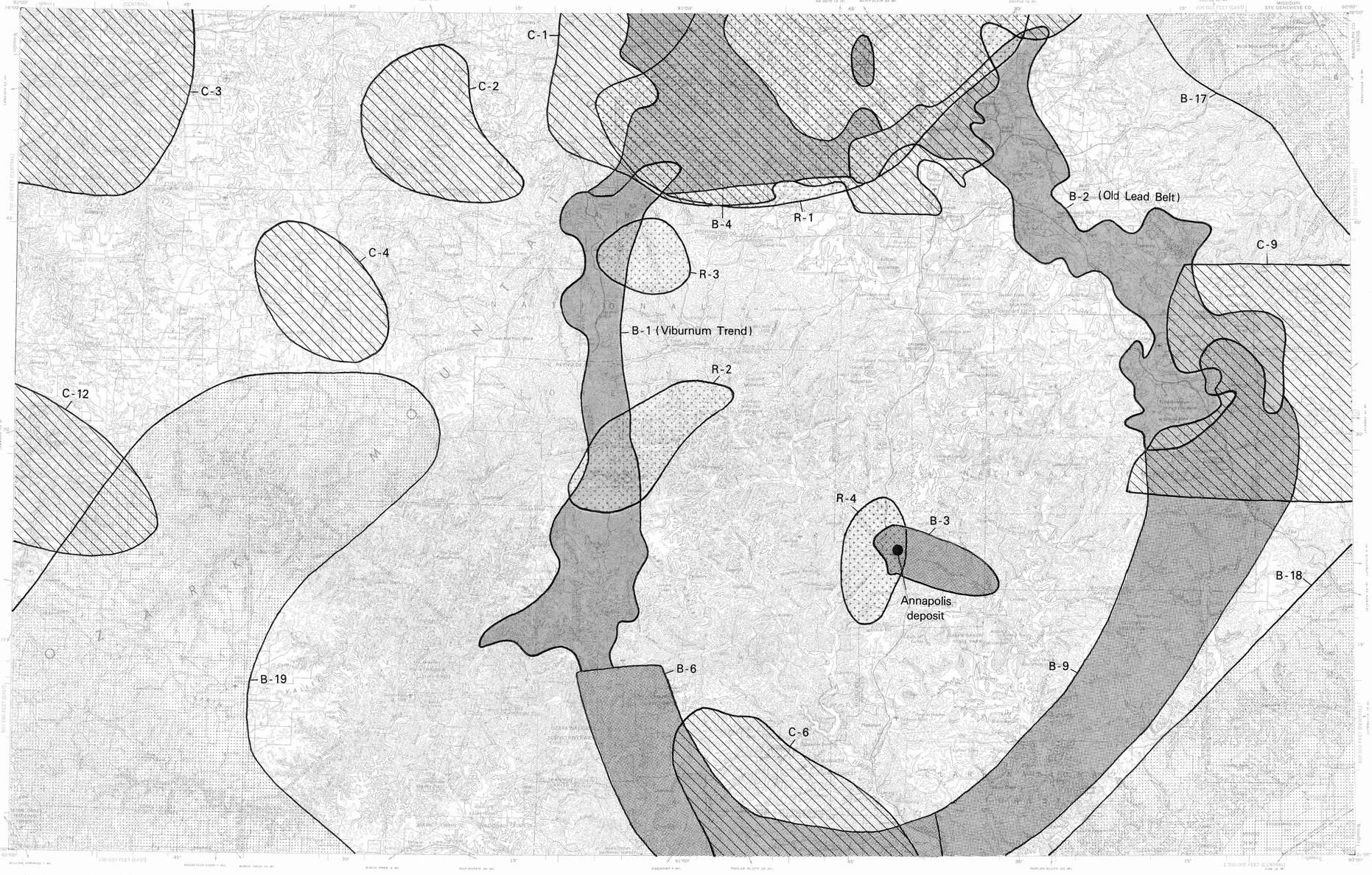
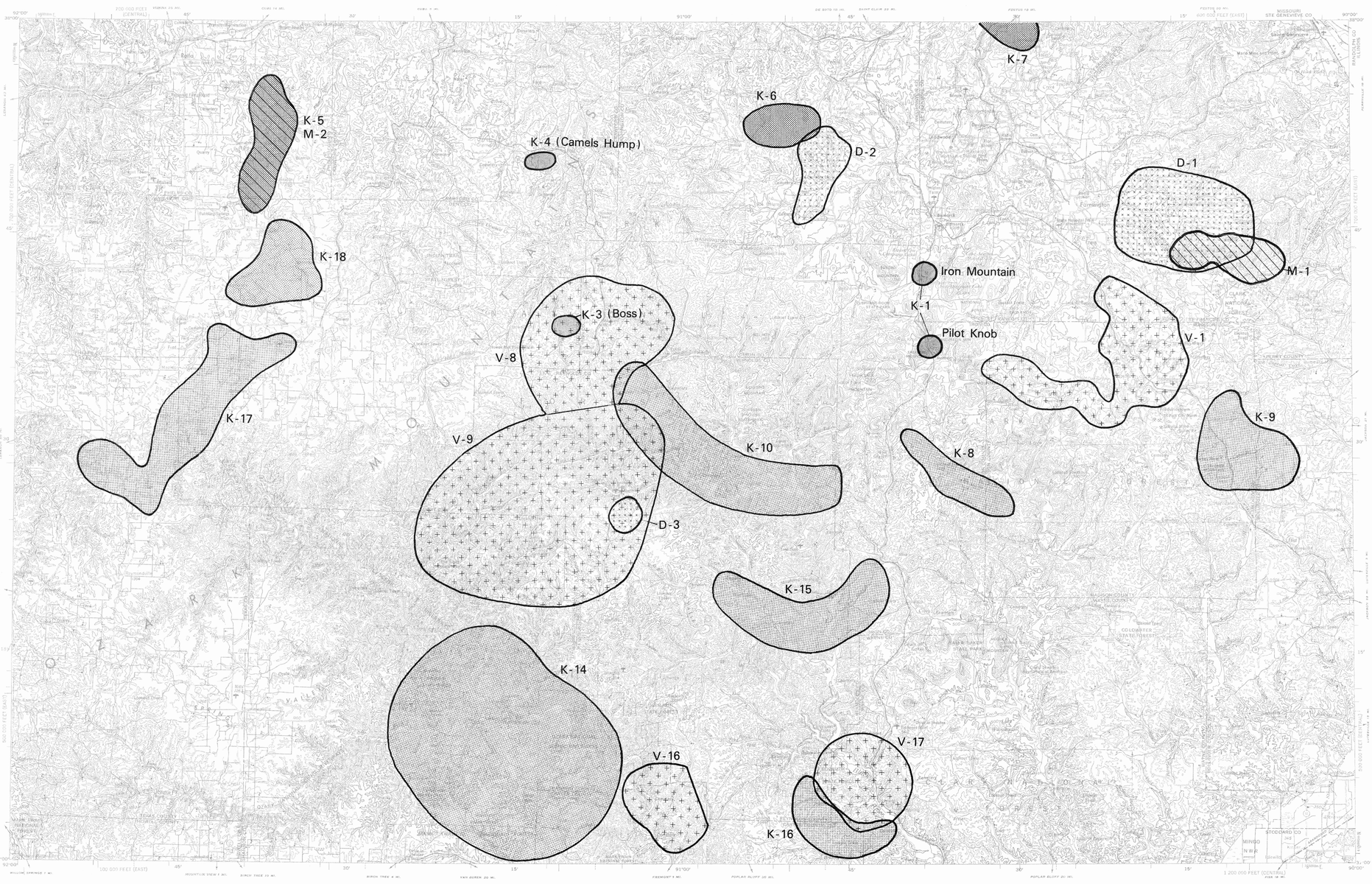


