GOLD, RARE EARTH ELEMENT, AND OTHER POTENTIAL BY-PRODUCTS OF THE PEA RIDGE IRON ORE MINE, WASHINGTON COUNTY, MISSOURI

(Contribution to Precambrian Geology No. 21)

by
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October 1989

OFR—89-78-MR

MISSOURI DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGY AND LAND SURVEY
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CONTENTS

EDITOR'S NOTE

This report, prepared for the St. Joe Minerals Corporation during 1984 and 1985, summarizes the work of James Husman for the evaluation of gold as a potential by-product of iron ore mining at the Pea Ridge mine. In addition to his results, Husman summarizes work completed before his investigation.

The Missouri Department of Natural Resources, Division of Geology and Land Survey (DGLS) does not take credit for the report or its data. The report was modified from an internal St. Joe Minerals Corporation document. DGLS thanks the Pea Ridge Iron Ore Company and James Husman for permission to release the report as a Contribution to Precambrian Geology. We hope that these data are useful to those who are forming exploration models for "Olympic Dam-type" ore deposits in the Midcontinent Middle Proterozoic.

In 1988, DGLS entered a cooperative agreement with the United States Geological Survey (USGS) to evaluate Missouri's Precambrian iron ore deposits as potential Olympic Dam-type variants. This cooperative study, the "Olympic Dam Comparison Project," is funded under the auspices of the USGS Strategic and Critical Minerals Program. Geologic mapping and various topical studies of the Pea Ridge deposit, the only accessible iron ore mine in the United States in a geologic setting similar to that of the Olympic Dam deposit, is included in this project. We feel that Husman's work is significant and of the quality needed in planning our approach to documenting the geology of Pea Ridge.

In additon, the report is an introduction to the possibility that Pea Ridge may be an Olympic Dam-type of deposit; it should aid the exploration geologist in developing a model to prospect for such deposits. The chemistry incorporated in the report, as condensed summaries, is available for inspection at the DGLS offices in Rolla. The information, like the report, is in open-file status because of the generosity and spirit of economic development of the Pea Ridge Iron Ore Company.

GOLD, RARE EARTH ELEMENT, AND OTHER POTENTIAL BY-PRODUCTS OF THE PEA RIDGE IRON ORE MINE, WASHINGTON COUNTY MISSOURI

James R. Husman; The Doe Run Company, P.O. Box 500, Viburnum, MO 65566

ABSTRACT

In the late 1970's, a radioactive zone in the Pea Ridge mine was evaluated for potential uranium production. In 1980, a radioactive portion of an underground ore-reserve diamond drill core was discovered to contain significant gold mineralization. Preliminary work noted that gold was associated with telluride minerals. During the next three years, several small-scale projects attempted to evaluate the potential for gold recovery.

By 1984, accumulated data justified a large-scale sampling and drilling program. Over 400 underground rock chip samples were collected, core from 33 existing drill holes was sampled, and over 8,000 ft of core was drilled and sampled. The project identified three zones from which all samples containing greater than 1 ppm gold occur: the specular hematite zone, the silicified zone, and a vein enriched in thorium and rare-earth elements. Assays indicate that the vein contains the greatest potential for economic gold recovery.

The thorium and rare earth-bearing vein has been intersected by diamond drilling in undeveloped areas of the mine, on and below the 2275-ft level. Development drifts will probably intersect this vein on or below the 2475-ft level and will allow mapping and more detailed vein sampling. In addition to gold, rare-earth elements, and thorium, the vein contains significant quantities tin, uranium, and phosphate.

INTRODUCTION

In 1978, there was considerable interest in the potential recovery of accessory minerals as by-products from the Pea Ridge mine. Two primary objectives were a gravity anomaly beyond the mine workings (southwest of the No. 1 and No. 2 shafts) and radioactive zones in the silicified footwall of the deposit.

Geophysical analysis of the gravity anomaly suggested a massive sulfide deposit. Two diamond drill holes, 78W9 and 79W2 (formerly USBM #2), failed to intersect massive sulfide mineralization, but subeconomic concentrations of disseminated molybdenite, pyrite-enriched zones, and several radioactive zones were intersected (Ludwig, 1978 and 1979 unpub. company correspondence).

During a regional evaluation of uranium potential in Missouri, from 1978 to 1979, St. Joe American examined the radioactive zones in the Pea Ridge mine. After completion of a radiometric survey, a longhole jackhammer exploration program evaluated the radioactive zones documented during the survey. Twenty-two jackhammer holes, totaling 1,813 ft, were drilled in late 1979 and early 1980. Semiquantitative x-ray fluorescence analyses were performed by FLUO-X-SPEC Incorporated for some 789 samples.

During the longhole drilling, a scintillometer survey was conducted on drill core acquired during ore reserve drilling and stored in the Pea Ridge core library. Samples from diamond drill hole 961-6 were sent for assay. Pulp from an earlier iron assay for the interval 576-600 ft returned 3.1 ppm Au, 10.0 ppm Ag, and 1.6 percent Sn. Assays from hole 961-6 are listed in Table 1. The telluride minerals, melonite and altaite, were identified in polished core sample thin sections (unpub. company correspondence).

The underground exploration program initiated in 1984 was designed to explore further the gold mineralization at Pea Ridge; the results are summarized in this report.

GEOLOGIC SETTING

The Pea Ridge magnetite deposit, 12 mi south of Sullivan (Fig. 1), is a discordant magnetite body that cuts a series of Middle Proterozoic volcanic rocks. The ore body and volcanic rock assemblage is overlain by Cambrian and Ordovician sedimentary rocks. The host volcanic rocks are genetically related to the Precambrian St. Francois Mountains, which outcrop approximately 50 mi southeast of the mine.

The St. Francois terrain is mostly silicic igneous rocks, mainly rhyolitic ash-flow tuffs and lava flows, and associated granitic plutons. At exposed contacts, the granites intrude volcanic rocks. U-Pb isotope dating of volcanic rocks places them at 1485 my (Bickford and Mose, 1975). Various authors have identified remnant calderas in the St. Francois mountains (Kisvarsanyi, 1980 and 1981; Sides et al., 1981). Kisvarsanyi (1980 and 1981) identified many volcanic rock ring complexes with inferred central plutons; the Pea Ridge deposit is in one such structure and is therefore believed to be underlain by a granite pluton (Fig. 2).

