DISCOVERY OF THE FLAMBEAU DEPOSIT, RUSK COUNTY, WISCONSIN

A GEOPHYSICAL CASE HISTORY

by

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ABSTRACT

Rocks of the Precambrian Shield of Rusk County, Wisconsin were recognized as a favorable host for volcanogenic base metal deposits by personnel of Bear Creek Mining Company. Most of the county is covered by a thick layer of glacial drift; consequently, geophysical techniques played a prominent role in the exploration program conceived and initiated there in 1966. The original work on three Precambrian exposures was followed by an airborne electromagnetic survey and subsequent ground follow-up. A geophysical evaluation of airborne anomaly 22 defined a target which was interpreted as a massive sulfide body. Numerous potential field and electrical tools were utilized to describe the geometry and physical properties of the target. Drilling confirmed the massive sulfide interpretation and eventually outlined a six million-ton copper deposit.

INTRODUCTION

Rusk County is located in the northwestern portion of the state of Wisconsin (Figure 1 inset). The topography is generally flat and dairy farming is the principal vocational activity. Forest and swamp lands are common, as are pasture and cultivated ground.

Rusk County is located along the southern exposure of the Precambrian Shield and is covered by a thick layer of glacial drift. Outcrops are rare, but the few available rock exposures indicate that bedrock is comprised of steeply dipping metamorphosed volcanic and sedimentary units reported to be of Early Proterozoic age. Thin remnants of flat-lying Cambrian sandstone are found directly under the glacial till in some places. The thickness of till and sandstone cover has been observed to be as much as 150 feet.

EXPLORATION SEQUENCE

In the 1950's Bear Creek Mining Company conducted a program of geologic reconnaissance in northern Wisconsin. At that time, note was made of a Wisconsin Geological and Natural History Survey report (Hotchkiss, 1915) which discusses the presence of copper oxides recovered from a water well on the Frank Skrypek property nine miles south of the town of Ladysmith. As a result of the interest thus generated in this area, a restricted airborne electromagnetic (EM) survey was flown over Skrypek's land and surrounding farms in 1955. No anomalies were recorded.

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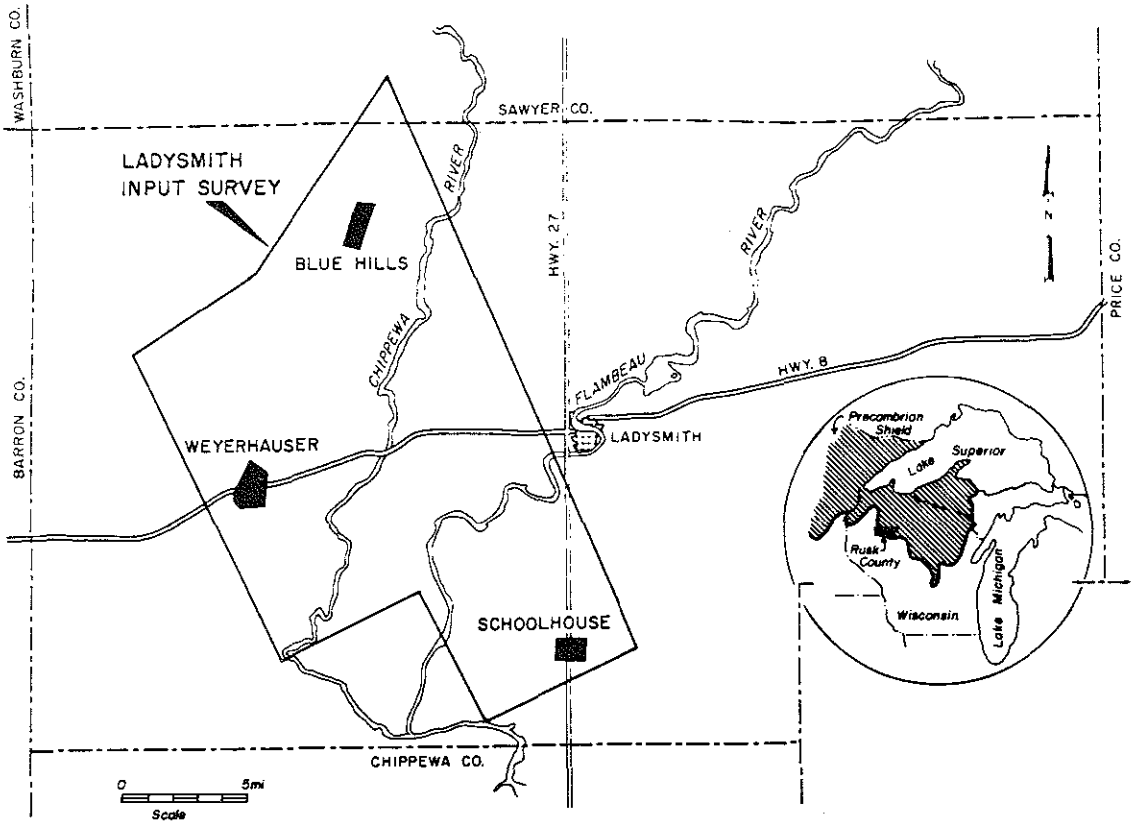

FIGURE I. RUSK COUNTY MAP SHOWING ORIGINAL PROSPECTS

After the close of Bear Creek's Central District office in 1960, no further work was done in this area until 1966 when geologic reconnaissance by J. S. Phillips once again focused attention on Rusk County. Based on three exposures of quartz-sericite schist, he recognized the potential of the area for the discovery of massive sulfide deposits. These three exposures came to be known as the Schoolhouse, Blue Hills (Glendale), and Weyerhauser prospects (Figure 1). The Schoolhouse area included the Skrypek property mentioned in the state literature.

