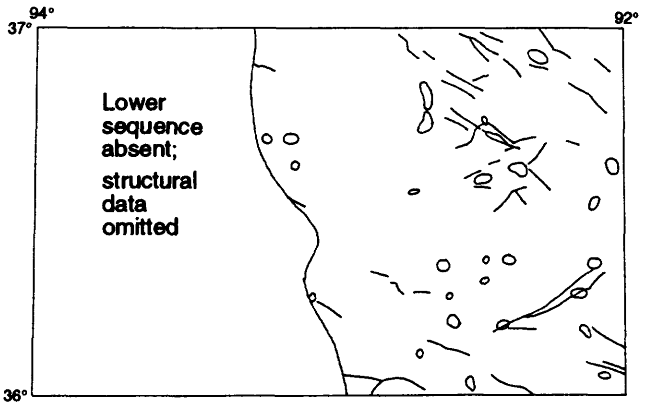

Figure 10. Distribution of structural criteria for MVT deposits in the lower sequence. **Line**, fault; **enclosed area**, Precambrian basement high inferred from aeromagnetic map.

mentioned in the description of area 1. It contains minor faults and no evidence of knobs, and it is assigned an assessment level of high potential and low certainty (H/L).

Area 3—Area 3 is the southeast part of a geochemical trend described by Erickson and Chazin (1991) that extends from the southern border of Missouri northwestward across the adjacent Springfield quadrangle. This trend appears to follow a northwest structural grain bounded on the northeast by the projection of the Bolivar-Mansfield fault zone. The segment of the trend within the Springfield quadrangle was given an assessment of high potential and moderate certainty for MVT deposits in the post-Bonneterre Cambrian rocks (upper sequence). Drill holes S-35 and DH-85 within this trend have the most highly anomalous metal values found in all our subsurface geochemical studies in the Ozark region. In addition to this favorable geochemistry, area 3 contains a combination of favorable lithologies—both abrupt changes from basinal to cryptalgalaminate facies within the Derby-Doerun and Potosi part of the upper sequence, and a limestone/dolostone interface in the subjacent Davis part of the upper sequence. The area also contains numerous faults and inferred Precambrian knobs. With an assessment level of high potential and moderate certainty (H/M), this area ranks as **the most favorable area in the quadrangle for potential undiscovered MVT deposits** in the upper sequence.

Area 4—This area is traversed by a zone of moderately abrupt lithofacies changes. The area is also on the dolostone side of (but mostly distant from) a limestone-dolostone interface, and it contains a few major faults, two small highly favorable geochemical anomalies within a larger moderately favorable geochemical anomaly, and three questionable Precambrian knobs. It is assigned a level of moderate potential and low certainty (M/L).

Area 5—This large area is mostly outside the zones of abrupt lithofacies changes. It is traversed by a limestone/dolostone interface but is mostly on the limestone side, and it contains a few faults and numerous inferred Precambrian knobs. There are no drill holes in the area and therefore no geochemical data, and on this basis it is assigned an unknown potential (U).

Area 6—This small area in the northeast corner of the quadrangle is outside the areas of favorable lithofacies changes and geochemistry, and the area contains one known fault and no inferred Precambrian knobs. It is assigned low potential and moderate certainty (L/M).

Area 7—Like Area 6, this area in the northwest part of the quadrangle is mostly outside the areas of favorable lithofacies changes and geochemistry, although it contains a few faults and one inferred Precambrian knob. It is also assigned low potential and moderate certainty (L/M).

Area 8—Favorable lithofacies changes and some faults are present in this area, but there are no known or geophysically inferred Precambrian knobs. Geochemistry is unfavorable in the eastern part of the area and undetermined in the western part because of the absence of drill holes. The area is assigned a level of moderate potential and low certainty (M/L).

Area 9—The north half of this area is within a zone of moderately abrupt lithofacies changes. The entire area is dolomitic, but it is distant from the limestone interface. Several major faults are present, and a few Precambrian knobs are inferred in the eastern part. The only geochemical data point is unfavorable, but it provides data only for the southwest corner of the area. The area is assigned a level of low potential and low certainty (L/L).

LOWER SEQUENCE—MAP B

The distribution of the six favorable criteria is shown on map B for the lower sequence model. The lower sequence consists of the lower and middle parts of the Bonneterre Formation—the carbonate rocks between the base of the Sullivan Siltstone Member of the Bonneterre and the top of the Lamotte Sandstone. These rocks are not present west of the north-south hachured line slightly west of the center of map B, and accordingly the area labeled "N" has no potential for MVT deposits in the

Bonneterre. The remainder of the quadrangle was divided into eight assessment blocks, as follows.

Area 1—Area 1 contains a zone of abrupt lithofacies changes and is mostly on the dolostone side of an inferred limestone/dolostone interface. It also contains a few short faults, several apparent Precambrian knobs, and the only favorable geochemistry in the lower sequence within the quadrangle—in fact the only favorable geochemical signature in the lower and middle parts of the Bonneterre yet to be found outside of the Southeast Missouri district. The assessment team considers this to be on the borderline between high and moderate potential, with a rating of moderate certainty (H-M/M).

Area 2—This area is traversed by a zone of abrupt depositional lithofacies changes. It is also in dolostone, and it contains major faults and numerous inferred Precambrian knobs. The only geochemical data point (drill hole) in the area is near the south end, and it shows unfavorable geochemistry. This combination of factors forced the team to another split decision: moderate to low potential with low certainty (M-L/L).

Area 3—This small area contains highly favorable lithofacies, a few faults, and one inferred Precambrian knob, but has unfavorable geochemistry. It is assigned a rating of low potential and moderate certainty (L/M).

Area 4—Area 4 coincides with part of a favorable lithofacies zone but contains no faults or knobs and has unfavorable geochemistry; it is rated as having low potential with low certainty (L/L).

Area 5—Area 5 includes the southeasterly extension of the favorable lithofacies zones in areas 2 and 4, and it is relatively close to two separate limestone/dolostone interfaces. It contains two inferred knobs, but it has no faults, and the geochemistry is unfavorable. It is assigned a moderate level of potential and low certainty (M/L).

Area 6—This large area contains numerous inferred Precambrian knobs and several major faults, but Bonneterre lithofacies data and geochemical data are absent because of the lack of deep drill holes; for this reason the area is assigned unknown potential (U).

Area 7—Area 7 is within dolomitic facies and contains a few inferred knobs but contains no abrupt lithofacies changes or known faults, and the geochemistry is unfavorable. It is assigned a rating of low potential and moderate certainty (L/M).

Area 8—Area 8 is within the dolomitic area and it contains a few faults. It is mostly in unfavorable lithofacies and it has unfavorable geochemistry and no inferred knobs. Like area 7, it is rated as having low potential with moderate certainty (L/M).

SUMMARY

In conclusion, three areas in the Harrison 1°×2° quadrangle are considered to have a high or marginally high potential for the occurrence of undiscovered MVT deposits in Cambrian rocks. In the upper sequence (map A), the post-Bonneterre Cambrian rocks and the upper part of the Bonneterre Formation, we assign a high potential with a moderate level of certainty to area 3, a northwest-trending band across the northeast quarter of the quadrangle. We also assign a high potential, but with a low level of certainty, to area 2, a northerly-trending area at the south center of the quadrangle. In the lower sequence (map B), the middle and lower parts of the Bonneterre Formation, we assign a borderline high-to-moderate potential with a moderate level of certainty to area 1, the south-central part of the quadrangle. Thus area 2 of the upper sequence can be considered a doubly prospective part of the quadrangle because it is included within area 1 of the lower sequence.