MINE GEOLOGY

Volcanic rock units: The magnetite body is enclosed by a series of rhyolitic lava flows and ash-flow tuffs (Figs. 3 and 4) that Emery (1968) named according to the level on which the rock was first noticed. Emery determined that the oldest rocks are on the hanging wall, and that rock units become progressively younger northward. The average strike of the volcanic rocks is N80°W and they dip 75° - 90° northeast.

The oldest (most southerly) rock unit has not been named and is exposed in the hanging wall of the lower mine levels and on the far west end of the mine. The unit is composed of orthoclase and perthite (orthoclase-albite intergrowth) phenocrysts in an aphanitic quartz and orthoclase groundmass.

Figure 1. Location of the Pea Ridge mine, Washington County, Missouri. From Emery (1968).

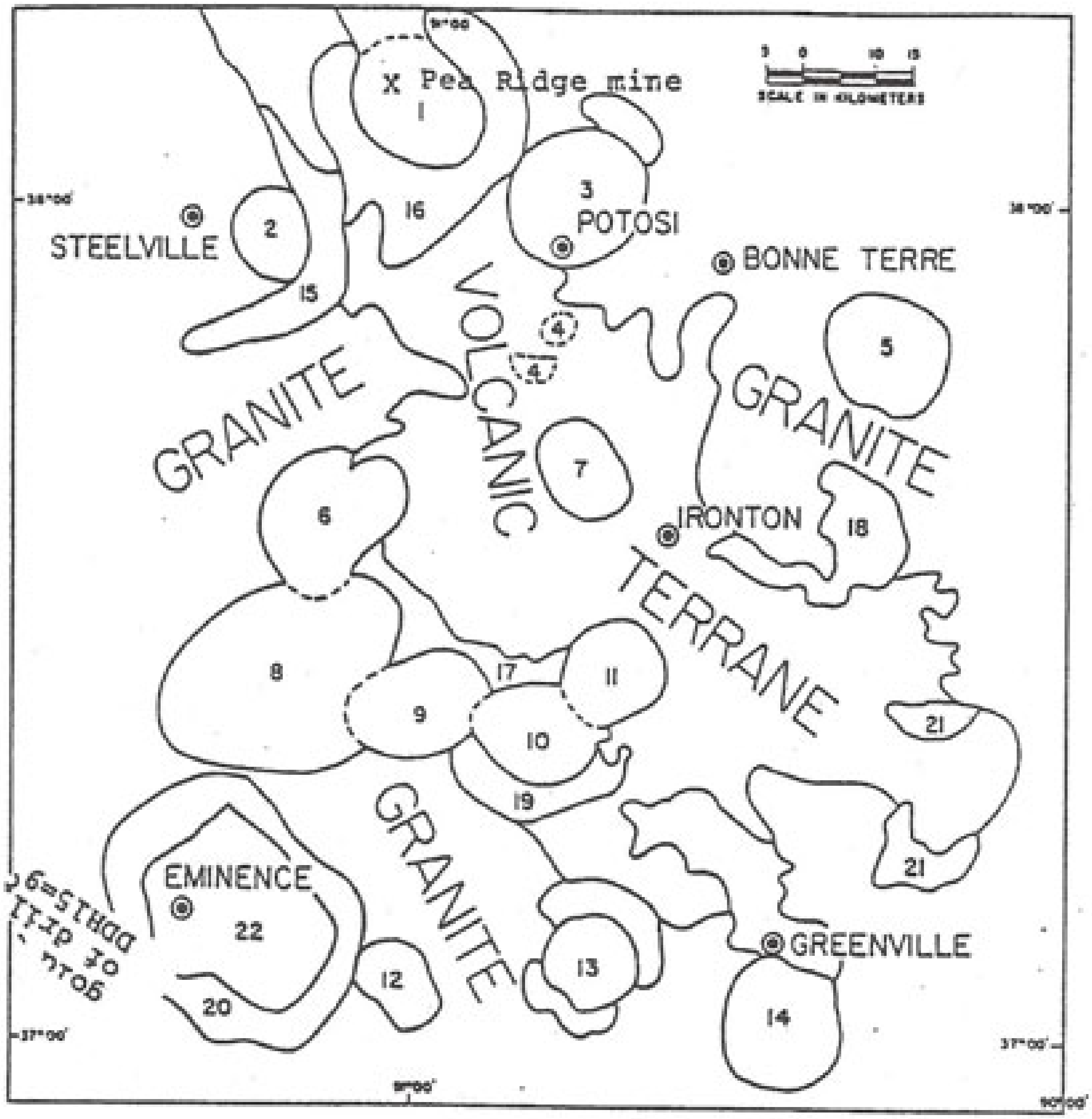

Figure 2. Regional map of the ring complexes in the St. Francois terrane. Named features 1 through 14 are inferred central plutons; 15 through 21 are inferred ring intrusions; features 20 and 22 constitute the Eminence cauldron-subsidence structure. Taken from Kisvarsanyi (1981).

1. Pea Ridge pluton(s)
2. Steelville pluton
3. Potosi pluton
4. Dent Branch — Furnace Creek pluton(s)
5. Hawn Park pluton
6. Buick pluton
7. Graniteville pluton
8. Bunker pluton
9. Corridon pluton
10. Redford pluton
11. Sabula pluton
12. Van Buren pluton
13. Piedmont pluton
14. Greenville pluton
15. Cherryville ring intrusion
16. Floyd Tower — Indian Creek intrusion
17. Lesterville intrusion
18. Silvermine ring intrusion
19. Redford-Annapolis ring intrusion
20. Eminence ring intrusion
21. Marquand-Buckhorn ring intrusion
22. Eminence cauldron subsidence structure

North of the unnamed unit is the 1975 porphyry: an ash-flow tuff with well developed collapsed pumice, highly altered orthoclase phenocrysts, and abundant disseminated magnetite.

North of the 1975 prophyry is the 2275 porphyry. Quartz and perthite phenocrysts in an orange-brown aphanitic quartz and orthoclase groundmass make this unit readily identifiable, even when altered. Near the contact with the 1975 porphyry, features resembling collapsed pumice suggest an ash-flow tuff origin.