Geophysical work was planned on these three prospects to study the extent of the sulfide distribution. Property easements were established, and in November and December of 1966 induced polarization (IP) work was done by Mineral Surveys, Inc. In each survey open-ended anomalies, presumably caused by disseminated sulfides, were detected.

The Schoolhouse prospect was chosen for a diamond drill test the following year. The source of the anomaly proved to be pyritized schist containing no base metals.

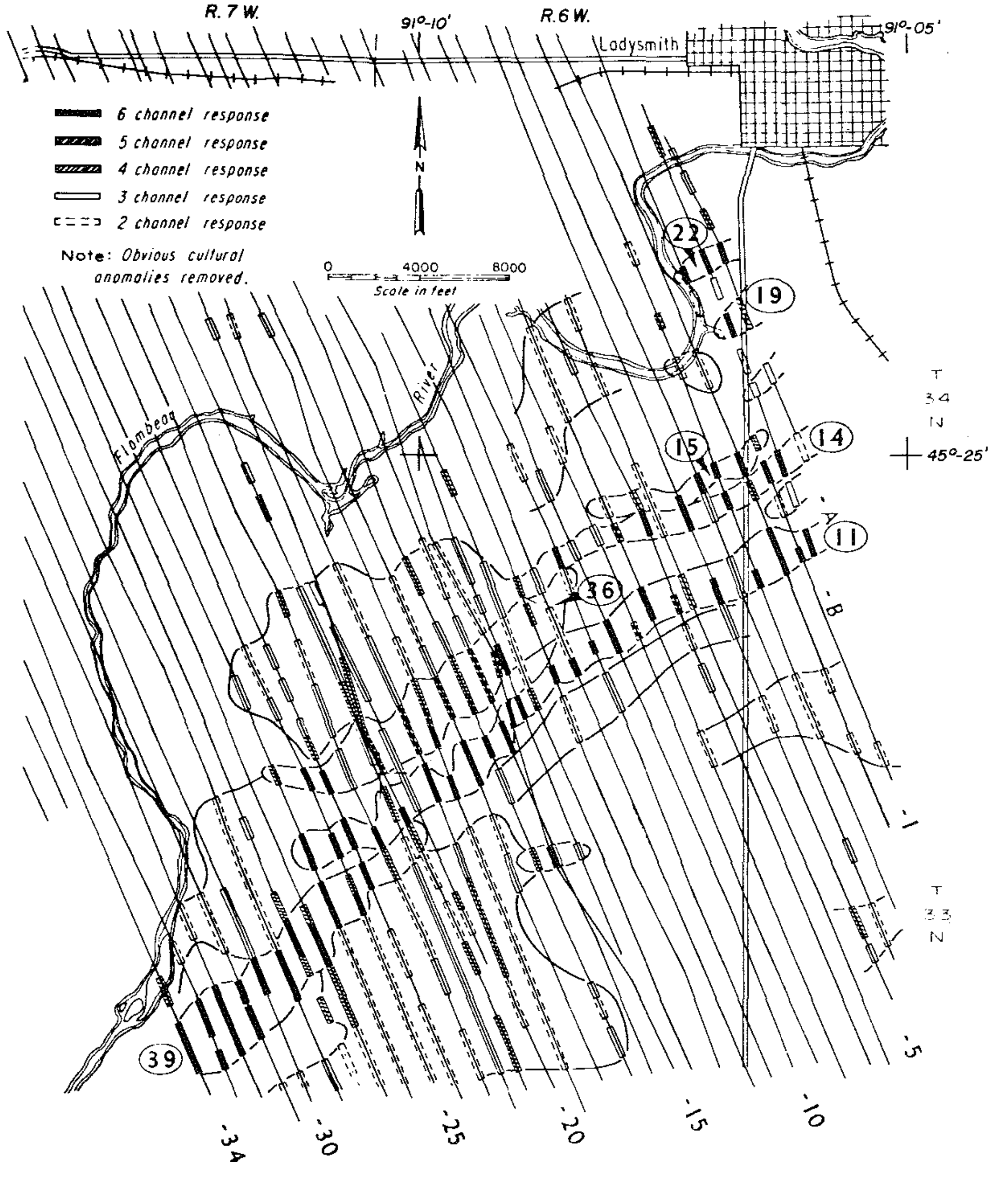

FIGURE 2. SOUTHEAST PORTION OF LADYSMITH INPUT MAP

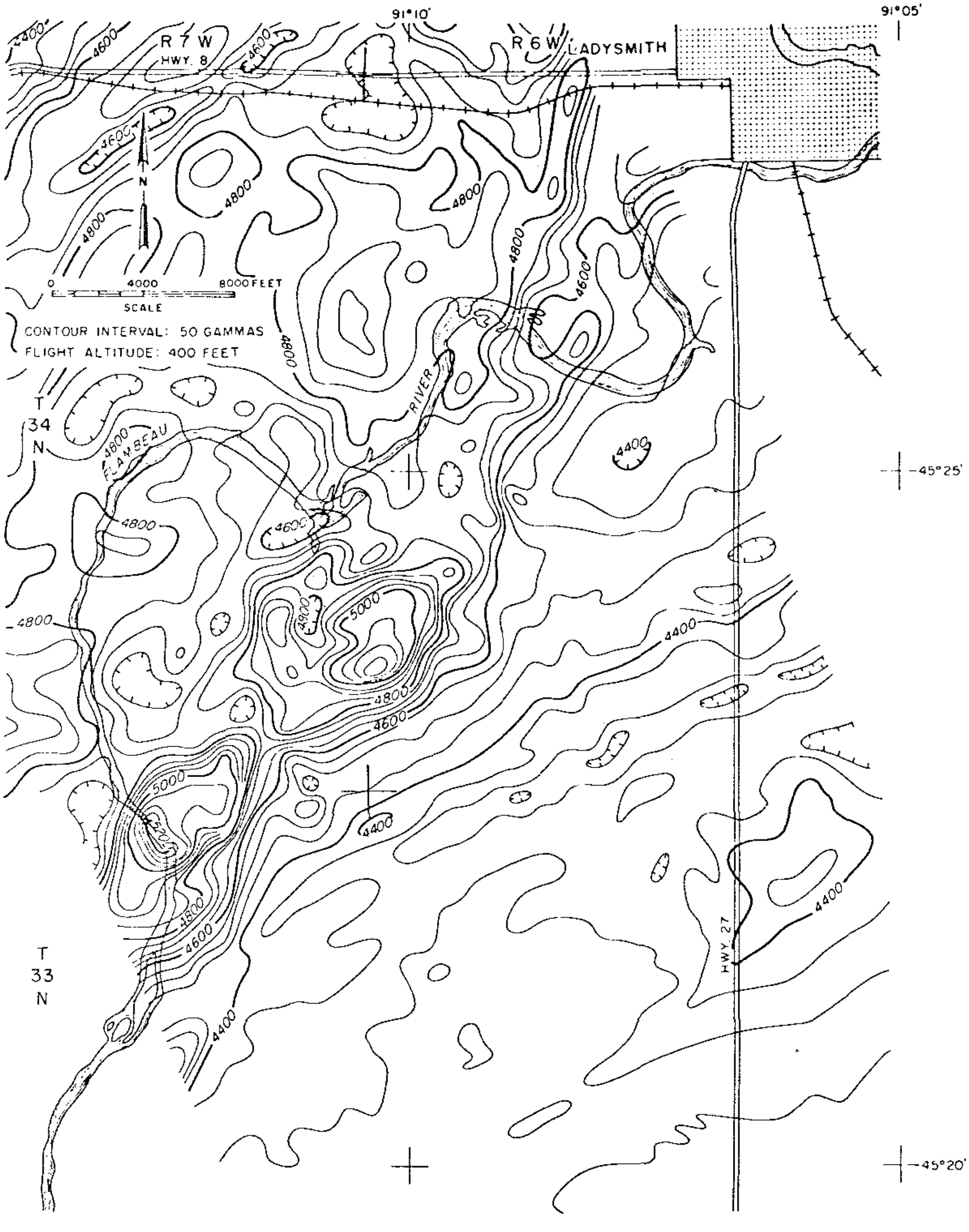

FIGURE 3. SOUTHEAST PORTION OF LADYSMITH AEROMAGNETIC MAP

In late May of 1967, an airborne EM (Mark V INPUT[2]) survey performed by Geoterrex, Ltd. was flown over a 220-square-mile block which included all three prospects. Survey specifications called for a flight line interval of 1,000 feet and terrain clearance of 400 feet. One-hundred-forty anomalies were recorded; most were caused by culture and overburden effects. No response was obtained over the three areas previously explored with IP. The southeast portion of the survey proved to contain a belt of high conductivity zones designated #11, 14, 15, 19, 22, 36, and 39 (Figure 2).

The aeromagnetic pattern (Figure 3) over the southeast portion of the survey displays a regional northeast strike. The belt of conductors falls in a locale devoid of well-defined magnetic patterns suggesting that rocks of felsic to intermediate composition predominate.