RESOURCE POTENTIAL FOR MISSISSIPPI VALLEY-TYPE DEPOSITS IN ORDOVICIAN AND MISSISSIPPIAN ROCKS, MISSOURI PART OF HARRISON 1°x2° QUADRANGLE

by Michael C. McFarland, Missouri Geological Survey

Eight mining areas in which Mississippi Valley-type (MVT) base-metal ore deposits have been mined from Ordovician and Mississippian rocks are in the Missouri part of the Harrison 1°×2° quadrangle (fig. 4). Zinc, lead, copper, and iron ores were mined from 1850 to 1955. The main ore minerals were sphalerite, smithsonite, hemimorphite, and galena. Cerussite, pyromorphite, chalcopyrite, pyrite, and marcasite were accessory minerals. Host rocks are mainly Mississippian cherty limestone and Ordovician cherty dolostone. The ore minerals occur as solution-collapse breccia cements, cavity and fracture fillings, horizontal beds, veins, disseminations, and residual surficial masses. Faults and fractures that trend northwest are the dominant structural features in most of the mining areas. The exception is the Aurora mines area (fig. 4), where north-south and east-west trends are prevalent. The mine workings consisted of vertical shafts, underground drifts and stopes, and surface pits. Underground developments were 40-260 ft deep. Surface pits varied from shallow diggings to excavations 300 ft in diameter and 60 ft deep.

Of the eight developed mining areas, only the Aurora mines area could be considered a major deposit, because of the size, number, and grade of ore bodies. Other areas were limited as to quality and quantity of ore. Known production from MVT deposits in Mississippian formations totaled 445,000 tons of metal concentrate, with a zinc:lead ratio of 10:1. The major producer, the Aurora mines area, generated 98 percent of the tonnage from Mississippian rocks. Known production from MVT deposits in Ordovician formations totaled 105,000 tons of ore, with a zinc:lead ratio of 20:1. Minor amounts of copper and iron ores were recovered from these Ordovician-hosted deposits. The Caulfield district (fig. 4), the major producer from Ordovician rocks, yielded 95 percent of the tonnage from Ordovician rocks.

There is a low potential for the existence of additional small MVT base-metal ore deposits in Ordovician and Mississippian rocks in the Missouri part of the Harrison 1°×2° quadrangle. Remaining inferred reserves of low-grade zinc ores (2-7 percent Zn) in the eight mining areas are estimated to be 265,000 tons, most of which is in Mississippian rocks of the Elk Valley mines area (fig. 4); however, Hayes and others (1992) estimate an additional 260,000 tons of low-grade (3 percent Zn) ore at the Alice mine in the Caulfield district. In addition, approximately 60 MVT near-surface mines, prospects, and undeveloped occurrences in Ordovician and Mississippian formations are known to exist outside these mining areas in the Missouri part of the quadrangle. It is believed that most important near-surface deposits have been discovered. There is also a low potential for the existence of any substantial MVT ore deposits in subsurface Ordovician and Mississippian rocks, as indicated by exploratory drill-hole and water-well data. However, subsurface information identifies several areas in the southern half of the Missouri part of the quadrangle where anomalous concentrations of zinc minerals are present in Ordovician rocks. These regions do not coincide with known surface deposits and should be considered potential prospecting sites.

At this time, the aforementioned zinc ore reserves (525,000 tons) in known mining areas appear to be the only MVT resources that may be marginally minable from Ordovician and Mississippian rocks in the Missouri part of the Harrison 1°×2° quadrangle. Improved economic conditions may warrant further exploration of the Aurora and Caulfield areas. Known mines, prospects, and occurrences outside mining areas, as well as areas with anomalous subsurface zinc mineralization, should also be considered for exploration.

RESOURCE POTENTIAL FOR MISSISSIPPI VALLEY-TYPE DEPOSITS IN ORDOVICIAN AND MISSISSIPPIAN ROCKS, ARKANSAS PART OF HARRISON 1°×2° QUADRANGLE

by George W. Colton, Arkansas Geological Commission

Sulfide and sulfide-derived ores of zinc, lead, iron, and copper have been mined in the Arkansas part of the Harrison quadrangle. Records of more than 360 localities where sulfide and sulfide-derived ores were reported have been examined for this study. The records contain data obtained from mines, prospects, a few exploratory drill holes, and cuttings from two water wells. Studies by Branner (1900) and McKnight (1935) provided the major sources of information. Nearly all known metal accumulations are in sedimentary rocks ranging in age from Early Ordovician to Early Mississippian. Zinc and lead sulfides were encountered in trace amounts in rocks of Cambrian age in one exploratory well, and lead sulfide was found in another exploratory well. Both wells encountered more than trace amounts of iron sulfides in Cambrian units. Copper minerals, although associated with many of the zinc and lead occurrences have been mined at only one locality, and small tonnages of iron ore may have been mined at one or two sites, although the records are unclear. The economic potential for deposits of copper and iron is negligible. Consequently the former will be treated very briefly here, and the latter is discussed in the section describing resource potential for brown iron-ore (limonite) deposits in Arkansas.

The following paragraphs discuss the known distribution of zinc and lead ores as related to the stratigraphy of the Paleozoic host rocks and to the effects of local surficial topography. Both are utilized in evaluating the potential of the area for further exploration.

STRATIGRAPHIC CONTROL

The rock units present in the Harrison quadrangle are summarized in figure 2. The stratigraphy is more complicated than figure 2 shows because of many unconformities of both local and regional extent. Some or all of the formations between the base of the Boone Formation and the upper part of the Everton Formation may be missing in parts of the study area.

The stratigraphic distribution of zinc, lead, and copper ores is far from uniform. For example, there are no known occurrences of these ores in Devonian or Silurian rocks, or in Ordovician rocks younger than the Everton Formation. As another example, about 61 percent of all zinc occurrences are in the Everton Formation.

In order to show the high degree of stratigraphic control on sulfide ores in the Harrison quadrangle, the relative areas of outcrop of the map units on the State geologic map (Haley and others, 1976) were determined by point count. The results are shown in figure 11. The most extensively outcropping unit is the Lower Mississippian Boone Formation (map unit Mb), which occupies about 33 percent of the Harrison quadrangle. Next in order of areal extent are the Jefferson City and Cotter Dolomites (map unit Ocjc) followed by the Everton Formation and St. Peter Sandstone (map unit Ose).

The affinity of the mineralizing fluids for specific rock units is seen by comparing figures 11 and 12. Starting with zinc, by far the most commonly mineralized part of the succession is the Middle Ordovician Series, which comprises the Everton, St. Peter, Joachim, Plattin, and Kimmswick Formations. Of these five formations, only the Everton has been reported to be mineralized. In other words, about 61 percent of all known occurrences of zinc minerals in the Harrison quadrangle are in the Everton (fig. 12), even though it (together with the overlying St. Peter) occupies only 16 percent of the area (fig. 11). The next most commonly mineralized part of the succession is the Lower Ordovician Series. Of its three formations, zinc occurrences are equally divided between the Cotter and Powell Dolomites. The Jefferson City Dolomite is barren. However, only about 9 percent of all known zinc occurrences are in the Mississippian part of the succession (fig. 12), and all of those are restricted to the Boone Formation. The other Mississippian formations are barren.