Base from U.S. Geological Survey, 1954-69

MAP A.-MAP SHOWING AREAS OF HIGH POTENTIAL FOR RESOURCES OF BASE METALS AND BARITE, AS OF SEPTEMBER 1980



Base from U.S. Geological Survey, 1954-69

MAP B.-MAP SHOWING AREAS OF POTENTIAL FOR RESOURCES OF KIRUNA-TYPE IRON ORE, KIMBERLITIC CARBONATITES, TIN-TUNGSTEN-BASE METAL VEINS, AND LAYERED IRON-COPPER-NICKEL-COBALT DEPOSITS, AS OF SEPTEMBER 1980

This map is part of a folio of maps of the Rolla 1° x 2° quadrangle, Missouri, prepared under the Conterminous United States Mineral Assessment Program. Other publications in this folio to date include U.S. Geological Survey Miscellaneous Field Studies Maps MF-1000-A, MF-1001-A and B, MF-1002-A through J, MF-1004-A through C, MF-1005-B, U.S. Geological Survey Miscellaneous Investigations Series I-1161, and U.S. Geological Survey Open-File Reports 78-330, 78-806, 79-966, 79-992, 79-1192, 81-518, and 82-61.

INTRODUCTION

A recent 5-year study of the Rolla 1° x 2° quadrangle, southeast Missouri, conducted cooperatively by the U.S. Geological Survey and the Missouri Division of Geology and Land Survey, culminated in a detailed appraisal of the metallic mineral-resource potential of the quadrangle (Pratt, 1981). In that report we considered the resource potential for 17 types of mineral deposits, on the basis of geologic environments and mineral occurrences known or inferred to be present, and concluded that the quadrangle has a substantial potential for the occurrence of several types of deposits. The present text and maps are intended to serve three purposes: as a summary of the appraisal methodology, as an overview of the criteria that we used to identify areas considered to have significant resource potential, and as a graphic summary of the locations of those areas. For full details regarding the mechanics of the appraisal, the reader is referred to the original open-file report (Pratt, 1981).