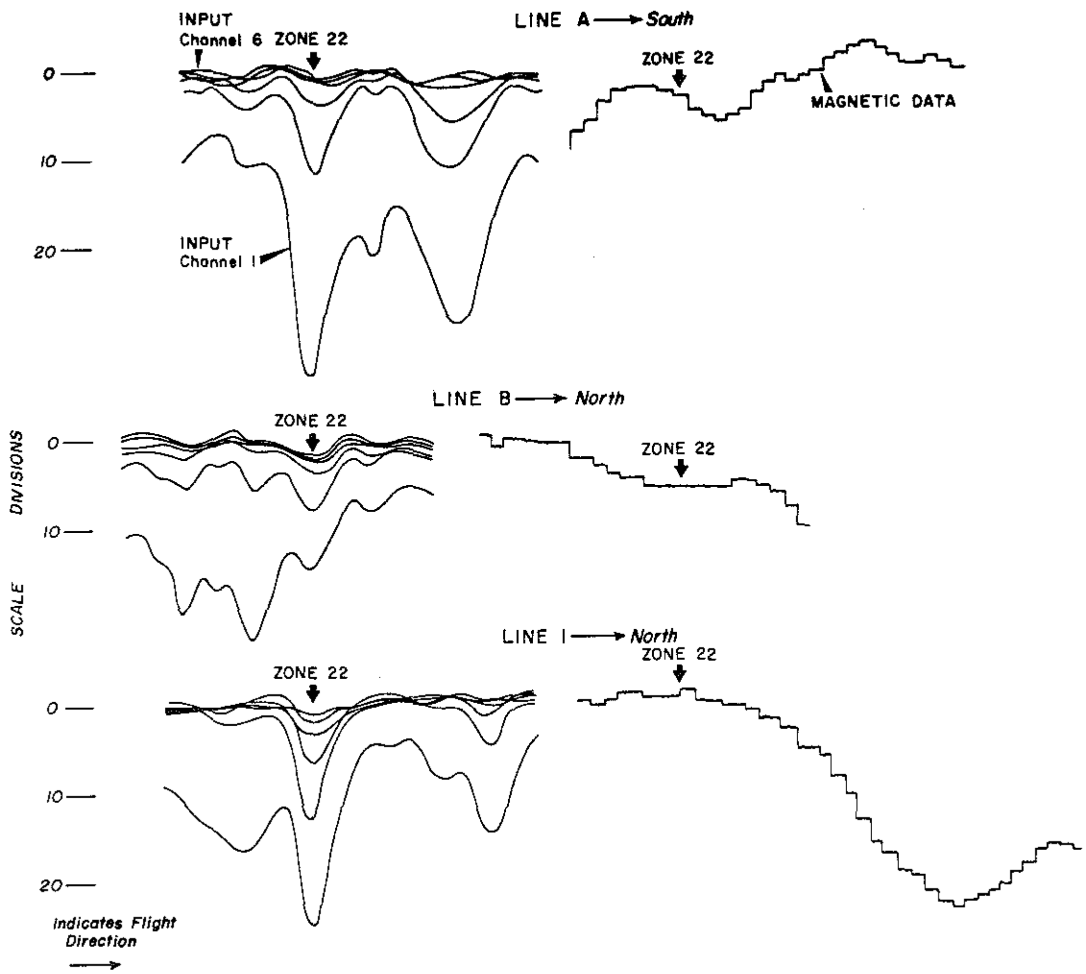

FIGURE 4. MK V INPUT TAPES OVER ZONE 22

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2 INPUT is a registered trademark for the time domain AEM system developed by Barringer Research, Ltd.

Zone 22, located on the north side of the belt of conductors, was detected only on the most easterly flight path, Line 1. Two short lines, A and B, were subsequently flown on the east side of the surveyed area. The additional flying confirmed that Zone 22 strikes to the northeast and remains open in that direction.

The INPUT profiles (Figure 4) are typical of the records acquired during this survey which, in general, reflect a high noise level. The profiles from flight line 1 indicate an excellent conductor with a 1st/4th channel ratio of 23/3. Profiles from flight paths A and B display a more subdued response; no associated magnetic anomaly was detected.

Two weeks after the flying was completed initial ground work was started by Kennecott personnel. Parts of June and July were spent sorting out cultural responses and attempting to get a feel for applicable ground tools. Work proceeded slowly as the company's previous experience in massive sulfide exploration in the U.S.A. was limited. The tools employed were a Ronka dual frequency slingram EM unit, a McPhar fluxgate magnetometer, and a Worden gravimeter. Field work in Wisconsin was discontinued in July because of other commitments.

During the third quarter of 1967, a segment of Zone 11 was earmarked for our initial land control effort. This block of ground was selected as a representative "slice" of the high conductivity belt, which would presumably be an appropriate place to begin a rigorous investigation. In addition, this central portion of Zone 11 exhibited a noticeable flexure or structural complication.

After freeze-up, geophysical work was again resumed. Our efforts were concentrated on accurately locating bedrock conductors and, hopefully,