The 1825 prophyry, which forms the northern contact with the 2275 porphyry, comprises two members. The southern member, which forms the contact with the 2275 porphyry, is an ash-flow tuff with abundant collapsed pumice, plagioclase phenocrysts, and orthoclase phenocrysts; banding is common along the 2275 porphyry contact. On and below the 2275-ft level, the collapsed pumice texture is less distinct than on higher levels.

The northern member of the 1825 porphyry contains angular lithic fragments, with no preferred orientation, in a tan aphanitic groundmass of quartz, orthoclase, and minor plagioclase. Plagioclase, orthoclase, and perthite phenocrysts are abundant and are extensively altered.

The youngest unit exposed in the Pea Ridge mine is the 1675 porphyry, which contains orthoclase, albite, hornblende, and quartz phenocrysts in an aphanitic groundmass of quartz and orthoclase. On the 1675-ft level, at the contact of the 1675 and the 1825 porphyry, a chill zone occurs in the 1675 prophyry.

On and below the 1825-ft level, a black porphyritic unit, between the 1675 and 1825 porphyries, contains plagioclase, orthoclase, quartz, perthite, and hornblende phenocrysts in a very fine-grained groundmass. Textural relationships suggest that the groundmass is divitrified glass. A chill zone occurs along the contact with the 1825 porphyry, but none is recognized at the 1625 porphyry contact.

<u>The magnetite deposit</u>: Emery (1968) divided the Pea Ridge deposit into a series of zones based on differences in lithology and mineralogy. The economically most important zone, the magnetite orebody, is roughly tabular, striking N55°-60°E, and dipping 75° to 90° southeast, with increased dip flattening below the 2475-ft level. Magnetite is the main ore body mineral. Typical grades exceed 50 weight percent magnetic iron. Common secondary minerals in the magnetite orebody are hematite, quartz, apatite, chlorite, pyrite, barite, fluorite, calcite, dolomite, and monazite.

On the eastern half of the orebody, on the footwall (north) side, a specular hematite zone forms a rim on the the magnetite (Figs. 3 and 4). Hematite is variably thick in plan view, thins with depth, and often shows weak schistosity. Secondary minerals in the hematite are quartz, apatite, martite, fluorite, barite, sericite, chlorite, monazite, and pyrite.

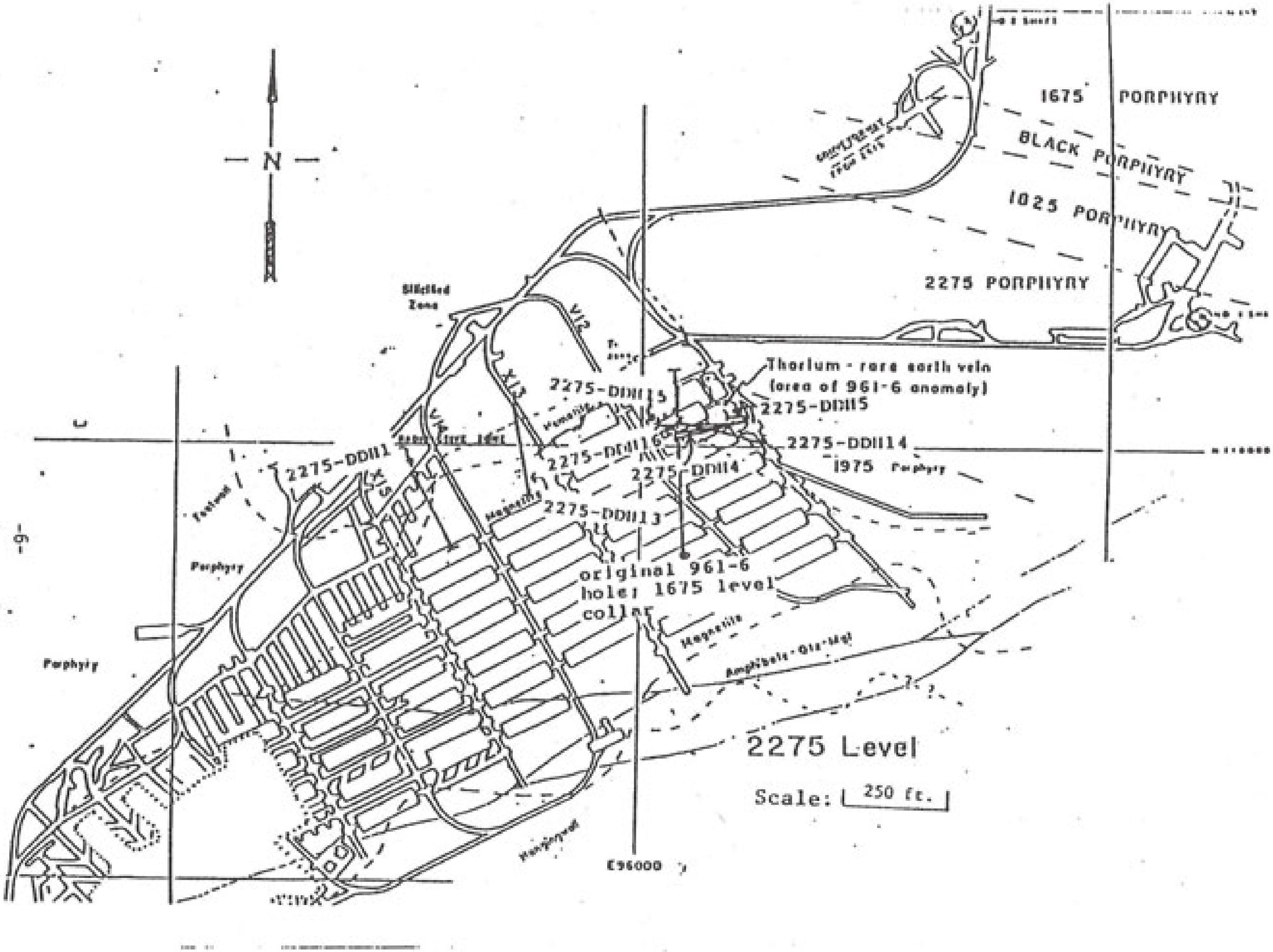

Figure 3. Geologic map of the 2275-ft level, Pea Ridge mine, Washington County, Missouri. The approximate trace of drill holes with anomalous gold content are shown. Inclination of drill holes: DDH1=4°; DDH4=20°; DDH5=45°; DDH14=1°; DDH15=9°; DDH16=15°; 961-6=62°

Adjacent to and north of the specular hematite, a silicified zone (Emery's footwall quartz-hematite zone) extends hundreds of feet to the north (Figs. 3 and 4) and also beyond the specular hematite to the west; it lies between the magnetite and porphyry on its western edge. In this zone, quartz is the main mineral; it is 50 percent to greater than 95 percent of the rock. Silicified zone accessory minerals include hematite, sericite, muscovite, fluorite, barite, pyrite, tourmaline, rutile, monazite, zircon, apatite, and topaz.