The date September 1980 is an essential part of the title of this report. A mineral resource is defined as a natural concentration of elements in such form that a usable commodity can be extracted from it. Critical factors in the appraisal of a potential resource are its economic viability--whether or not it can be extracted at a profit--and the certainty of its existence. With changes in economic and legal conditions, development of new technologies of mining and mineral processing, improved understanding and new theories of ore genesis, more detailed knowledge of the geology of the area, and renewed interest in new prospecting methods, an undiscovered or undiscovered mineral deposit may become a resource almost overnight. Thus any appraisal of resource potential is time dependent, being based on economic and legal conditions, scientific and technologic knowledge, and data available, at a given time. There is no such thing as a final appraisal of the resource potential of any area. Therefore, we emphasize that this report describes the resource potential of the Rolla quadrangle appraised **as of September 1980.**

METHODOLOGY

The appraisal method consisted of six steps:

(1) Compilation of geologic, lithofacies, geochemical, and geophysical maps of the quadrangle to identify the known and inferred geologic environments present. In addition to compilation of existing data, this step required new reconnaissance mapping of approximately 65 percent of the quadrangle, aeromagnetic surveying of the west half of the quadrangle, integration of lithofacies data from logs of some 1,000 drill holes, and spectrographic and chemical analysis of about 11,000 insoluble-residue samples from 62 drill holes.

(2) Determination of types of mineral deposits that could be expected to occur in the quadrangle on the basis of (a) known worldwide associations of certain mineral-deposit types with geologic environments that are present in the quadrangle, and (b) known mineral deposits and occurrences that actually exist in the quadrangle.

(3) Development of conceptual, descriptive models of these mineral-deposit types.

(4) From each descriptive model, derivation of recognition criteria for the occurrence of that type of mineral deposit.

(5) Systematic examination of the available data for existence of the recognition criteria.

(6) Evaluation of the areal distribution and relative importance of various recognition criteria to appraise the favorability for occurrence of each mineral-deposit type throughout the quadrangle, and also to indicate areas where data are insufficient for a knowledgeable appraisal.

Recognition criteria

Recognition criteria--geologic parameters that affect the favorability for the presence of a mineral deposit--may be either diagnostic, permissive, or negative. Diagnostic criteria are those that are present in all, or nearly all, known deposits, and in most cases are considered to be required for the presence of a mineral deposit; conversely, the known absence of such criteria may either severely limit or definitively rule out the possibility of the presence of a deposit. The existence of diagnostic criteria is merely a favorable indication that a deposit may be present; it does not guarantee that a deposit is present. For example, the descriptive model for the Mississippi Valley-type base-metal deposits in this area includes dolomite host rocks; thus the presence of dolomite is a diagnostic criterion, without which the existence of such deposits can be ruled out.

Permissive criteria are those that are present in enough known deposits that they may be considered to favor the presence of a deposit, although they are not required; their existence enhances the possibility for occurrence of mineral deposits, especially if diagnostic criteria are present, but their absence does not lessen the possibility. Using the same example--Mississippi Valley-type base-metal deposits--the deposits tend to be, but are not always, associated with buried Precambrian knobs; thus the presence of a Precambrian knob favors the presence of a deposit, but the known absence of a knob does not diminish the possibility if favorable diagnostic criteria are present.

Negative criteria generally can be equated with the known absence of diagnostic criteria: thus exposed Precambrian bedrock is negative for Mississippi Valley-type deposits because it means that dolomite cannot be present. Because of this redundancy, negative criteria are not considered separately here.

GEOLOGY AND MINERAL-DEPOSIT TYPES OF THE ROLLA 1° x 2° QUADRANGLE

The principal geologic formations of the Rolla 1° x 2° quadrangle are sedimentary rocks, mostly dolomite, of Cambrian and Early Ordovician age, which overlie volcanic and granitic rocks of Middle Proterozoic (Precambrian Y) age; figure 1 shows the names (as used by the Missouri Geological Survey), thicknesses, and lithologies of the individual formations, and figure 2 shows the approximate areas of outcrop of the Precambrian, Cambrian, and Ordovician and younger rocks. The Precambrian rocks are exposed mainly in the St. Francois Mountains in the eastern part of the quadrangle, where a complex of dominantly rhyolitic ash-flow tuffs is intruded by a composite batholith of biotite and amphibole-biotite granites; the buried Precambrian basement in the rest of the quadrangle is dominantly volcanic and metamorphic of biotite granite, central plutons of muscovite-biotite microcline and albite granite ("tin" granite), and ring intrusions of amphibole-biotite granites (Kisvarsanyi, 1980a,b). The Cambrian and Ordovician rocks generally are flat lying or dip gently away from the St. Francois Mountains; they are fairly well exposed around the flanks of these mountains but elsewhere in the quadrangle they are mantled by thick residual cherty clays. Where the entire section of Upper Cambrian and Lower Ordovician rocks is preserved, mostly in the western part of the quadrangle, its total thickness is about 2,000 ft. It is overlain by younger sedimentary rocks in the extreme northeastern and southeastern parts of the quadrangle.