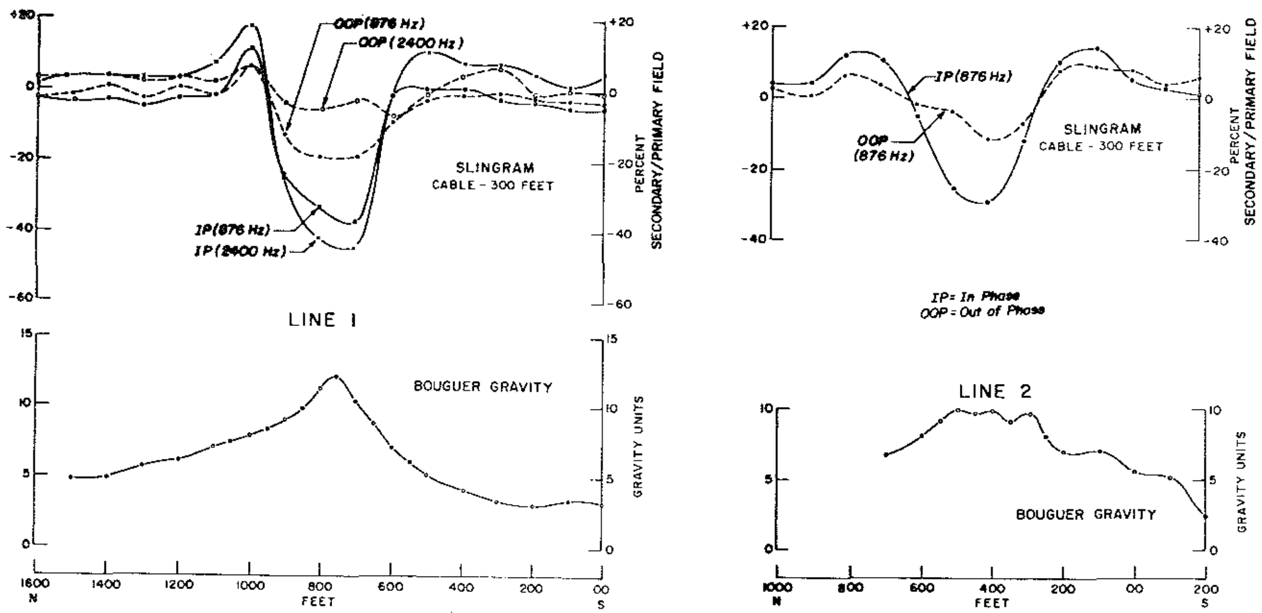


FIGURE 5. SLINGRAM AND GRAVITY PROFILES OVER ZONE 22

establishing a rank or priority for each zone. At this time slingram work on Zone 22 revealed a strong conductor along the east bank of the Flambeau River (Figure 5). A gravity profile taken over the same traverse indicated a coincident 0.80 (±.05) milligal gravity anomaly. Additional slingram and gravity profiles to the east demonstrated the continuing coincidence of the gravity and EM responses along strike. An expansion of our land position was immediately recommended.

Sufficient ground geophysical work was completed to outline the parameters of the zone. An interpretation of the slingram results permitted the following target description:

strike length	2,000 feet minimum
thickness	100 feet maximum
depth	30 feet on west end; gentle plunge to east
dip	80 degrees north
conductivity-thickness	6 mhos

In addition, density model studies accomplished with a dot chart suggested that to satisfy both the geometrical model and the gravity field data, a density contrast of 1.6 gm/cc would be necessary. A massive body composed of two-thirds sulfide material was predicted as the probable source (Figure 6).

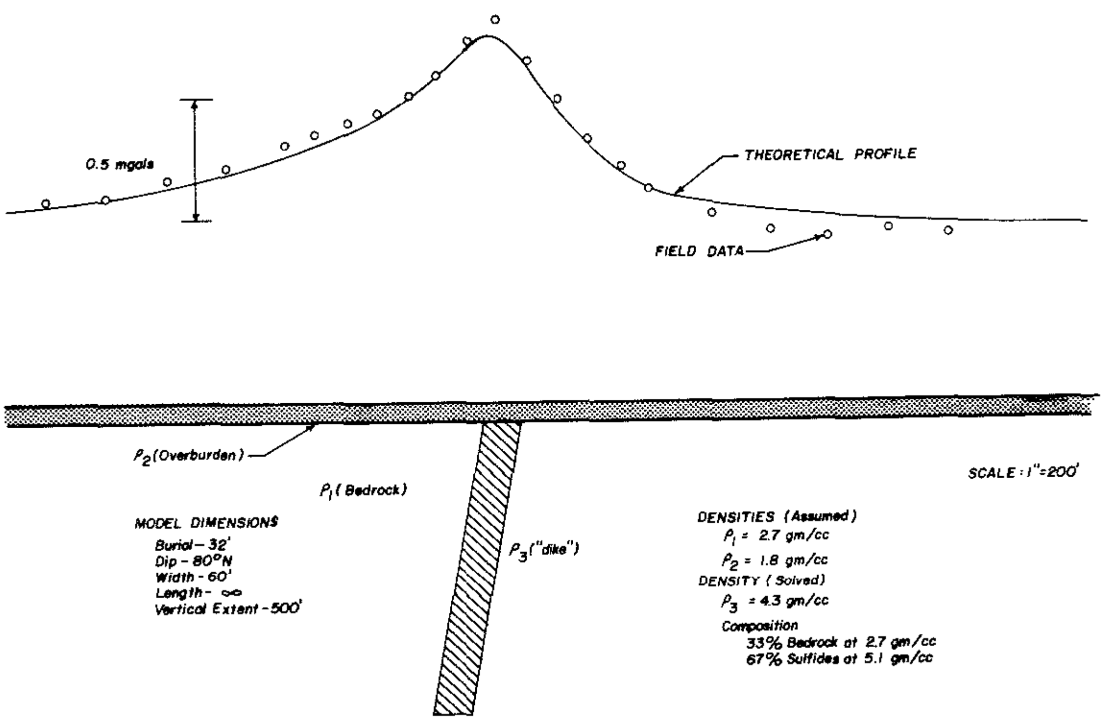


FIGURE 6. GEOPHYSICAL MODEL OF TARGET.