Emery's prophyry breccia zone is not one zone but several widely spaced breccia zones, the largest of which is on the western edge of the magnetite orebody, where the wall rock porphyry has been brecciated and is cemented by magnetite. Breccia fragments often show chloritic alteration rims; occasionally they are totally replaced by chlorite. In some parts of the mine, porphyry breccia zone magnetite concentration attains ore grade. Breccia is ubiquitous in the mine and is observed in almost all drill core.

On the eastern (hanging wall) edge of the orebody is a smaller prophyry breccia zone, where porphyry breccia fragments are more widely spaced in the magnetite and are generally smaller than the western breccia fragments. Most fragments in this area are totally replaced by chlorite or contain a silicious porphyry core enclosed in chlorite.

Porphyry breccia also occurs on the footwall on the eastern side of the orebody, in the western edge of the specular hematite zone (2275-ft level, X13 drift), where breccia fragments, about 50 percent of the rock, are cemented by hematite in the eastern portion of the zone and magnetite in the western portion. In addition, breccia fragments occur erratically in the magnetite orebody, within several hundred feet of the hanging wall and footwall sides of the deposit.

The amphibole-quartz-magnetite assemblage (Emery's quartz-amphibole zone) occurs in various locations throughout the mine, the largest occurrence of which is on on the eastern hanging wall, in contact with the prophyry breccia zone. Typically, this assemblage comprises actinolite, quartz, and magnetite in varying amounts, with subsidiary apatite and pyrite. Actinolite occurs throughout the mine and locally replaces limited areas of wall rock or it forms wall rock fracture fillings.

RECENT WORK

1980-1984: After the initial discovery of gold in drill core from hole 961-6 in 1979, little follow-up work was undertaken until 1983. In March 1980, St. Joe American contracted Dr. Sidney A. Williams to study petrographically eight Pea Ridge samples, including a sample from hole 961-6. From that time until August 1983, routine mine geology was performed without coordinated gold exploration. In late August 1983, Williams had again been contracted to do additional petrographic analyses of Missouri Precambrian rocks, including specimens from the Pea Ridge. His report covered 56 samples collected from Pea Ridge, Pilot Knob, Boss-Bixby, and several other Precambrian areas.

After Williams completed his 1983 report, samples of available pulps and rejects from the 1979-1980 jackhammer drilling, the entire core of hole 961-6, and the core from surface diamond drill hole 79W2 were submitted for gold