The principal metallic mineral deposits exploited in the quadrangle to date have been Mississippi Valley-type lead-zinc-silver-copper-nickel-cobalt ores in the Bonneterre Formation in the Mine La Motte-Fredericktown area, the Old Lead Belt, and the Viburnum Trend, and Kiruna-type iron ores in Precambrian rhyolites in the St. Francois Mountains. Residual barite and lead deposits, derived largely from Mississippi Valley-type deposits in the Eminence and Potosi Dolomites, have in some past times been of national significance; Missouri still ranks second among the States in barite production. Several other types of mineral deposits or occurrences are known in the quadrangle, and certain geologic environments in the quadrangle suggest a potential for still others. In all, 17 types of mineral deposits are considered in this appraisal, on the basis of known mineral deposits and occurrences in the quadrangle and known associations of deposit types with geologic environments present in the quadrangle:

1. Mississippi Valley-type base-metal deposits (lead-zinc-copper-nickel-cobalt) in the Bonneterre Formation and Lamotte Sandstone
2. Mississippi Valley-type base-metal and barite deposits in Cambrian and Ordovician rocks overlying the Bonneterre Formation
3. Barite deposits in residuum derived from vein and replacement deposits in Paleozoic rocks
4. Kiruna-type iron-apatite(-copper) deposits
5. Fluorine-thorium rare-earth-bearing kimberlite-carbonatite complexes
6. Vein deposits of tin-tungsten-copper-zinc-lead-silver in Precambrian rocks
7. Uranium and thorium in Precambrian rocks
8. Uranium in Paleozoic sedimentary rocks
9. Coastal plain-type uranium deposits
10. Iron-copper-nickel-cobalt(-platinum-chromium-titanium) deposits in layered mafic-ultramafic complexes
11. Manganese in Precambrian rocks
12. Marcasite-pyrite-hematite deposits of filled stoks
13. Residual brown iron ore deposits
14. Manganese deposits in sedimentary rocks and residuum
15. Copper deposits in sedimentary rocks
16. Base and precious metals in Precambrian veins
17. Massive sulfide deposits in Precambrian volcanic rocks

MINERAL-RESOURCE APPRAISALS

Of the 17 types of deposits listed above, nos. 1, 2, 3, 4, and 6 are especially significant because the quadrangle is considered to have substantial potential for economically important undiscovered deposits of those types. Types 5 and 16 are significant because a potential for important deposits apparently exists, but cannot be appraised on the basis of available information. For type 7, we concluded only that the region in general may have a high potential for granitic uranium deposits at considerable depths, but that the pipe-and-breccia geometry and relatively small size of this type of deposit would present a prohibitively elusive target for deep exploration; the areas of exposed Precambrian rocks can be eliminated because they did not show significant anomalies in recent aerial radiometric surveys. Although there is a potential for uranium deposits in the Lamotte Sandstone (type 8), which does not appear to have been tested adequately, the resource appraisal did not identify any specific areas in the quadrangle that might be favorable for such occurrences. For the other types of deposits, we concluded that the quadrangle either has little or no apparent potential for undiscovered deposits (types 9, 16, and 17), or has some potential for deposits of little commercial interest (types 11-15).

The two accompanying 1:250,000-scale maps (maps A and B) show the outlines of the significant areas. Map A shows areas of high potential for Mississippi Valley-type and related deposits (types 1-3). Map B shows areas considered to have a high potential for Kiruna-type iron-ore deposits (type 4) and for tin-tungsten-base metal vein deposits (type 5); it also shows areas of potential for layered deposits, which theoretically have a potential for fluorine-thorium rare-earth-bearing carbonatites (type 5), and two areas of magnetic anomalies that may be related to deeply buried mafic-ultramafic complexes and therefore may have a potential for layered iron-copper-nickel-cobalt deposits (type 10). The general potential for uranium deposits of types 7 and 8 is not adequately defined to permit outlining favorable areas on the map of the quadrangle. **Users of maps A and 3 should be aware that the areas of favorability were identified on the basis of subjective evaluations of a variety of widely spaced data; therefore the lines that define these areas are approximations only.**

In the following sections we summarize the recognition criteria and evaluations of only the significant areas discussed above. Areas appraised to have low potential are not included here but were identified in detail in the original report (Pratt, 1981), to which the reader is referred for more complete discussions of each model and for maps showing the areal distribution of the recognition criteria.