Meanwhile our ground follow-up work on the other Rusk County anomalies was thwarted by the depth capability of our slingram unit. For this reason we chose

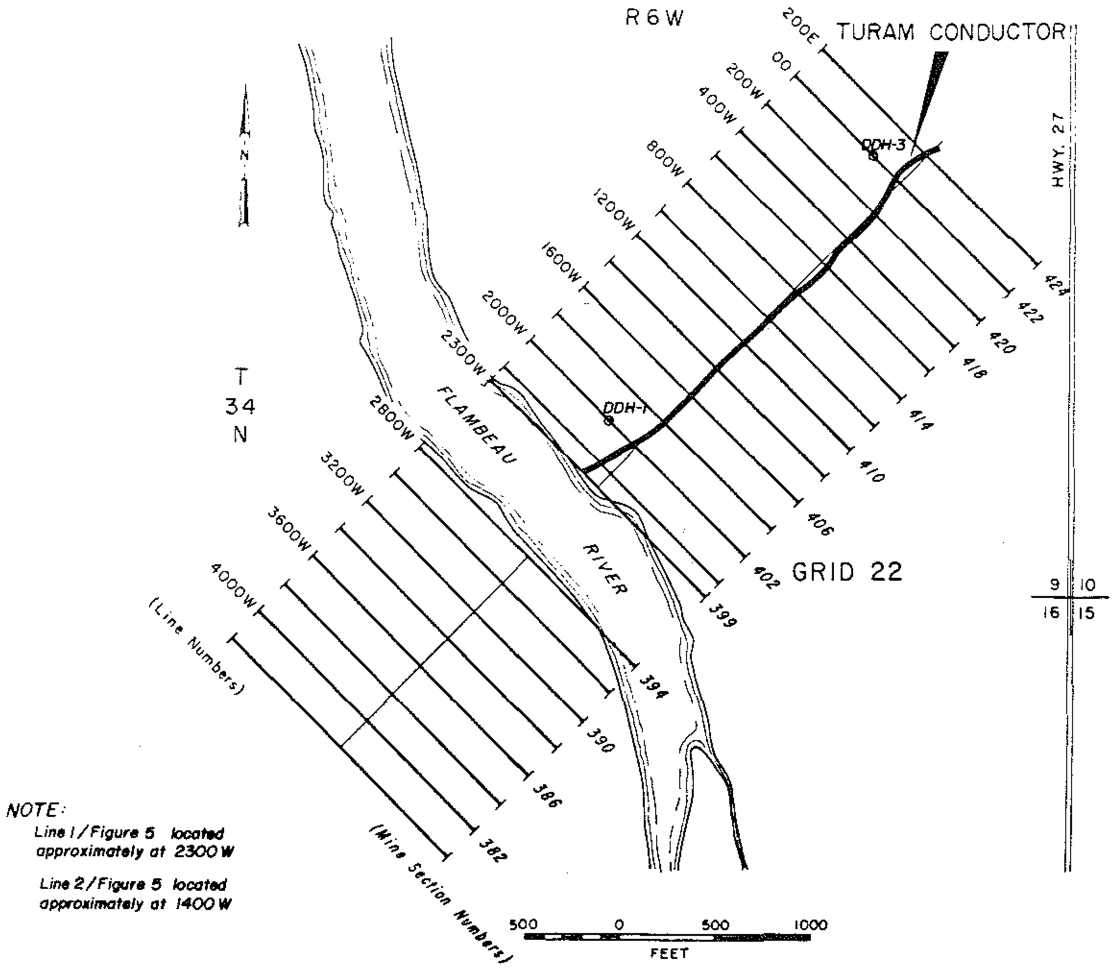


FIGURE 7. CONDUCTOR PLAN MAP

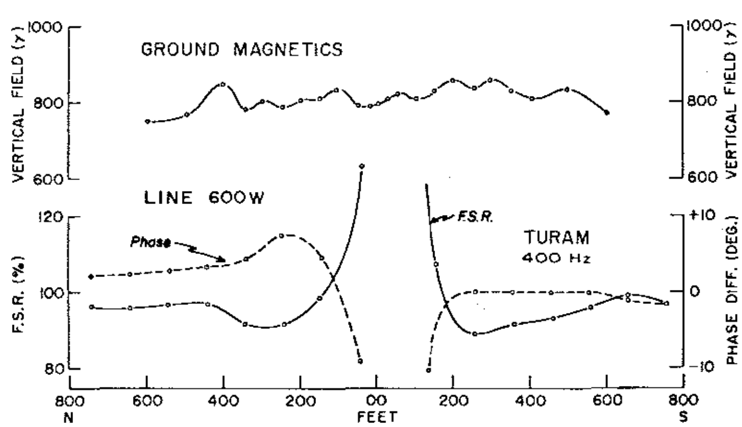


FIGURE 8. TURAM AND MAGNETIC PROFILES

turam EM as an alternative method. This approach was more successful and was done under contract to Mineral Surveys, Inc. utilizing a Scintrex SE-700 instrument.