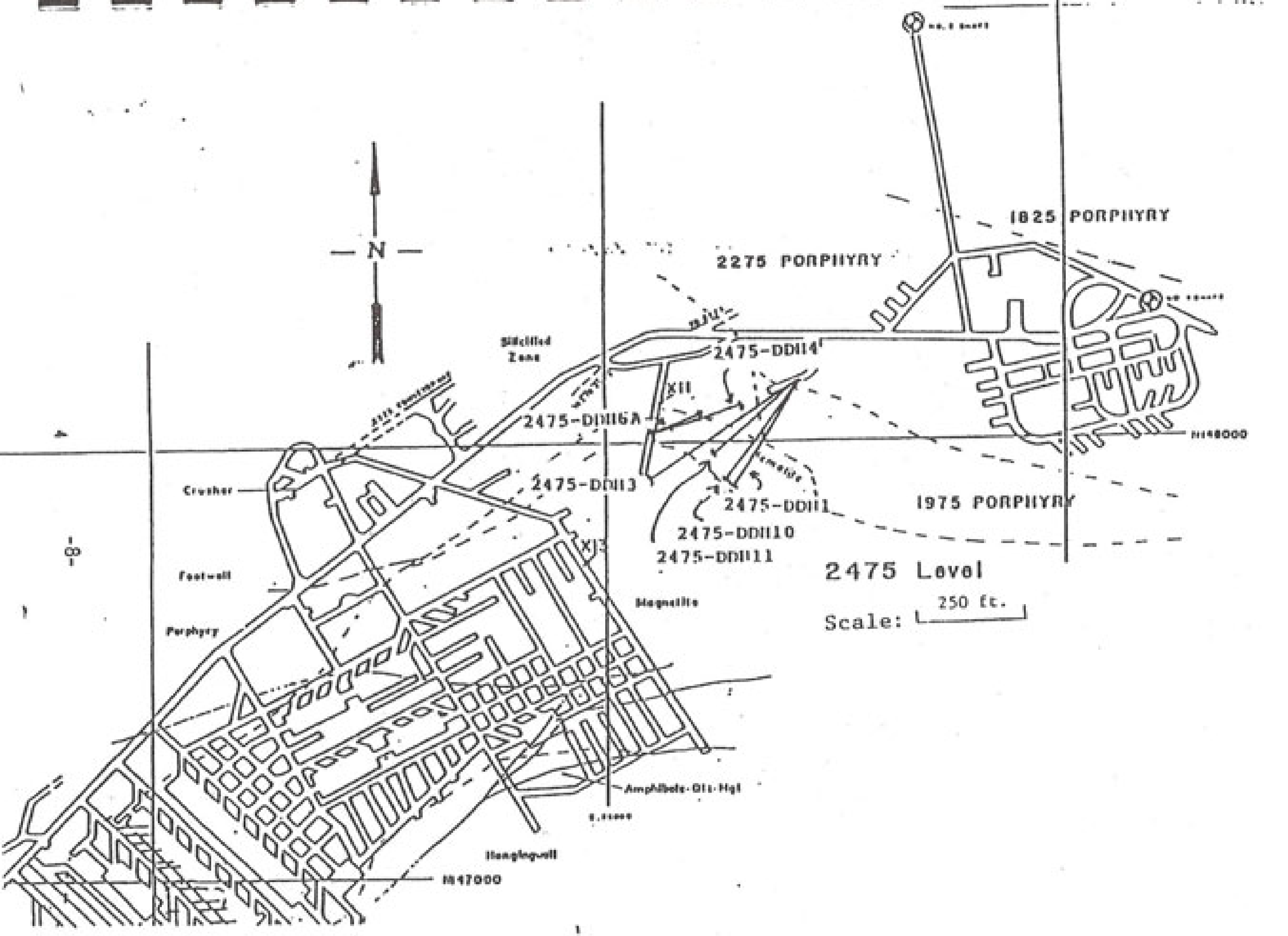

Figure 4. Geologic map of the 2475-ft level, Pea Ridge mine, Washington County, Missouri. The approximate trace of drill holes with anomalous gold content are shown. Inclination of drill holes: DDH1=31°; DDH4=-32°; DDH6A=66°; DDH10=1°; DDH11=-31°.

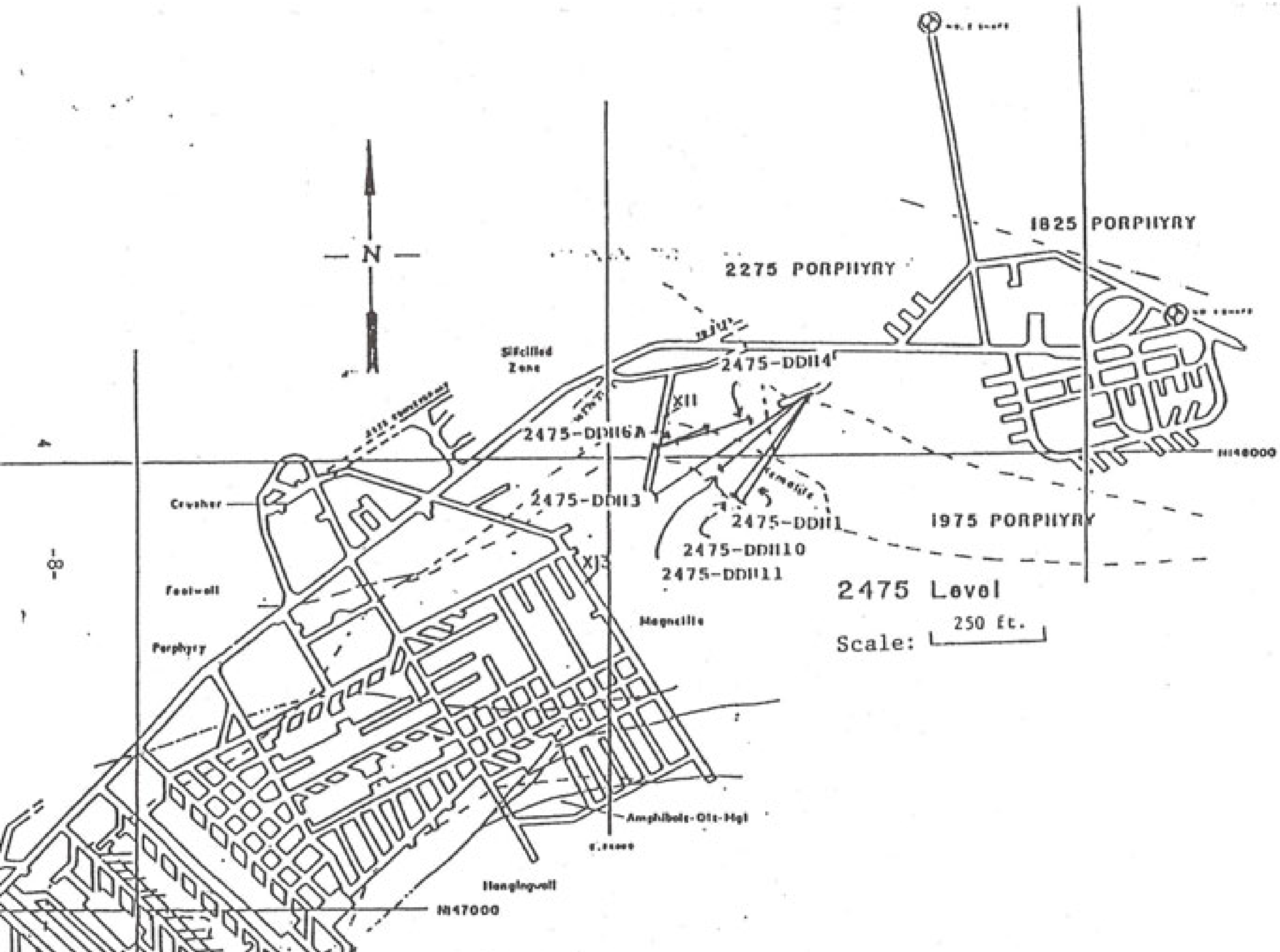

Figure 4. Geologic map of the 2475-ft level, Pea Ridge mine, Washington County, Missouri. The approximate trace of drill holes with anomalous gold content are shown. Inclination of drill holes: DDH1=31°; DDH4=-32°; DDH6A=66°; DDH10=1°; DDH11=-31°.

assay. Based on results from holes 961-6 (Table 1) and the 1979-1980 jackhammer holes (Table 2), it was determined that gold be evaluated as a potential by-product at Pea Ridge. St. Joe Minerals Corporation, SEMO Geology Department, was responsible for the Pea Ridge project; the Tucson office of St. Joe American assisted the project. In March 1984, a geologist and geological assistant were assigned the Missouri Precambrian Reconnaissance Program; they were to concentrate mostly on the Pea Ridge mine.

SAMPLING

The initial phase of exploration program was to sample existing diamond drill core in the Pea Ridge mine core library and to collect underground rock chip samples. To aid sampling, a new core storage and sampling facility was established in a building on the 880-ft level, into which all core was moved. Sampling began from drill holes in the the vicinity of the 961-6 gold intercept, 50 ft above the track level of the 2275-ft level, south of stope X1116 (Fig. 3). The intercept is in the magnetite-hematite interface, marked by high radioactivity.

Samples from thirty-three pre-1980 diamond drill holes were subjected to semiquantitive spectrographic analysis for 31 elements and quantitive assays for Au, Ag, Sn, Te, and U. Some earlier samples were also analyzed for Th.