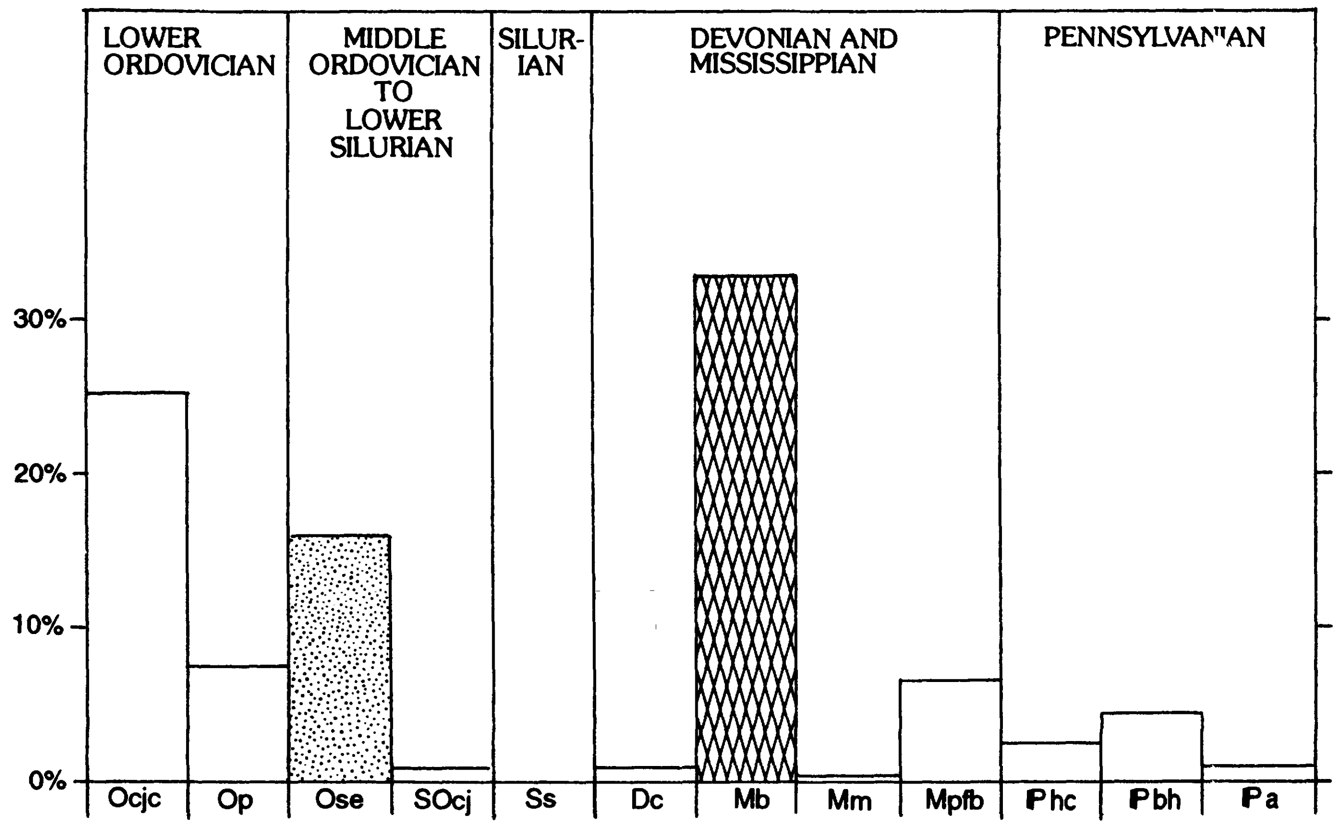

Figure 11. Histogram for the Arkansas part of the Harrison quadrangle showing outcrop areas (in percent) occupied by the map units shown on the "Geologic Map of Arkansas" (Haley and others, 1976). Ocjc is a map unit that includes the Jefferson City and Cotter Dolomites; Op, the Powell Dolomite; Ose, the Everton Formation and St. Peter Sandstone; SOcj, the Joachim, Plattin, Kimmswick, Fernvale, and Cason Formations; Ss, the St. Clair Limestone; Dc, the Clifty and Chattanooga Formations; Mb, the Boone Formation; Mm, the Moorefield Formation; Mpfb, the Batesville, Fayetteville, and Pitkin formations; Phc, the Cane Hill Member of the Hale Formation; Pbh, part of the Hale Formation and the Bloyd Formation; and Pa, the Atoka Formation. Patterns shown in two blocks are for easier comparison with figure 12.