During April 1968, an accurate grid was cut over Zone 22 utilizing 200-foot traverse intervals. At this time we decided to methodically survey the entire length of the zone with the turam system (Figure 7). A typical profile is shown on Figure 8. The abrupt distortion evident in the electromagnetic field could not be accurately measured with the 100-foot coil separation used; hence, the incomplete field strength and phase curves. No magnetic association was apparent in our data taken with an Askania vertical field instrument. Drill sites were immediately selected.

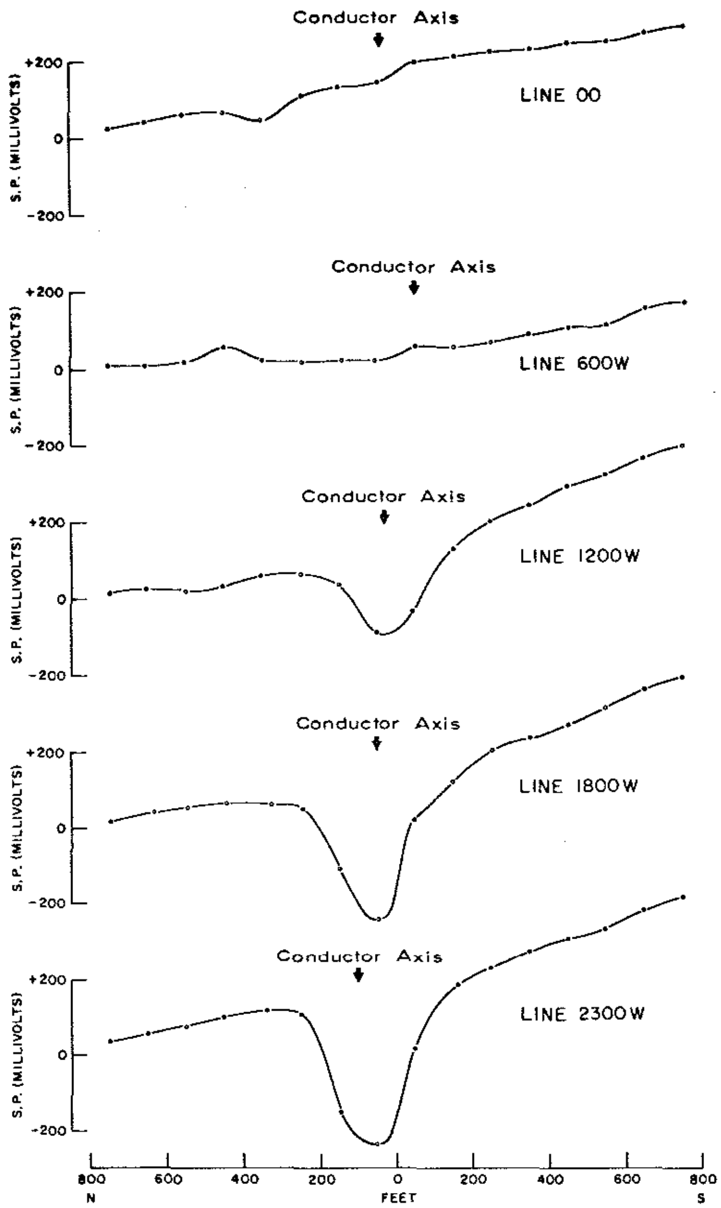
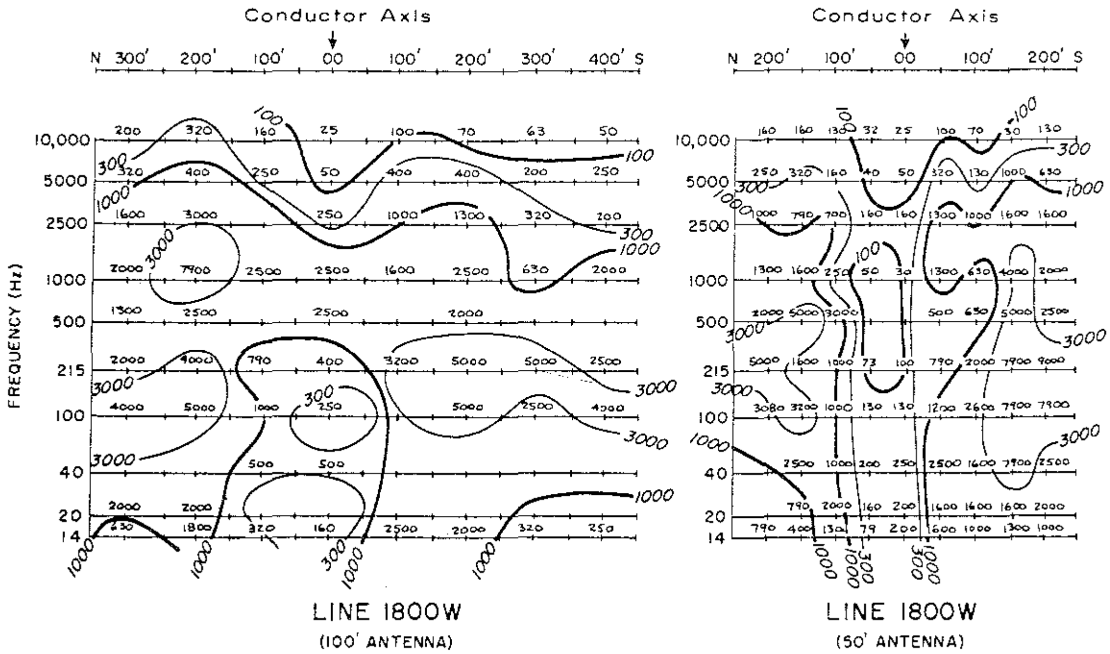