In addition to drill core sampling, more than 400 underground rock chip samples were collected for assay, from the 1825-ft level down to the 2505-ft sub level, mostly from the eastern footwall side of the deposit. Samples of various lithologies established a geochemical base used to identify objectives of greatest potential. Ten samples contained greater than 1 ppm Au. Eight were from the 2275-ft level, in the SD1118 stope off the X11 crosscut drift, which is the original intersection of mine workings with the REE-rich vein. The sample with the highest Au assay from this stope contained 1.57 oz/ton Au (48.8 ppm), 0.57 oz/ton Ag, 22,500 ppm Sn, 2,900 ppm Te, 6,400 ppm Pb, 65 ppm Bi, and 210 ppm U. Of the two samples not from the 2275-ft level REE-vein, one from the 2320-ft sub level contained 2.20 ppm Au, 13.0 ppm Ag, 0.435 percent Sn, 150 ppm Te, and 0.20 percent U. The other sample, from the 2475-ft level, contained 5.40 ppm Au, 26.0 ppm Ag, 360 ppm Sn, 265 ppm Te, 75 ppm Pb, 2 ppm Bi, and 160 ppm U.

GEOLOGIC MAPPING

Geologic mapping was performed during underground sampling. Much of this mapping updated and refined existing geologic maps; the primary purpose was to better understand relationships between various lithologies and mineralization.

Mapping results include the recognition of two distinct ash-flow tuff units in the mine and determination of the age relationship of the silicified zone to the magnetite orebody. The mapping also helped confirm the contact metamorphic relationship of the amphibole-quartz-magnetite zone to the magnetite orebody.

Unfortunately, mapping did not help to determine the cause of the unusual shape of the eastern end of the magnetite orebody (Fig. 3). At this point, the magnetite abruptly pinches from greater than 500 ft thick to less than 100 ft

Table 1. Analysis from three pre-1984 diamond drill holes found to contain anomalously high gold contents, Pea Ridge mine, Washington County, Missouri.

Hole No.	Interval (feet)	Au (ppm)	Ag (ppm)	Pb (%)	Te (%)	Sn (%)
961-6[1]	592-598	2.4	53.14	1.96	1.25	0.03
	598-602	5.14	16.11	0.56	0.30	0.71
	602-608	371.15	144.69	6.10	3.60	0.02
	608-612	7.2	52.46	2.06	1.25	0.04
961-6[2]	576-600	12.44	8.20	0.31	0.225	2.00
	600-625	0.66	11.00	0.40	0.220	0.38

Hole No.	Interval (feet)	Actual Core[3] (feet)	Au (ppm)	Ag (ppm)	Te (ppm)	Sn (ppm)
962-11	349-360	2.3	0.78	<0.2	34.00	300.00
		1.3	6.50	<0.2	80.00	100.00
	360-370	1.4	0.18	<0.2	95.00	70.00
958-2	20- 25	1.8	1.30	<0.2	14.00	60.00
	87- 93	1.1	1.10	<0.2	32.00	95.00
	103-120	0.8	1.20	<0.2	175.00	60.00

[1] Core samples

[2] Pulp material from ore reserve determinations (previous iron assays)

[3] Assays for holes 962-11 and 958-2 are from skeletonized core. In 962-11, five ft of actual core represent 21 ft of original core

and the strike changes from about N60°E to due east. The magnetite thickens eastward, but does not attain a width comparable to the main ore zone. This feature could possibly result from a pre-magnetite zone of structural weakness, such as a fault. The 30° change in strike suggests an extension fracture from a major fault or the junction of two faults. During mapping, no indication of such a fault zone was noted.

DRILLING

In June 1984, a contract for 5,000 ft of core drilling was awarded to the Longyear Company; drilling began in July. Twenty-one holes, amounting to 5,248 ft, were drilled with a Longyear LMN37 core rig, with a 46LKT bit (1.40 in. diameter core). Fourteen holes were drilled on the 2275-ft level, three on the 2475-ft level, and four on the 2505-ft sub level.

All holes were drilled on the eastern footwall side of the magnetite orebody. Five holes investigated the silicic alteration zone and the remainder intersected the porphyry-iron ore (specular hematite-magnetite) contact zone, which contained anomalous gold intercepts of holes 961-6 [10.825 oz/t Au (371.1 ppm) in a 6 ft interval] and 962-11 [0.106 oz/t Au (3.64 ppm) in an 11 ft interval]. Holes containing anomalously high metal contents are listed in Table 3. Hole 2475-DDH1 had the highest grade Au intercept, with an average of 2.51 ppm Au over 22.4 ft; this intercept occurred approximately 100 ft below the 2475-ft level, in unmined ground.

Anomalous Au intercepts in holes 961-6 and 2475-DDH1 that appeared to be mineralogically and lithologically equivalent are separated by 300 ft vertically. In an attempt to correlate the two Au intercepts and evaluate the mineral potential between them, a second phase of underground drilling was begun.

In December 1984, the Longyear Company was again awarded the drilling contract; the second phase drilling began in January 1985. Drilling was finished in March 1985 with 12 holes drilled, amounting to 3,040 ft; nine holes on the 2475-ft level and three holes on the 2275-ft level. Table 4 summarizes intercepts with anomalously high metal contents.

ELEMENTAL AND MINERALOGICAL ASSOCIATIONS

Certain elemental and mineralogical associations were established from data acquired by fire assay, emission spectrography, microprobe analysis, and petrographic study. The tellurides, altaite and melonite, accompanied monazite in the highly radioactive section of hole 961-6. Anomalous Sn was also found in assay (Table 1). Subsequent assays of 961-6 found significant Au and Ag (Table 1).

With additional data, the following elements have been established as indicators for potential gold mineralization at Pea Ridge: Ag, Te, Sn, Bi, La, Ni, Pb, Th, and Y. Ba and Cu are frequently associated with anomalous Au values but not to the same extent as the other elements listed. Of the indicator elements, Ag, Bi, Te, and Pb show the strongest correlation with Au, when Au values are greater than 0.05 ppm.

Table 3. Anomalous gold intercepts from the 1984 diamond drilling project, Pea Ridge mine, Washington County, Missouri.