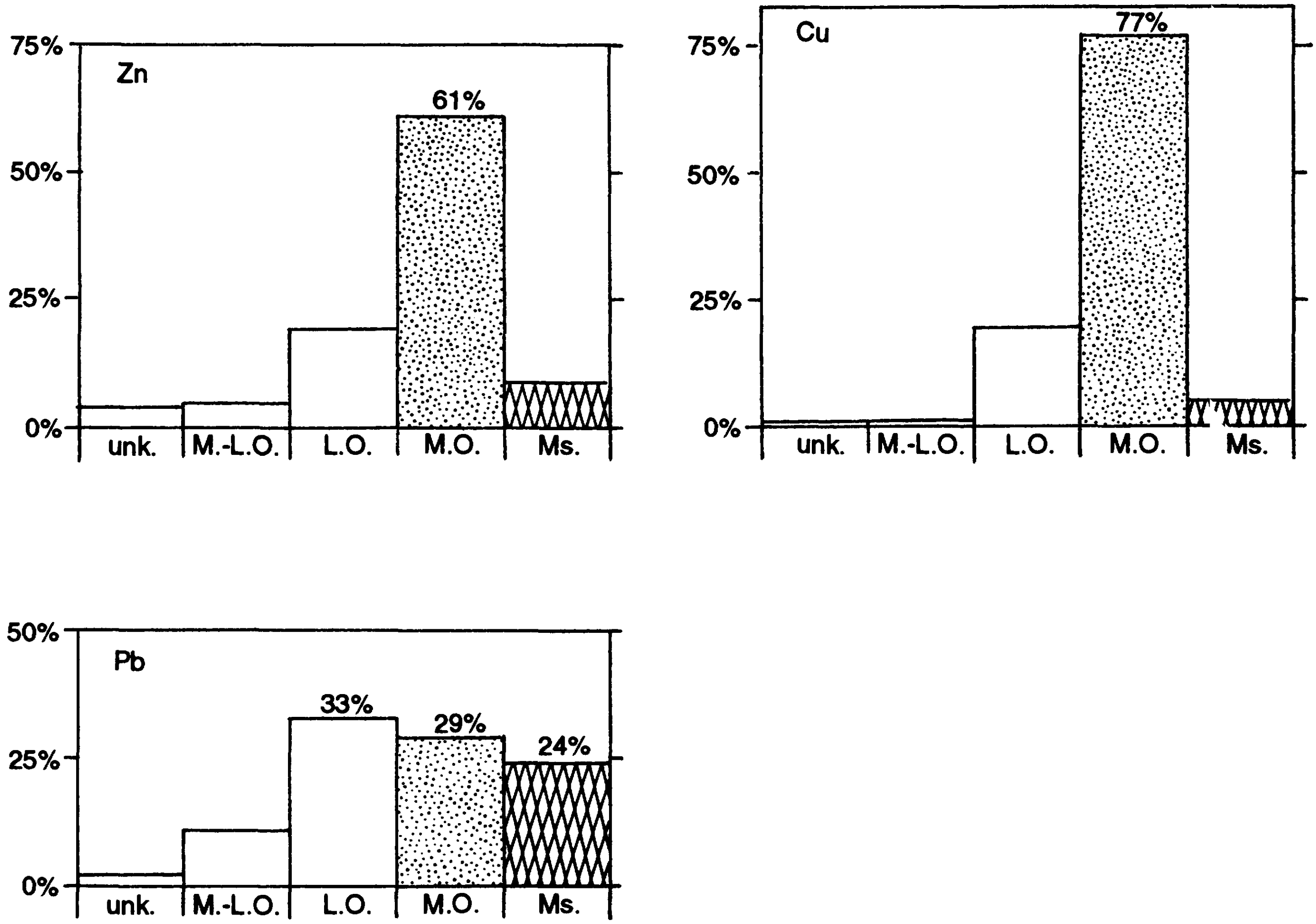

Figure 12. Histograms showing the relation between the frequency of occurrence (in percent) of reported zinc (335 occurrences), lead (90), and copper (139) minerals and age of host rocks. Symbols are as follows: unk—record is so imprecise that age of host rock cannot be determined; M.-L.O.—age is either Early or Middle Ordovician; L.O.—age is Early Ordovician; M.O.—age is Middle Ordovician; Ms.—age is Mississippian. Patterns are for easier comparison with figure 11.

Preference of lead for a specific formation is much less pronounced. Only about 29 percent of the 90 occurrences reported are in the Everton Formation, which is roughly in proportion to its outcrop area (16 percent) in the Harrison area. The other unit combined with the Everton to compose column M.O. in figure 12, the St. Peter Sandstone, is barren. About 33 percent of the lead localities are in the Lower Ordovician Series, mostly in the Powell Dolomite and partly in the Cotter Dolomite. As is true for zinc, the Jefferson City Dolomite is barren of lead. In contrast to zinc occurrences, where relatively few (9 percent) of the occurrences are in the Boone Formation, about 24 percent of the known lead localities are in the Boone. With the exception of one mine where galena is present in the basal part of the Batesville Formation, all other Mississippian units are barren.

The relationship between copper minerals and host formation is very similar to that for zinc minerals. Of the 139 known occurrences of copper-bearing minerals about 77 percent are in the Everton Formation and 17 percent in the Lower Ordovician Series, mostly in the Powell Dolomite. A remarkably small 5 percent of the copper localities are in the Boone (fig. 12), although it is the most widespread formation in outcrop in the Harrison area. The other Mississippian units are barren of copper minerals.

TOPOGRAPHIC CONTROL

Another factor controlling the pattern of distribution of known mineralized localities is the effect of local surficial topography.

Most of the exploration in the Harrison quadrangle was conducted before the end of World War II, without the benefit of systematic exploratory drilling. The developed deposits and prospects were mostly located by prospectors who probably prospected by looking for mineralized outcrops and mineralized float that could be traced back to its point of origin. In this deeply dissected terrain, most natural outcrops are found along the steeper valley walls, especially along the lower walls and in some large valleys along the rim. Discovery of a likely prospect in one valley led to further prospecting along the same valley or in nearby valleys, and perhaps to the eventual development of a mining district.

When mineralized sites whose records provide accurate locations are plotted on large-scale maps, it is apparent that the majority of sites are along the steeper valley walls, commonly in the lower walls and even on the valley floors. Relatively few are in the gentler valleys or on the hills between valleys. Some of the broader plateau-like areas are essentially devoid of mines and prospects.

Another guideline for the early prospectors was the belief that mineralization was controlled by faulting. Many of the faults are along valleys and undoubtedly played a role in determining the location of some valleys. Although a few large mines are on fault planes where there has been much displacement, more are close enough to faults so that the host rocks have been brecciated or otherwise disturbed by faulting. The majority of mines and prospects, however, are in areas where no faults have been recognized. Yet other faults have been mapped that do not follow valleys and along which no mineralization has been found. In brief, faulting is only a partial control of mineralization.

SUMMARY

If further exploration for MVT deposits in Ordovician and Mississippian rocks is undertaken in the Arkansas part of the Harrison quadrangle, the following observations deserve consideration. Of the outcropping units, the Everton Formation should be the most likely target, especially for zinc. For lead, the Cotter and Powell Dolomites and the Boone Formation are the most likely host rocks. Based on the single small deposit of minable copper discovered to date, further discoveries of copper ores seem unlikely. Many areas between valleys probably have not yet been prospected. However, considering the small size of most known ore bodies, a drilling program would require a costly pattern of closely spaced holes.

RESOURCE POTENTIAL FOR RESIDUAL BROWN IRON-ORE (LIMONITE) DEPOSITS IN SURFICIAL MATERIALS DERIVED FROM ORDOVICIAN AND CARBONIFEROUS ROCKS

MISSOURI

by Michael C. McFarland, Missouri Geological Survey

Residual brown iron-ore (limonite) deposits were mined in the Missouri part of the Harrison quadrangle from 1890 to 1958. Most of them were developed in the West Plains Brown Iron District, which is in the northeast quarter of the quadrangle but extends into several adjacent quadrangles. The main ore mineral is limonite with subordinate hematite, pyrite, and marcasite. The vast majority of deposits are in chert and clay-rich residual material derived by dissolution from Ordovician (Canadian) cherty dolostone and sandstone. A very few deposits are in similar material derived from Mississippian cherty limestone and Pennsylvanian sandstone. Most brown iron-ore deposits are surficial limonite rock masses, ranging in size from pebbles to boulders. These surface deposits are a few tens of feet to a few hundred feet in diameter. Some iron deposits are stalactitic limonite rock masses in surficial residual material and thin iron sulfide veins in Ordovician dolostone. Limonite pseudomorphs of iron sulfides (pyrite and marcasite) are common. Faults and fractures trending northwest are the dominant structural features in the mining district. The mine workings consisted of vertical shafts and surface pits. Maximum shaft depths were 90 ft. Surface pits varied from 10 ft in diameter and 3 ft deep to 250 ft in diameter and 35 ft deep.

Known production from residual brown iron-ore deposits in the north half of the Harrison quadrangle totaled 20,000 tons of ore. Remaining inferred reserves are estimated to be 165,000 tons, containing 25-35 percent metallic iron. Considering their small size and scattered occurrence, the deposits are not well suited for large mechanized mining operations, and they are unlikely to be mined on any significant scale in the future.

There is a low potential for the existence of additional small residual brown iron-ore deposits in

Ordovician and Carboniferous rocks in the Missouri part of the Harrison quadrangle. Most major deposits have probably been discovered, because known deposits were readily located by surface concentrations of limonite boulders. The aforementioned iron ore reserves (165,000 tons) therefore appear to be the only brown iron-ore resources that may be minable on a limited scale in the future.