Mississippi Valley-type base-metal deposits in the Bonneterre Formation and Lamotte Sandstone

Stratabound deposits of base-metal sulfides in carbonate host rocks, commonly referred to as Mississippi Valley-type deposits, are economically the most important deposits known in the Rolla quadrangle. The Old Lead Belt produced some 8 million tons of lead during its long history; the newer mines of the Viburnum Trend currently supply about 90 percent of the nation's lead as well as significant quantities of zinc, silver, copper, and cadmium, and they contain notable resources of nickel and cobalt.

From the descriptive model, we identified 12 recognition criteria, 5 of which we consider diagnostic and 7 permissive:

Diagnostic criteria and sources of data

1. In dolomite, near interface with limestone (Kisvarsanyi, 1982; Thacker and Anderson, 1979a)
2. In "brown rock" near interface with "white rock" (Kisvarsanyi, 1982)
3. Near areas of faults and fractures in enclosing or underlying rocks (Pratt, 1982)
4. Near or within favorably situated digitate reef-complex facies (Kisvarsanyi, 1982)
5. Near areas of anomalously high amounts of base metals in insoluble residues of apparently barren Bonneterre Formation (Erickson and others, 1978, 1979)

Permissive criteria and sources of data

1. Deposit or occurrence of base-metal minerals is known to be present in subject formation or in overlying formations (Miller, 1982)
2. Davis Formation is an impermeable shale facies, defined as having clastic-to-carbonate ratio ≥1:16 (Thacker and Anderson, 1979b)
3. Subsurface Precambrian knobs are known to be present (Kisvarsanyi, 1979)
4. Lamotte Sandstone thins or pinches out (Thacker and Anderson, 1979c)
5. Bonneterre Formation is 200-400 ft thick (Thacker and Anderson, 1979c)
6. Insoluble residue of Bonneterre Formation is >50 percent shale (Thacker and Anderson, 1979d)
7. Small, circular pluton of "tin" granite is present in basement (Kisvarsanyi, 1980b)

Using the sources indicated, we plotted the areal distribution of each of these criteria on a map of the quadrangle. Areas of outcropping Precambrian rocks can be eliminated as having no potential because the Bonneterre and Lamotte formations are absent. The remainder of the quadrangle was divided into 19 numbered areas in which various combinations of diagnostic criteria are known or suspected to be present (see map A). Areas B- 1, 2, 3, 4, 6, and 9 are the areas of large known deposits or high potential and are discussed below. Areas B- 17, 18, and 19 are considered conditionally favorable: a potential exists because the Bonneterre Formation and Lamotte Sandstone can reasonably be assumed to be present, but no data are available regarding the presence or absence of the other recognition criteria. The remaining 10 of the numbered areas are not shown on map A or listed in table 1 because they are not considered to have a high potential.

As a means of assigning an objective score to each of the numbered areas in order to compare their relative favorability, we listed the areas in tabular form, along with columns for the various diagnostic and permissive criteria (table 1). For each area, the widespread presence of a criterion was assigned a value of 1, the known absence was given a value of -1, and a lack of sufficient information to determine the presence or absence of the criterion was indicated by 0; presence of the criterion in only part of the area was given a value of 1/2. The scores for each area were then summed, and the summed scores indicating relative favorability are shown in the final column under diagnostic and permissive criteria. The two sums must be considered separately because by definition, the presence of a positive criteria enhances the favorability for mineral deposits only if diagnostic criteria are also present, whereas the absence of permissive criteria does not lessen the favorability if diagnostic criteria are present.

Our subjective interpretation of the resource potential indicated by these quasi-objective scores is as follows:

Large known deposits in areas B- 1, 2, 3
Very high potential in areas B- 4, 6, 9; areas B-1 and B-2 would have very high potential but were assumed to be fully explored
High potential in area B-3

Appraisal of areas B- 4, 6, and 9 could change on the basis of additional data regarding presence or absence of certain criteria indicated by 0 in table 1.

The meaning of these evaluations can be better expressed qualitatively than quantitatively or statistically. Qualitatively, we believe the available data indicate that areas B- 4, 6, and 9 should have top priority as prospective areas for concealed base-metal deposits in the Bonneterre Formation and Lamotte Sandstone. That is to say, we believe the combination of recognition criteria is so compelling as to indicate a very high probability that at least one deposit of significant size (millions of tons, and probably has a high potential for additional undiscovered small deposits, but much of the area has already been thoroughly prospected.

Area R-2 contains reported but unverified occurrences of barite in the Potosi-Eminence outer area and anomalous barium in insoluble residues two drill holes. If the reported surface occurrences can be verified, the area should warrant further study by panning stream sediments to determine the extent of barite occurrences. The barite occurrences lie between the Black fault to the northeast and the Ellington fault to the southwest, which may define a structural block in the sense of diagnostic criterion 2. The extent of possible minor faulting within this area is unknown. Any major deposits of residual barite within this area probably would have been penetrated by one or more of the many holes that were drilled during exploration for deeper base-metal deposits. Therefore any potential that exists would likely be for smaller deposits only.