Hole No.	Interval (feet)	Actual Feet of Core	Au (ppm)	Ag (ppm)	Te (ppm)	Sn (ppm)
2275-DDH1	3- 6	2.8	0.61	16.0	65.00	35.0
	6- 9	3.4	0.33	4.8	55.00	4.0
	28- 31	2.9	0.20	0.4	11.00	8.0
	36- 39	3.1	0.21	0.8	1.10	10.0
2275-DDH1A	4- 6	2.0	0.33	10.0	90.00	230.0
2275-DDH4	35- 38	3.0	0.03	0.2	0.86	85.0
	38- 41	3.0	0.03	<.2	0.41	370.0
	41- 44	3.0	0.04	0.2	1.90	1350.0
	44- 47	3.2	0.14	0.8	20.00	2400.0
	47- 50	3.1	<.02	1.6	120.00	780.0
	50- 53	2.9	0.03	0.4	44.00	200.0
2275-DDH5	60- 63	3.0	0.04	<.2	0.18	170.0
	63- 66	2.6	<.02	<.2	0.12	1100.0
	66- 69	2.8	1.40	<.2	0.28	2300.0
	69- 72	2.9	1.40	0.4	2.20	650.0
2275-DH13	54- 57	3.2	0.35	<.2	0.19	40.0
2475-DDH1	201-204	4.0	1.10	<.2	0.59	310.0
	204-207	3.1	1.70	0.2	5.20	450.0
	207-210	2.9	0.61	0.2	8.80	560.0
	210-213	2.9	2.20	<.2	8.70	220.0
	213-216	3.0	3.80	3.2	16.00	2100.0
	216-219	3.3	6.30	35.0	15.00	1150.0
	219-222	3.2	0.05	3.2	1.30	210.0
	243-246	3.2	1.40	<.2	0.64	760.0
	246-249	3.1	0.20	1.2	0.31	680.0
	249-252	2.8	0.32	<.2	0.55	840.0
2475DDH3	219-222	2.8	0.28	<.2	0.28	20.0
	222-225	2.9	0.39	<.2	0.66	18.0

Table 4. Anomalous gold intercepts from the 1985 diamond drilling project, Pea Ridge mine, Washington County, Missouri.

Hole No.	Interval (feet)	Actual Feet of Core	Au (ppm)	Ag (ppm)	Te (ppm)	Sn (ppm)
2275-DDH14	71- 73	2.3	0.05	<.2	16.00	3400.0
	73- 76	2.8	0.02	<.2	16.00	3000.0
2275-DDH15	38- 41	2.9	0.04	<.2	16.00	310.0
	41- 44	2.9	<.02	<.2	110.00	490.0
	44- 48	3.5	0.16	<.2	60.00	560.0
	48- 50	1.5	<.02	0.2	80.00	270.0
2275-DDH16	40- 43	3.3	0.15	<.2	36.00	420.0
	43- 46	3.3	0.08	<.2	110.00	370.0
	46- 50	3.3	0.62	<.2	165.00	410.0
2475-DDH4	119-121	3.0	0.22	<.2	- - -	- - -
2475-DDH6A	225-228	3.0	0.31	0.4	0.36	1600.0
	228-231	3.0	0.07	0.4	72.00	790.0
	231-234	3.1	0.03	<.2	60.00	410.0
	234-237	3.0	0.33	0.6	21.00	230.0
	237-239	1.7	0.02	<.2	0.66	220.0
	239-242	3.0	0.19	0.2	0.72	480.0
2475-DDH10	207-209	2.3	0.08	<.2	27.00	- - -
	209-211	2.6	2.90	0.6	170.00	- - -
	211-214	2.9	0.73	<.2	24.00	- - -
2475-DDH11	173-176	3.4	0.21	0.2	18.00	230.0
	176-178	2.3	0.05	0.8	24.0	290.0

Frequently La, Th, and Y are found in anomalous concentrations without the other associated elements. Ni and Sn by themselves have a high degree of variation and a wide distribution at Pea Ridge. When Bi, La, Ni, Pb, Sn, Te,

Th, and Y are found together, with or without Au or Ag, three distinct environments are delineated: the specular hematite zone, the silicified zone, and a radioactive, rare earth element (REE)-bearing vein.

The specular hematite and silicified zones were described above. The vein is on the far eastern footwall side of the orebody (Figs. 3 and 4); on the 2275-ft level it strikes approximately N7°W, and dips 80° to 90° northeast. Where it has been intercepted by drilling below the 2475-ft level, the strike appears to be N55°W. The vein is in the specular hematite zone or at the contact of specular hematite with either magnetite or porphyry; contacts are generally sharp and distinct. Vein-like structures are characterized by unique mineralogy and texture.

The vein minerals (Table 5) are dominated by four minerals: quartz, barite, chlorite, and monazite. Frequently barite and quartz crystals are zoned or show overgrowths. Monazite (the primary REE-bearing mineral), variable in amount from sample to sample, sometimes forms more than 50 percent of a drill core sample.

Based on emission spectrography, the combined REE total often exceeds two weight percent. In addition to monazite, the REE-bearing minerals are allanite, bastnaesite*, tengerite*, synchisite*, and/or parisite*. Thorite, the major radioactive mineral, is generally found as discrete grains in the rare earth minerals.

The tellurides, altaite (the most common), melonite, hessite*, sylvanite*, and electrum* occur locally in the REE-bearing vein and are generally scattered through REE-rich segments as discrete grains

Other metal-bearing minerals in the REE-bearing vein are hematite, magnetite, pyrite, chalcopyrite, cassiterite, and galena. Hematite, the most common of these minerals, often constitutes 5 to 10 percent of a sample. Chalcopyrite and galena are relatively uncommon. Although cassiterite is rare in thin section, Sn values of vein material are generally greater than 100 ppm.

Two types of vein textures have been identified and are most apparent when comparing the REE-rich vein texture from the 2275-ft level SD1118 stope with vein texture below the 2275-ft level. In the SD1118 stope, the vein is dark brown, very dense and hard, and medium to fine grained. In drill core samples below the 2275-ft level, the vein is orange to pale red, porous, very friable, and coarse grained, and appears altered in comparison to the exposures in the SD1116 and SD1118 stopes of the 2275-ft level. In both types of REE-rich veins, quartz and barite occur as matrix and as discrete crystals. As matrix, they occur with chlorite, hosting clumps of monazite grains, which, because of their angularity, often appear to have replaced pre-existing rock fragments. In stope X1116 on the 2275-ft level, the entire vein contains breccia fragments, mostly hematite, that appear to have been partially replaced by vein

* Tentative identification based upon microprobe analysis

Table 5. Mine-alogy of the thorium-rare earth vein, Pea Ridge mine, Washington County, Missouri.