ARKANSAS

by George W. Colton, Arkansas Geological Commission

Iron-sulfide minerals are commonly associated with zinc and lead sulfide and sulfide-derived ores in many of the mines and prospects in the Harrison quadrangle. Marcasite, pyrite, and less commonly chalcopyrite were specifically reported in about 50 of the 365 recorded sites. More than half of these sites are in the Everton Formation (Middle Ordovician). Most of the remainder are in the Cotter and Powell Dolomites (Lower Ordovician) (fig. 13). Only two are in the Boone Formation, although it outcrops over 33 percent of the area of the Arkansas part of the Harrison quadrangle. Nowhere do the iron-bearing minerals exist in large amounts. They are probably present but were probably overlooked as unimportant by prospectors in many of the remaining sites. Limonite and hematite were not reported in most workings, probably because of their ubiquitous nature in the Paleozoic rocks of this area.

In the eastern part of the Harrison quadrangle, in Baxter and Fulton Counties, Stroud and others (1969) reported nine localities where small residual bodies of brown iron ore are present. All of them are west of an area containing the iron deposits of northeastern Arkansas as outlined by Penrose (1892). Logically these form a westward extension of the iron-ore region of Penrose (1892) and a southward extension of the West Plains brown-ore district of Missouri (see preceding section).

Very little information is available for the brown-ore deposits. Most of them are in the Middle Ordovician Everton Formation, but three may be in the Everton or in the Lower Ordovician Cotter or Powell Dolomites. The few analyses available indicate that iron content may be as high as 58 percent, but commonly it is much less. The iron ore occurs as pellets, nodules, boulders, lenses, and beds in clay or in residual chert that is being weathered to clay. It may also occur in pockets in sandstone, chert, limestone, or dolomite. None of the bodies have been adequately explored to determine their size or grade, but individual deposits probably do not exceed a few thousand tons. Stroud and others (1969) report that a few thousand

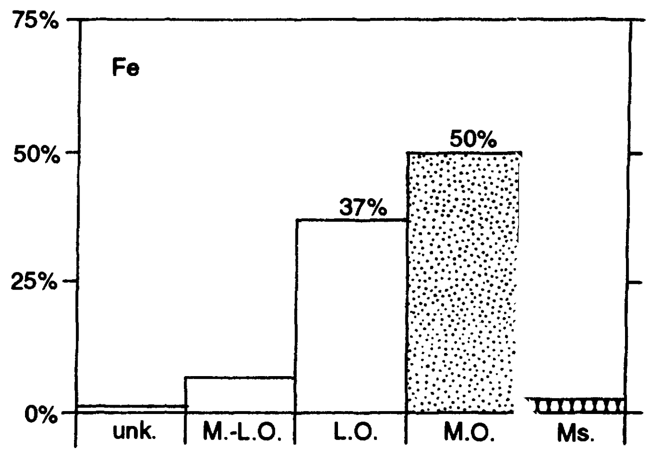

Figure 13. Histogram showing relation between the frequency of occurrence (in percent) of iron-bearing minerals (60 occurrences of oxides and sulfides) and the age of host rocks. Symbols are as follows: unk—record is so imprecise that age of host rock cannot be determined; M.-L.O.—age is either Early or Middle Ordovician; L.O.—age is Early Ordovician; M.O.—age is Middle Ordovician; Ms.—age is Mississippian. Patterns are for easier comparison with figures 11 and 12.

tons of ore were mined in T. 20 N., R. 13 W. in Baxter County in 1956, and that more than 10,000 tons were mined in Fulton County from 1956 to 1958. The exact source of these ores is not known.

RESOURCE POTENTIAL FOR LEAD-ZINC DEPOSITS IN SANDSTONE

by Timothy S. Hayes, U.S. Geological Survey

In the Fredericktown and Indian Creek subdistricts of the Southeast Missouri district, lead-zinc-copper ores occur in sandstone host rocks in the uppermost part of the Cambrian Lamotte Sandstone, immediately underlying MVT deposits in dolostone of the Bonneterre Formation (Snyder and Gerdemann, 1968; Gutierrez and Kyle, 1984). Geologic evidence suggests that the sandstone-hosted ores were formed by the same processes that formed the dolostone-hosted ores (Björlykke and Sangster, 1981), and, at both places, paragenetic observations suggest similar mineral sequences in the sandstone and dolostone host rocks (Horrall and others, 1983). Although thousands of holes have penetrated the upper part of the Lamotte Sandstone in southeast Missouri and in widely spaced areas outside the district, there is no place currently known where lead-zinc minerals exist in the Lamotte without similar mineralization above or nearby in the overlying Bonneterre dolostone. Therefore the potential for Lamotte-hosted lead-zinc deposits in the Harrison quadrangle follows closely the potential (and level of confidence) for carbonate-hosted lead-zinc deposits in the Bonneterre Formation.

RESOURCE POTENTIAL FOR RED BED-EVAPORITE-ASSOCIATED STRATABOUND COPPER DEPOSITS

by Timothy S. Hayes, U.S. Geological Survey

The CUSMAP study of the Springfield 1°×2° quadrangle (to the immediate north) identified a potentially favorable horizon for red-bed-evaporite-associated stratabound copper (RBEASC) deposits, using a descriptive and (preliminary) genetic model. The horizon consists of pyrite-bearing marine rocks that immediately overlie a marine transgressive surface (disconformity) and basal, nonmarine, hematitic sandstone within the Lamotte Sandstone (Hayes, 1991). Although that study concluded that no evidence existed for a "paleoactive" RBEASC system in either the Springfield or the Rolla quadrangles, the presence of the Lamotte Sandstone in the Harrison quadrangle required assessment of the potential for RBEASC deposits there.

In the Harrison quadrangle, a number of deep drill holes penetrated the favorable marine transgressive surface within the Lamotte Sandstone, and using the same RBEASC descriptive model, there was no evidence for a RBEASC mineralizing system. Drill coverage of the favorable horizon in the Harrison quadrangle is sparser than in the Springfield and Rolla quadrangles, so that a large RBEASC deposit could go undetected, but all other observations are similar to the Rolla and Springfield quadrangles: no occurrences of copper minerals are known in this horizon; the basal Lamotte red beds are relatively thin in all drill holes; and thick evaporite sections do not exist anywhere nearby in Paleozoic rocks. On this basis, the potential for large RBEASC deposits in the Harrison quadrangle is considered to be very low, with a moderate level of confidence.

POTENTIAL FOR MINOR DEPOSITS OF URANIUM, PYRITE, MANGANESE, COAL, SILVER, ARSENIC, AND CADMIUM, ARKANSAS PART OF HARRISON QUADRANGLE

by William V. Bush and John David McFarland III, Arkansas Geological Commission

CHATTANOOGA SHALE

The Chattanooga Shale in the Arkansas part of the Harrison quadrangle has little economic potential. It is normally very thin, usually less than 10 ft thick. It may be as much as 50 ft thick locally around Beaver Lake in the southwestern part of the quadrangle, or absent as in the south-central part of the quadrangle. The Chattanooga, a Devonian black shale, has been prospected from time to time for trace metals that are commonly associated with black shale, but without significant results. It has been shown to be locally enriched in radioactive minerals at some localities outside the Harrison quadrangle. A phosphatic sand unit is commonly associated with the Chattanooga Shale but it is too thin to be considered economic in the Harrison quadrangle.