Areas R-3 and R-4 contain anomalous barium in insoluble residues from several drill holes in the Potosi-Eminence outcrop area. Like area R-2, these areas are in potentially favorable structural settings but have been intensely explored by deep drilling, and therefore may have some potential for small deposits only.

Kiruna-type iron-apatite-(copper) deposits

Known deposits of this type include the Iron Mountain, Pilot Knob, Camels Hump, and Boss deposits in the Rolla quadrangle, and the Pea Ridge deposit located about 8 mi (12 km) north of the quadrangle in Washington County. Several of these magmatic-hydrothermal and contact metasomatic, nontitaniferous iron-ore deposits in the region have been important producers in the past, but in September 1980 only the Pea Ridge and Pilot Knob mines were active. The latter was permanently shut down in the fall of 1980. The Iron Mountain deposit was depleted and the mine closed in 1966. The Camels Hump and Boss deposits have been extensively drilled but have not yet been exploited; the copper mineralization is the main interest in the Boss deposit. Total production from the various mines amounts to more than 42 million tons of ore and high-grade pellets; apatite is recovered for phosphate fertilizer manufacture.

From the descriptive model we identified six diagnostic and three permissive criteria:

Diagnostic criteria and sources of data

1. Magnetite, hematite, and (or) chalcopyrite in seams, veins, or as disseminations (Crane, 1912; Kisvarsanyi, 1975)
2. Precambrian silicic volcanic rocks (Pratt and others, 1979; Kisvarsanyi, 1980b)
3-4. Magnetite-trachytes and (or) alkalic-intermediate rocks (Kisvarsanyi, 1980b)
5. High-amplitude, positive magnetic anomaly (U.S. Geological Survey, 1978, 1979)
6. Location within or near cauldron subsidence structure (Kisvarsanyi, 1980b)

Permissive criteria and sources of data

1. Recognition of characteristic gangue mineral: in drill cores (Kisvarsanyi, 1975)
2. Location near Precambrian topographic high (Kisvarsanyi, 1979)
3. Location on or near Precambrian faults or fractures (Kisvarsanyi, 1979)

Using the sources indicated, we plotted these criteria on a quadrangle map as follows:

1. Locations of active and inactive mines and prospects
2. Locations of drill holes which penetrate mineralized rock or a diagnostic rock of the descriptive model (such as magnetite-trachyte)
3. Areal distribution of silicic volcanic rocks (surface and subsurface)
4. Areal distribution of trachytic rocks (surface and subsurface)
5. Major fault zones and inferred cauldron subsidence structures
6. Outlines of high-amplitude positive magnetic anomalies

Areas where two or more of the diagnostic criteria coincide were arbitrarily blocked out as being favorable for the occurrence of deposits of the model type. They are numbered from K-1 through K-18 (map B and table 3). The scoring within each area is as follows: presence of a criterion = +1; absence of a criterion = -1; insufficient data = 0. As most of the criteria are present only within part (and often a very small part) of any given area, 1/2 values were not used. Our subjective interpretation of the resource potential indicated by the scores is as follows (area K-2 is the Pea Ridge deposit, which lies 8 mi north of the quadrangle and is not shown here):

Large known deposits:	areas K- 1, 3, 4
Very high potential for large to moderate-size deposits:	areas K- 5, 6, 7
High potential for moderate to small-size deposits:	areas K- 8, 9, 10, 14, 15, 16, 17, 18

In areas K-17 and K-18, although the sum of diagnostic criteria amounts to only 1, neither the presence nor the absence of 6 criteria can be verified from the available data. We consider these areas more favorable than K- 11, 12, and 13 on the strength of favorable magnetic patterns and the recognition of 4 diagnostic criteria in the adjacent area K-5. Area K-18 coincides with the Salem gravity anomaly discussed under the ore deposit model for layered intrusives. However, the combined magnetic pattern of areas K- 5, 17, and 18 is similar to that associated with volcanic terranes in the St. Francois Mountains. Area K-18 therefore has a potential for both Kiruna-type deposits in shallow volcanic rocks of the St. Francois terrane, and deep ore bodies of the layered model.

The potential for Kiruna-type deposits in the rest of the quadrangle is considered very low. Areas underlain by granite are the least favorable; those underlain by silicic volcanic rocks are somewhat more favorable. The latter may contain deposits consisting wholly of hematite.