Mineral	Composition
Principal gangue minerals:	
quartz	SiO_2
barite	$BaSO_4$
Iron oxide minerals:	
specular hematite	Fe_2O_3
red granular hematite	Fe_2O_3
limonite	$Fe_2O_3(OH)$
magnetite	Fe_3O_4
Thorium and rare earth minerals:	
monazite	$(Ce,La,Th)PO_4$
allanite	$(Ca,Ce,La)_2(Al,Fe,Mg)_3(SiO_4(OH)$
bastnaesite*	$(Ce,La)(CO_3)F$
thorite*	$ThSiO_4$
synchisite*	$(Ce,La)Ca(CO_3)F$
and/or	
parisite*	$(Ce,La)_2Ca(CO_3)_3F_2$
tengerite*	$Y(CO_3)\ 3H_2O$
Telluride minerals:	
altaite	PbTe
melonite*	NiTe
hessite*	Ag_2Te
sylvanite*	$AuAgTe_4$
Accessory minerals:	
chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(H)_8$
muscovite-sericite	$KAl_2(Si_3Al)O_{10}(OH)_2$
biotite	$K(Fe,Mg)_2(Si_3Al)O_{10}(OH)_2$
apatite	$Ca_5(PO_4)_3(OH,F,Cl)$
rutile	TiO_2
K-feldspar	$KAlSiO_3O_8$
calcite	$CaCO_3$
sphene	$CaTiSiO_5$
fluorite	CaF_2
pyrite	FeS_2
galena	PbS
chalcopyrite	$CuFeS_2$
cassiterite	SnO_2
electrum*	AuAg

*Tentative identification based upon microprobe analysis minerals. In the 2475-DDH1 intercept, monazite clumps, rimmed by allanite, occur randomly with no distinguishable breccia texture.

CONCLUSIONS AND RECOMMENDATIONS

Underground sampling and diamond drilling at Pea Ridge have identified three zones containing anomalous Au mineralization: the specular hematite zone, the silicified zone, and a thorium-rich REE-bearing vein. Precious metal mineralization in these zones is associated with tellurides and rare earth minerals.

Geochemistry and accessory mineral associations in the three zones suggest they are genetically related. Post-magnetite, silica-rich fluids introduced along the eastern footwall of the magnetite body, oxidized the magnetite and formed specular hematite; in addition, a large volume of the volcanic host rock was silicified; varying from partial to total replacement of the wallrock by quartz. The thorium-rich REE-bearing vein may represent the last stage of hydrothermal mineralization; it contains the highest concentrations of REE, Sn, Au, Ag, and Te.

Sporadic Au values in the specular hematite zone and in the silicified zone are generally less than 1 ppm. In the specular hematite zone, anomalous samples did not correlate with one another or form a zonation in the hematite. In the silicified zone, anomalous values occur near the specular hematite contact.

The most promising mineralization is in the thorium-rich REE-bearing vein on the eastern footwall. Diamond drill holes 961-6, 962-11, and 2475-DDH1 have intersected significant Au mineralization in the vein. Assays show Te to be pervasive in the eastern footwall silicified and specular hematite zones. Coupled with the drill hole intercepts, this may indicate greater mineralization below the 2475-ft level in an undeveloped area of the mine.

Intersection of the vein at various elevations on and below the 2275-ft level suggests that the vein has a strike length of approximately 150 ft and a minimum length of 350 ft along the rake. The average width is 15 ft, with suspected pinching and swelling. The general shape of the vein is cylindrical. The vein between the 2275-ft level and the 2475-DDH1 intercept has a potential of around 100,000 of raw vein material.

With continued development on the eastern footwall, there is a possibility of cutting a Au-Ag mineralized area on or below the 2475-ft level. Earlier sample testing showed that the Au-Ag mineralization in 2475-DDH1 is amenable to heap leaching (Harold Ray, pers. communication); it is therefore recommended that periodic sampling and mapping be conducted in new development areas on the eastern side of the Pea Ridge orebody.

Several samples collected in May 1985 from the 2475-ADE, D5, and D6 development headings contained abundant thorium and rare-earth minerals in a 1 ft thick zone at the specular hematite-silicified zone contact; this suggests an environment similar to that on the 2275-ft level.

Other secondary mineral potential at Pea Ridge includes Sn, U, Th, REE, and phosphate, which all occur in significant quantities in the thorium-rich REE-bearing vein. REE are especially attractive because they have a naturally high concentration in the vein and could be recovered with phosphate. In addition, phosphate, as apatite, occurs throughout the magnetite orebody and could be recovered as a by-product.

REFERENCES CITED

Bickford, M. E. and Mose, D. G., 1975, Geochronology of Precambrian rocks in the St. Francois Mountains, southeast Missouri, Geological Society of America Special Paper 165, 48 p.

Emery, J. A., 1968, Geology of the Pea Ridge iron ore body, in Ridge, J. D., ed., Ore Deposits of the United States 1933-1967: American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., New York, p. 359-369.

Kisvarsanyi, E. B., 1980, Granitic ring complexes and Precambrian hot-spot activity in the St. Francois terrain, midcontinent region, United States: Geology, v. 8, n. 1, p.43-47.

_____, 1981, Geology of the Precambrian St. Francois terrain, southeastern Missouri: Missouri Department of Natural Resources, Division of Geology and Land Survey, Report of Investigations 64, 58 p.

Sides, J. R., Bickford, M. E., Shuster, R. D., and Nusbaum, R. L., 1981, Calderas in the Precambrian terrain of the St. Francois Mountains, southeastern Missouri: Journal of Geophysical Research, v. 86, n. B11, p. 10349-10364.

GOLD; RARE EARTH ELEMENT, AND OTHER POTENTIAL BY-PRODUCTS OF THE PEA RIDGE IRON ORE MINE, WASHINGTON COUNTY, MISSOURI

(Contribution to Precambrian Geology No. 21)

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