PYRITE

A small deposit of pyrite is in sec. 12, T. 20 N., R. 25 W., in Carroll County near the town of Berryville. It has been estimated to contain approximately 482,000 long tons of ore with an average sulfur content of 24.3 percent (Stroud and others, 1969). This deposit is in fractured beds of dolomite in the Lower Ordovician Cotter Dolomite and is too small for consideration as a potential resource at this time. Limited exploration drilling occurred in the late 1930's, with the drilling of approximately 21 holes. Additional exploration would be necessary to give this site a proper evaluation.

MANGANESE

There are no known manganese deposits in the Arkansas part of the Harrison quadrangle. The nearest occurrence of manganese is approximately 8.5 mi east of the Harrison quadrangle in sec. 34, T. 20 N., R. 8 W., in Fulton County. Here, manganese oxide occurs in nodules and boulders with clay in fractured zones of sandstone in the Cotter Dolomite. About 500 tons were mined in the mid-1950's (Stroud and others, 1969).

COAL

Some coal was mined from a few localities in the south-central part of the Harrison quadrangle (northwest Newton County) during the early part of this century. A total production of 1,500 tons is recorded. A brief drilling program conducted by the Arkansas Geological Commission indicated insufficient quantities for profitable mining. The coal beds are usually thin but may thicken to as much as 19 inches. It is medium volatile, noncoking, bituminous coal. The ash content is about 15 percent and the sulfur content is less than 1 percent.

SILVER, ARSENIC, AND CADMIUM

Trace amounts of various other elements, such as silver, arsenic, and cadmium, have been noted by several researchers, usually as very small sporadic occurrences. These trace elements are fairly common throughout the region. In the future some of them may be economically extracted if mining costs are supported by other resources or if advances in extraction technology occur.

INDUSTRIAL MINERAL RESOURCES

MISSOURI

by Ardel Rueff, Missouri Geological Survey

Industrial mineral resources of the Missouri part of the Harrison quadrangle consist mostly of low-value commodities. Those being produced at present are stone and construction sand and gravel. Resources with potential for future development include clay and shale, industrial sand, and dimension stone.

Clay and Shale

Clay and shale resources are small, are restricted essentially to one county, Barry County, and have very limited economic potential. Raw materials potentially suitable for the manufacture of structural clay products, such as building brick, and for lightweight aggregate, are present in the Chattanooga Shale and the Fayetteville Formation.

The Chattanooga Shale, in a recent testing program, was deemed suitable for the manufacture of structural clay products; it was not suitable for the manufacture of lightweight aggregate. In earlier testing programs utilizing different procedures and different laboratories, some samples were suitable for lightweight aggregate manufacture. In Barry County, the Chattanooga Shale approaches 20 ft in thickness.

Fayetteville Formation shale was not evaluated for ceramic potential because of its thin and erratic distribution. It appears similar to other shale that has been evaluated and found suitable for the manufacture of structural clay products; consequently, it may represent a very speculative resource. The Fayetteville Formation is present at restricted localities in southwestern Barry County.

Construction Sand and Gravel

Resources of sand and gravel suitable for construction purposes exist as alluvial deposits along most streams. The largest and highest quality resources are found in the eastern half of the quadrangle along the main channels and tributaries of Bryant Creek and the North Fork of the White River. Chert gravel and quartz sand derived from surrounding Ordovician bedrock predominate in the eastern part of the quadrangle. In areas of Mississippian bedrock, mostly in the western part of the quadrangle, chert gravel is present but quartz sand is lacking.

In both areas, chert gravel is generally subangular to subrounded, dense, and has a brown patina. Sand normally consists of subangular to subrounded quartz, and it is commonly mixed with gravel. Most stream deposits contain organic material and considerable amounts of clay and silt. Tonnage and composition of individual deposits vary greatly depending on the size and geologic setting of the stream.

The primary reported use of sand and gravel is as aggregate in readymix concrete. Lesser amounts are used in fill and concrete products, and a minor amount as plaster sand. The production of large tonnages of material for fill and road surfacing is probably not reported. Total production of construction sand and gravel in 1985 is estimated at 200,000 tons with a value of approximately $500,000. During 1985, four permanent plants were in operation and numerous additional sites were worked intermittently with portable plants. Production comes from all counties.

Industrial Sand

Several quartz sandstone units that may be considered speculative resources of industrial sand are present in the Harrison quadrangle. Beds that have some resource potential are present in the Roubidoux Formation, the informal Swan Creek sandstone of the Cotter Dolomite, the Batesville Formation, and the

Wedington Sandstone Member of the Fayetteville Formation. Only the Roubidoux and to a lesser extent the Swan Creek are extensive and thick enough to have a realistic potential for development.

Sandstone in the Roubidoux Formation is medium grained, somewhat angular, and chemically less pure than commonly desired for an industrial sand. Resources suitable for potential development are present in the eastern part of the area, and thicknesses may locally exceed 35 ft. The Swan Creek is much the same except for a finer grain size. Resources are minor and generally restricted to the north-central part of the quadrangle. Thicknesses in the Swan Creek are commonly less than 20 ft. Sandstone beds in the Batesville and Fayetteville Formations have an extremely limited distribution and thus very little potential for development. No past or present use of sandstone for industrial sand production is known and the possibility for future production is very speculative.

Crushed Stone

Resources of crushed stone, the most valuable mineral commodity currently being produced in the quadrangle, are present throughout the quadrangle. In 1985, the most recent year for available data, over 650,000 tons were produced with a value of nearly $2,000,000. Production was reported from 10 quarries. The primary use of crushed stone in the quadrangle is for aggregate; smaller amounts are used for aglime. Both dolostone and limestone are utilized for crushed stone; chert is a common impurity.

Rock units that have the greatest economic importance are the Ordovician Gasconade, Jefferson City, and Cotter Dolomites and the Mississippian Compton, Pierson, Burlington, Keokuk, and Warsaw Formations. Thicknesses of individual units range from about 20 ft for the Compton, to several hundred feet for the Jefferson City and Cotter Dolomites and the Burlington and Keokuk Formations.

As major sources for high-specification aggregate and high-purity limestone, parts of the Burlington and Keokuk, Warsaw, and to some extent the Compton Formations, represent the most desirable resources available. The remaining units are suitable for less stringent aggregate and aglime use. Overall, resources of crushed stone are large, although units meeting stringent chemical and physical requirements are not evenly distributed.

Dimension Stone

Dimension or building stone resources are large and diverse, although there is little present production. In the past, limestone, dolomite, and sandstone were quarried. Production consisted mostly of rough building stone with little processing or finishing.

Dolostone from the Jefferson City and Cotter Dolomites and limestone from the Compton, Pierson, Burlington and Keokuk, and Hindsville Formations along with sandstone from the Roubidoux and Batesville Formations have been quarried. Resources of dimension stone are sufficiently large and accessible to support a small industry should a market develop.

Summary

The current economically important industrial mineral resources of the Missouri part of the Harrison quadrangle are crushed stone and construction sand and gravel. Resources are more than adequate for present and expanded rates of production. Very speculative resources of clay, shale, and industrial sand are available should a market develop.