Fluorine-thorium rare-earth-bearing kimberlitic carbonatite complexes

Kimberlitic carbonatite diatremes and associated volcanic rocks occur at three localities in the Rolla quadrangle. Although economic mineralization is not known to be associated with them, their potential could be important because of their similarity to the cryptovolcanic center at Hicks Dome, Ill., 90 mi (145 km) east of the Rolla quadrangle. At Hicks Dome, a cluster of mineralized explosion breccias in Devonian rocks contain thorium, niobium, beryllium, and rare-earth minerals, as well as fluorite, barite, and sphalerite, that are thought to be related to dikes of alkalic peridotite, lamprophyre, and kimberlite (Brown and others, 1954; Heyl and others, 1965, p. 810-811; Heyl, 1972, p. 887). There may be a potential for similar mineralization associated with the diatremes in the Rolla quadrangle. The three diatreme areas (map B) are as follows:

Avon (area D-1).--Within an area of about 75 sq mi near Avon, an estimated 100 or more kimberlitic diatremes and dikes of alkalic peridotite occur. (As of 1982, both pyrope and chromian diopside, two of the three minerals diagnostic of true kimberlites, have been found in at least one locality; the third diagnostic mineral, magnesian ilmenite, has not--A. V. Heyl, oral commun., 1982). Associated with some of the intrusions are galena, sphalerite, barite, and fluorite (Heyl, 1972, p. 888-889). Mansker (1973) identified olivine, phlogopite, clinopyroxene, and chromian spinel in brecciated lamprophyric kimberlite; Rinehart (1974) recognized eclogite-like garnet-bearing peridotite fragments in carbonatite breccia. Trace amounts of thorium, niobium, chromium, yttrium, and rare-earth elements have been reported from some of the diatremes (Heyl, 1972; Rinehart, 1974). The age of the rocks is Devonian (Zartman and others, 1967).

Dent Branch-Furnace Creek (area D-2).--Lapilli tuffs in the Bonneterre Formation contain clasts of alkalic-ultramafic composition at Dent Branch and Furnace Creek; at Dent Branch, crystalline calcite of possible carbonatitic origin is present (Snyder and Gerdemann, 1965; Wagner and Kisvarsanyi, 1969). The rocks are believed to be associated with nearby eruptive centers or explosion pipes similar to the Avon diatremes. Small amounts of millerite have been identified in the Dent Branch tuffs.

Bee Fork (area D-3).--Lapilli tuffs around Bee Fork are similar in age and composition to those at Dent Branch, but are known only from drill holes. The possible presence of several ancient eruptive centers in this area suggests that another cluster of diatremes intersects the basement rocks (Kisvarsanyi and Howe, 1983).

The geologic setting and composition of the diatremes and lapilli tuffs are consistent with the interpretation that they represent the upper levels of alkalic-ultramafic plutonic complexes that occur at depths from several hundred to several thousand feet below the surface. Therefore, in each of these three localities there is a potential for diamondiferous kimberlites and for rare-earth minerals associated with carbonatites; at this time, however, the available data do not permit an appraisal as to whether this potential is high or low.

Vein deposits of tin-tungsten-copper-zinc-lead-silver in Precambrian rocks

Tin-tungsten vein deposits in the Silver mine area have been considered unique in the midcontinent region. Our descriptive model, therefore, was based on published and unpublished reports and data on the known deposits. However, in our appraisal of the resource potential we considered broader aspects of the geologic and tectonic environment of the region, examined descriptive models of similar deposits in other parts of the world, and tried to establish salient features which are favorable to mineral deposits of this type.

The basic premise in our appraisal of tin-tungsten-silver-lead resources in the Rolla quadrangle is that the Silver mine deposits are not fortuitous but are characteristic of the Precambrian geologic and tectonic environment of the region. The deposits form an integral part of the St. Francois terrane which makes up the subsedimentary basement over most of the area (Kisvarsanyi, 1980a). The St. Francois terrane has a number of distinctive features, listed below, which in other parts of the world are diagnostic of platform-type tin-metallogenic provinces (Lugov, 1977; Olade, 1980):

1. High-level, anorogenic tectonic environment
2. Continental volcanic-plutonic terrane with granitic ring complexes
3. Late intrusions of granitoid plutons
4. Tension fractures and joints, some related to ring faults
5. Predominance of alkalic-silicic rocks
6. "Tin" granites with distinctive trace-element suite (enrichments in tin, lithium, niobium, thorium, and rare-earth elements)
7. Potassium exceeds sodium in most granitoids
8. Negative gravity anomalies

Platform-type granites in tin-metallogenic provinces may give rise to two types of primary tin mineralization: (1) pegmatitic tin-niobium-tantalum, and (2) hydrothermal tin-tungsten-zinc-lead. We believe that both models are pertinent to the Precambrian geology of the Rolla area and may prove to be helpful in exploration for this type of deposit. Both types of primary deposits may also be sources for placer deposits.

These models are not detailed here, but comparison of their parameters with the St. Francois terrane suggests that in the Rolla quadrangle, the central ("tin" granite) plutons are favorable as host rocks for the pegmatitic model, and the ring intrusions are favorable for the hydrothermal model. On the basis of the available data (Kisvarsanyi, 1980a, 1980b; U.S. Geological Survey, 1978, 1979) we have selected a number of features which we consider to be indicators of favorable geologic environments for tin-tungsten resources (map B). The areas numbered V- 1, 8, 9, 16, and 17 indicate inferred central plutons and ring intrusions in the buried Precambrian terrane; the numbers are keyed to table 4. Where the indicator is known to be present, a value of 1 is given; where available information is not sufficient to determine whether the indicator is present or absent, a value of 0 is given. The sums of indicators for each area, therefore, should not be ranked against each other; each sum only shows how many of the indicators are known to be present.

Indicators of favorable geologic environments

1. "Tin" granite pluton indicated by outcrop or drill hole
2. "Tin" granite pluton inferred from aeromagnetic map (circular or oval magnetic low)
3. Inferred ring intrusion
4. Pegmatites
5. Greisen-type alteration, quartz veins, or albitization
6. Pathfinder elements

Area V-1 has the resource potential of most immediate interest, for two reasons. First, the known veins in the Silver mine area were mined only for the tungsten and argentiferous galena in the veins; the potential for tin and tungsten in the greisens along their borders apparently has not been evaluated. Random samples of both greisen and sulfide-quartz vein material contain significant amounts of tin, and the vein material also contains notable tungsten, as would be expected. Second, recent geochemical surveys suggest some potential for tin-tungsten base-metal veins over an area of at least 4 sq mi northwest and southwest of the Einstein mine (Gustavson, 1977), and there may also be a potential for undiscovered veins under a thin cover of Lamotte Sandstone southeast and east of the Einstein mine.

Aside from area V-1, areas V- 8, 9, 16, and 17 appear to have the highest potential in the quadrangle for undiscovered tin-tungsten minerals because of the large number of indicators identified. Prospecting and exploration in these and 14 other areas identified in the original report will be handicapped by the thick cover of sedimentary rocks. The potential for these types of deposits elsewhere in the quadrangle appears to be nil.

Iron-copper-nickel-cobalt-(platinum-chromium-titanium) deposits in Precambrian layered mafic-ultramafic complexes

These types of deposits are not known in the Rolla quadrangle, but speculation about their occurrence is warranted by the fact that several differentiated, layered intrusions of gabbro-norite elsewhere in Missouri (Kisvarsanyi, 1974) cause magnetic anomalies similar in amplitude and areal extent to certain anomalies in the Rolla quadrangle. Disseminated pyrrhotite, magnetite, pentlandite, and chalcopyrite totaling as much as 15 percent of the rock by volume have been identified in some drill cores of these rocks from other parts of Missouri. The petrology of the intrusions is comparable to that of layered mafic-ultramafic complexes, such as the Stillwater, Sudbury, Skaergaard, and Bushveld, which contain some of the world's most important resources of chromium, platinum, nickel, and cobalt.

The potentially metal bearing intrusions in Missouri are within the Precambrian basement, covered by 700 to 3,300 ft of sedimentary rocks. They have been penetrated by drilling to a maximum of 800 ft. Typically, they have a differentiated cap of diorite and quartz-diorite, grade through gabbro, norite, and troctolite with depth, and are cut by granite dikes. The concentration of metallic minerals increases with depth. Ultramafic rock was not penetrated in any of the drill holes.

The two magnetic anomalies in the Rolla quadrangle that might be related to mafic-ultramafic complexes are the Avon and Salem anomalies (map B).

The Avon anomaly (area M-1 on map B)

A dumbbell-shaped, 3,265-gamma magnetic high was tested by a single core hole. At 674 ft depth, coarse-grained diorite was found, and mafic rocks were penetrated to the bottom of the hole at 1,094 ft. The rock is cut by several granite dikes, causing extensive hybridization. The section is similar to the dioritic cap of layered intrusions elsewhere in Missouri, and it grades into gabbro at about 950 ft depth.

The Salem anomaly (area M-2 on map B)

A large gravity anomaly near Salem was modeled by Cordell (1979) and attributed to an intrabasement ultramafic pluton. The gravity anomaly is along an arcuate chain of prominent magnetic highs trending north-northeast from Licking to St. James. A test hole drilled in 1928 penetrated 876 ft of Precambrian rock from 1,750 to 2,626 ft depth. The quality of samples from this well is extremely poor. The section has been logged as diorite with syenite and andesite dikes on the basis of examination of cuttings by binocular microscope (Kisvarsanyi, 1975). The dominant minerals are plagioclase, amphibole, biotite, epidote, and chlorite. Short sections were interpreted as dikes because of distinct mineralogical changes, but no actual intrusive contacts were observed in the cuttings. If Cordell's interpretation of the Salem gravity anomaly is correct, the top of the ultramafic body must be below the penetrated depth of Precambrian rock in this drill hole. Alternatively, the pluton may be a layered intrusive body with a dioritic cap, grading into more mafic compositions with depth.

Thus there is some evidence for the existence of two layered mafic-ultramafic plutons in the Rolla quadrangle; however, the metallic resource potential of these plutons cannot be realistically appraised on the basis of the available data.

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