ARKANSAS

by George W. Colton, Arkansas Geological Commission

Within the Arkansas part of the Harrison quadrangle, in approximate order of decreasing tonnage, limestone, dolostone, sand and gravel, sandstone, silica sand, and clay have been produced. Records show that one or more of these industrial mineral commodities have been produced in each of the Arkansas counties within the study area (Stroud and others, 1969; Bush and Stroud, 1979). However, data have not been available since 1979 to show the amounts produced annually, and there has been no recent field inventory to show which commodities are being produced today. As of 1979, the only industrial minerals being produced were crushed stone, sand and gravel, small amounts of limestone for agricultural or chemical uses, and some silica sand. There are also no quantitative studies of the resource potential for industrial mineral resources within the area, but, for some purposes, limestone, dolostone, sand and gravel, and sandstone have considerable potential.

Limestone and Dolostone

Large amounts of limestone and lesser amounts of dolostone have been quarried, mostly as crushed stone for use as road metal, concrete aggregate, and riprap. Over the years, the Boone Formation (Mississippian) and the Cotter Dolomite and Fernvale Formation (both Ordovician) have been major sources of limestone and dolostone in the Harrison quadrangle and nearby counties.

The Mississippian Pitkin Limestone and Fayetteville Formation (which contains much interbedded limestone) and the Ordovician Kimmswick and Plattin Limestones have also been sources of limestone and dolostone. The leading producing counties in 1979, the last year for which data are available, were Benton County with nearly 700,000 tons and Baxter County with nearly 400,000 tons. It is not known how much of the tonnage from Benton County was from that part of the county within the Harrison quadrangle. Much smaller amounts of rock were quarried in Baxter and Izard Counties for agricultural and chemical limestone. It is not known which formations provided the tonnages in those two counties. Limestone and dolostone resources in the Harrison quadrangle are huge. The Boone Formation in particular could provide much high-calcium rock (98-99.5 percent $CaCO_3$; Stroud and others, 1969). It is the most extensively outcropping unit in eastern Benton, northern Madison, Carroll, and Boone Counties.

Sand and Gravel

Sand and gravel are abundant in the beds and floodplains of many streams and rivers in the area. Supplies are adequate, at least for local needs, in all counties in the Harrison quadrangle. However, many of the more extensive deposits of sand and gravel became unavailable when dams were constructed on the White River to create Beaver, Table Rock, and Bull Shoals Lakes, and when most of the Buffalo River valley was designated as a National River. Aside from alluvial sand and gravel, which are used mostly for concrete aggregate and road surfacing, there are large resources of colluvial deposits of chert, limestone, and dolomite fragments in clay and sand that are suitable for road-base material.

In 1979, when data were last available, Boone and Marion Counties were the leading producers of sand and gravel, totaling more than 500,000 tons. At least small amounts were produced in all other counties in the quadrangle.

Sandstone and Silica Sand

After dolostone and limestone, sandstone is the most abundant rock in the Arkansas part of the Harrison quadrangle. However, relatively little sandstone has been produced to date, although large volumes of rock suitable for crushed stone in building and construction, for dimension and facing stone, and for use as high-silica sand, possibly even as glass sand, are present.

The only sandstone operation reported by Stroud and others (1969) was in southeastern Boone County where an estimated 300,000 tons of high-silica sand were quarried from the St. Peter Sandstone of Middle Ordovician age. Operations ceased in 1947. Among the formations from which sandstone suitable for building and construction could be obtained are several sandstone units in the Everton Formation (Middle Ordovician), the Clifty Limestone (Middle Devonian) in the few places where it is present, the Batesville Formation (Upper Mississippian), and the Hale (Lower Pennsylvanian) and Atoka Formations (Middle Pennsylvanian). The units listed by Stroud and others (1969) as perhaps being suitable for high-silica sand (more than 99 percent SiO_2) are the Kings River Sandstone Member in the lower part of the Everton Formation, the Calico Rock Member in the middle part of the same formation, and the St. Peter Sandstone overlying the Everton. For many years, the St. Peter Sandstone has produced glass-quality sand at Guion, Izard County, only 7 mi southeast of the Harrison quadrangle. Although the outcrop pattern for all three sandstones is notably lenticular, they crop out in many places along the White and Buffalo Rivers and along Crooked Creek.

As of 1979, there was no reported production of sandstone from the Harrison quadrangle (Rush and Stroud, 1979), but some of the processed rock reported as "crushed stone" may have been sandstone.

Tripoli

Bodies of tripoli have been reported in several counties in northern Arkansas, but records are available for only one locality in the Arkansas part of the Harrison quadrangle (Stroud and others, 1969). That deposit, which is in northwestern Madison County (sec. 33, T. 18 N., R. 27 W.), does not appear to be suitable for commercial development because of the poor quality of the tripoli. Other occurrences in Fulton, Independence, and Izard Counties are mentioned by the same authors, but locations are not given. West of the border of the Harrison quadrangle, in Benton and Washington Counties, 16 other deposits are known. One deposit in Benton County, only 2 mi west of the Harrison quadrangle, was operated for more than 20 years and yielded an estimated 35,000 tons of tripoli before the operation was shut down in 1949. This and all other known deposits are in the Boone Formation and apparently developed through leaching of chert or cherty limestone.

There probably has been little systematic exploration for tripoli in the Harrison quadrangle, and in view of the large area underlain by the Boone Formation, it seems likely that other deposits exist, one or more of which might be of commercial value.

RESOURCE POTENTIAL FOR METALLIC MINERAL DEPOSITS IN PRECAMBRIAN ROCKS

by Eva B. Kisvarsanyi, Missouri Geological Survey

INTRODUCTION

Very few deep holes in the Harrison quadrangle penetrate the Precambrian basement. In the Missouri part of the quadrangle, there is one core hole and two other (rotary) holes from which only cuttings are available; similarly, in the Arkansas part of the quadrangle, there are one core hole and two holes with only cuttings. Because of the sparse data, the Precambrian basement map for the Harrison quadrangle was drawn at 1:500,000 scale (map C).

ROCK TYPES IN MISSOURI

The three holes in the Missouri part of the quadrangle are B-1 and B-2 in Barry County and Ta-1 in Taney County (map C).

Drill-hole B-1 is the City of Monett #2 water well, drilled in 1916. Only cuttings are available from this hole. The bottom sample, 1,908 ft from the surface, shows red granophyric granite which was assigned to the Spavinaw epizonal terrane (Sims and others, 1987, p. 17) on the basis of its mineralogical similarity and proximity to known Spavinaw Granite outcrops and subcrops. Some epidote, chlorite, and pyrite were also noted in this sample.

Drill-hole B-2 is the Barry County Oil and Gas Company's #1 Jenkins well, drilled in 1922. This well penetrated 194 ft of Precambrian rock identified as a sequence of rhyolite, tuff, and andesite or trachyte. The rocks are extensively altered (epidote, chlorite, sericite) and, possibly, weakly metamorphosed. There is some fine sericite-phyllite in the cuttings. Microveinlets of quartz and calcite were also observed. This section of volcanic rocks is possibly related to Denison's "Washington County Volcanic Group" (Oklahoma nomenclature), which has a rather extensive subsurface distribution in the Tri-State area (Denison, 1966). These volcanic rocks are assumed to be related to the Spavinaw terrane which is inferred to underlie much of southwestern Missouri.

Drill-hole Ta-1 is St. Joe Lead Company's 64W58 mineral exploration hole, which cut 10 ft of granite at the bottom. The granite is medium- to coarse-grained, porphyritic, and mafic-rich. It has large (as much as 1 in.) insets of microcline-perthite in a hypidiomorphic fabric of orthoclase-perthite and quartz. The mafic mineral is euhedral amphibole, but biotite is also present. Accessory minerals include apatite, zircon, fluorite, and magnetite. The rock is classified as an amphibole-biotite-alkali feldspar granite, probably related to the Spavinaw terrane, but its age has not been determined.

All three of the above described drill holes are in the western half of the Harrison quadrangle.

ROCK TYPES IN ARKANSAS

The three drill holes in the Arkansas part of the quadrangle are 67AK1 in Carroll County and MD-1 and MD-4 in Madison County (map C). The following descriptions of the rocks encountered in those drill holes are taken from Denison (1984).

Drill-hole 67AK1 is St. Joe Lead Company's mineral exploration hole, which cut 21 ft of red porphyritic-micrographic granite porphyry characteristic of the Spavinaw terrane. Phenocrysts of plagioclase, some quite large (as much as 7 mm), are rimmed by perthite. These are set in a generally micrographic quartz-feldspar matrix (1.0-1.8 mm). The perthite is dusted with extensive hematite and vesicles. Plagioclase is calcic oligoclase and contains locally intense sericite-epidote-clay alteration. Amphibole is in clots with other accessory minerals; both a pale green amphibole and actinolite are present. Chlorite is associated with these clots. Sphene occurs as reddish anhedral crystals. Both apatite and zircon are found as numerous small crystals. Carbonate veins and carbonate replacement in mafic minerals are conspicuous. The general texture and mineralogic abundances are typical of epizonal granite in northwest Arkansas.

Drill-hole MD-1 is Independent Oil Company's No. 1 Banks test, drilled in 1929, which penetrated a few feet of Precambrian rhyolite porphyry. Phenocrysts of altered plagioclase and sparse perthite are set in a quartz-feldspar groundmass. The general texture of the groundmass is not well defined, as parts of it appear to have optically oriented rodlike quartz. Feldspar is altered and contains hematite dust. Plagioclase contains sericite flakes and epidote granules. Chlorite masses replace parts of some feldspar phenocrysts and are in the groundmass as probable pseudomorphs after a mafic mineral and as disseminated shreds. Iron oxide granules are partly surrounded by sphene-leucoxene. Phenocrysts (about 2 mm) are set in a groundmass averaging 0.2 mm in grain size. The texture is porphyritic-felted. The rock is probably part of the Spavinaw terrane.

Drill-hole MD-4 is the Layne Western No. 1 Huntsville test, drilled in 1981, which penetrated 5 ft of metarhyolite porphyry. Phenocrysts of feldspar and some quartz (about 1.3 mm) are set in a finely granoblastic groundmass (0.03 mm) composed of the same minerals. The largest cutting chip observed is about 1.5 mm in length. Hematite dust and vesicles cloud feldspar. Chlorite replaces mafic minerals and occurs as fine shreds in the groundmass. The texture is relict porphyritic-granoblastic. The metamorphosed rhyolite at this locality suggests a nearby pluton at depth.

PRECAMBRIAN STRUCTURE

The Chesapeake and Bolivar-Mansfield tectonic zones are projected to trend southeasterly across the quadrangle (map C). The western part of the quadrangle is dominated by the eastern flank of the Spavinaw arch, a Precambrian high underlying the Tri-State district to the west (Denison, 1966). The Precambrian surface dips to the east and south, and may be down-faulted along the Chesapeake tectonic zone. Contour lines on top of the Precambrian surface, projected from drill holes outside of the Harrison 1°×2° quadrangle, suggest a deep embayment, graben, or trough between the Chesapeake and Bolivar-Mansfield tectonic zones; this inferred embayment appears to widen to the southeast toward the Mississippi embayment.

BASEMENT TERRANE

The six drill holes that penetrate Precambrian basement in the Harrison quadrangle are in the western half of the quadrangle. With the exception of drill-hole Ta-1, all penetrate rhyolite and epizonal granite, probably correlative with the Spavinaw terrane (1.34-1.40 Ga) which underlies extensive regions of southwest Missouri, northwest Arkansas, northeast Oklahoma, and southeast Kansas (Sims and others, 1987). Drill-hole Ta-1 reflects the presence of a mesozonal granite of mafic-rich composition similar to granite associated with ring intrusions in the St. Francois terrane (Kisvarsanyi, 1981). It too is correlated with the Spavinaw terrane because the magnetic pattern associated with it is similar to that farther west where rhyolite and granophyre occur (Kisvarsanyi, 1984).

Between the Chesapeake and Bolivar-Mansfield tectonic zones it is assumed that rocks of the Early Proterozoic Central Plains orogen (Sims and Peterman, 1986) compose the basement. The orogen is inferred to extend into the Harrison quadrangle from the northwest; it is documented by drill holes in the adjoining Springfield quadrangle to the north.

An odd-shaped area of magnetic highs in the southeastern part of the quadrangle is provisionally assigned to the 1.45-1.48 Ga St. Francois terrane, a terrane of epizonal granite and associated rhyolite in the Rolla quadrangle (Kisvarsanyi, 1981), solely on the basis of the magnetic pattern of this area (Kisvarsanyi, 1984). The northeastern corner of the quadrangle, north of the projection of the Bolivar-Mansfield tectonic zone, is also inferred to be underlain by rocks of the St. Francois terrane. This assumption is based on projections from the neighboring Springfield and Rolla quadrangles.

MINERAL RESOURCE POTENTIAL

There are no metallic mineral resources known in the Precambrian rocks within the Harrison quadrangle. However, the two Middle Proterozoic epizonal terranes, the Spavinaw and the St. Francois, tentatively identified in the region, are both generally favorable for the occurrence of metallic mineral deposits. These epizonal terranes have the potential for hosting Kiruna-type iron-ore deposits such as those in southeastern Missouri, Olympic Dam-type copper-uranium-gold deposits, and tin-tungsten deposits such as those at Silver Mine in southeastern Missouri (Kisvarsanyi, 1990).

In a discussion of possible Olympic Dam-type deposits in the U.S. midcontinent, Sims and others (1987) elaborate on a favorable terrane in clastic rocks accumulated in the graben defined by the Chesapeake and Bolivar-Mansfield tectonic zones. However, evolving concepts for the Olympic Dam ore-deposit model (Naomi Oreskes, oral commun., 1988) do not require the presence of clastic rocks for hosting a hypothetical Olympic Dam-type deposit. Rather, positive identification of rhyolite and granite breccias, high magnetic anomalies, and coincident gravity anomalies are the more favorable diagnostic criteria.

In view of this change in the original Olympic Dam model (Roberts and Hudson, 1983), nine areas are outlined on map C as generally favorable for iron-dominated, complex metallic ore deposits. Area 1 is the most favorable because of a coincident magnetic and gravity high (McCafferty and others, 1989); however, the St. Francois terrane is only inferred here. Areas 2, 3, 4, and 5 are less favorable because only magnetic highs are associated with them; there are no coincident gravity highs.

Areas 6 and 7 are favorable because of magnetic highs and positive (drill-hole) identification of the Spavinaw terrane. Area 8 is defined by a magnetic high within inferred St. Francois terrane rocks. Area 9 marks a magnetic high outside the graben and containing inferred Early Proterozoic rocks. However, drill-hole H-67 (map C) bottomed in an exceptionally thick and coarse sequence of clastic rocks and may therefore mark an area of moderately favorable ground for mineralization.

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