FIGURE 9. SPONTANEOUS POLARIZATION PROFILES

This well-defined, excellent conductor became a convenient testing ground for evaluating other techniques. Figure 9 shows the results obtained from spontaneous polarization experiments. These data were recorded with a Kennecott Exploration, Inc. (KEI) Mark I, IP receiver. A 100-foot dipole was utilized to measure the gradient and the true potential was calculated at each station. A maximum response of -430 millivolts was obtained along the east side of the river. The size of the anomaly decreased toward the east, apparently because of the increasing overburden thickness. The water table appears to overlie the conductor along the entire length of the zone and does not seem to be a controlling factor. Beyond Line 600 W. no SP phenomenon was detected.



E FIELD ANTENNA DUE EAST. DATA PLOTTED AT COIL END OF DIPOLE IN OHM-METERS

FIGURE 10. MAGNETOTELLURIC PROFILES

Magnetotelluric experiments were conducted with a KEI Mark V audio magnetotelluric receiver operating on 10 frequencies between 14 and 10,000 Hz (Figure 10). On the initial line a resistivity contrast of 10:1 was obtained. With the E-field antenna length shortened from 100 to 50 feet, the response became more pronounced exhibiting a 30:1 contrast. Note that near-surface resistivities are approximately 100 ohm-meters and background is roughly 3,000 ohm-meters.

A drill test of this exceptional target was made on November 6, 1968, when DDH 22-1 (on Line 2000 W.) intersected massive copper sulfides at a depth of 199 feet. Subsequent drill holes confirmed the tabular model constructed from the geophysical interpretation. Henceforth, Zone 22 became known as the Flambeau copper deposit.

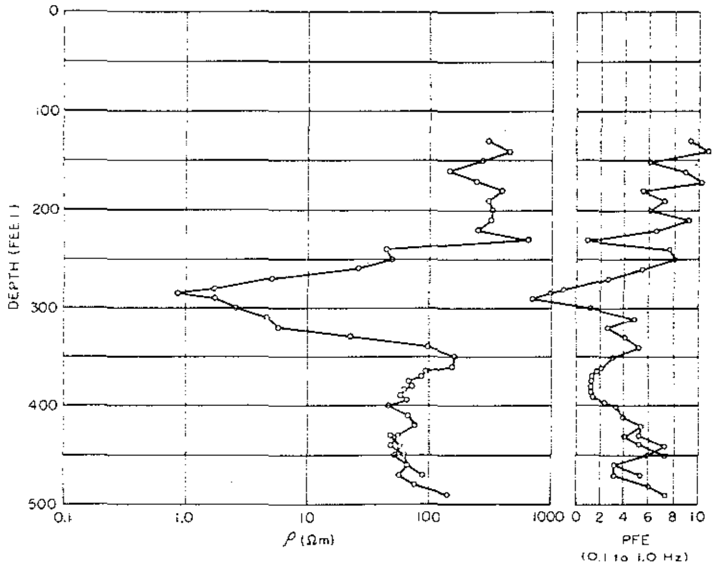


FIGURE 11. IP/RESISTIVITY LOG. DDH 22-3

Following the completion of DDH 22-3 on Line 200 W., an IP-Resistivity log was recorded by G. D. Van Voorhis (Figure 11). A three-array, downhole configuration employing an "a" spacing of 10 feet was used. Resistivity measurements in the massive sulfide zone compare closely with the conductivity-thickness estimate from slingram. The target horizon exhibits a resistivity of one ohm-meter contrasted with downhole and uphole wall rock resistivities of 70 and 300 ohm-meters, respectively. A negative IP response was measured through the sulfide zone which presumably performed like a short-circuit across the electrodes. The uphole portion of the wall rock exhibited higher frequency effects than the rock beneath the conductor.

Prior to plugging the hole with cement, a lead electrode was planted in the conductor at a depth of 280 feet. An effort was made to utilize this electrode in a mise a la masse configuration to further trace the east end of the horizon beneath the cultural interference associated with Highway 27. However, regular surface techniques proved far more effective and no additional downhole-source work was attempted.

Early in 1969 land was acquired in both directions on strike from the orebody. An extensive IP program was undertaken to map any disseminated tail or flare-out from the massive zone. Our equipment consisted of a standard KEI frequency domain (0.15 and 1.20 Hz) Mark II receiver and a Mark I, 4-amp transmitter.

An anomaly was traced in both directions using a dipole-dipole configuration which employed "a" spacings of 200, 300, and 500 feet. Directly over the conductor we recorded frequency effects exceeding 4 percent which were associated with prominent resistivity "lows." Progressing away from the main zone a recognizable resistivity pattern became difficult to discern; the IP response generally weakened and the source-depth appeared to increase. Typical profiles are displayed on Figure 12.

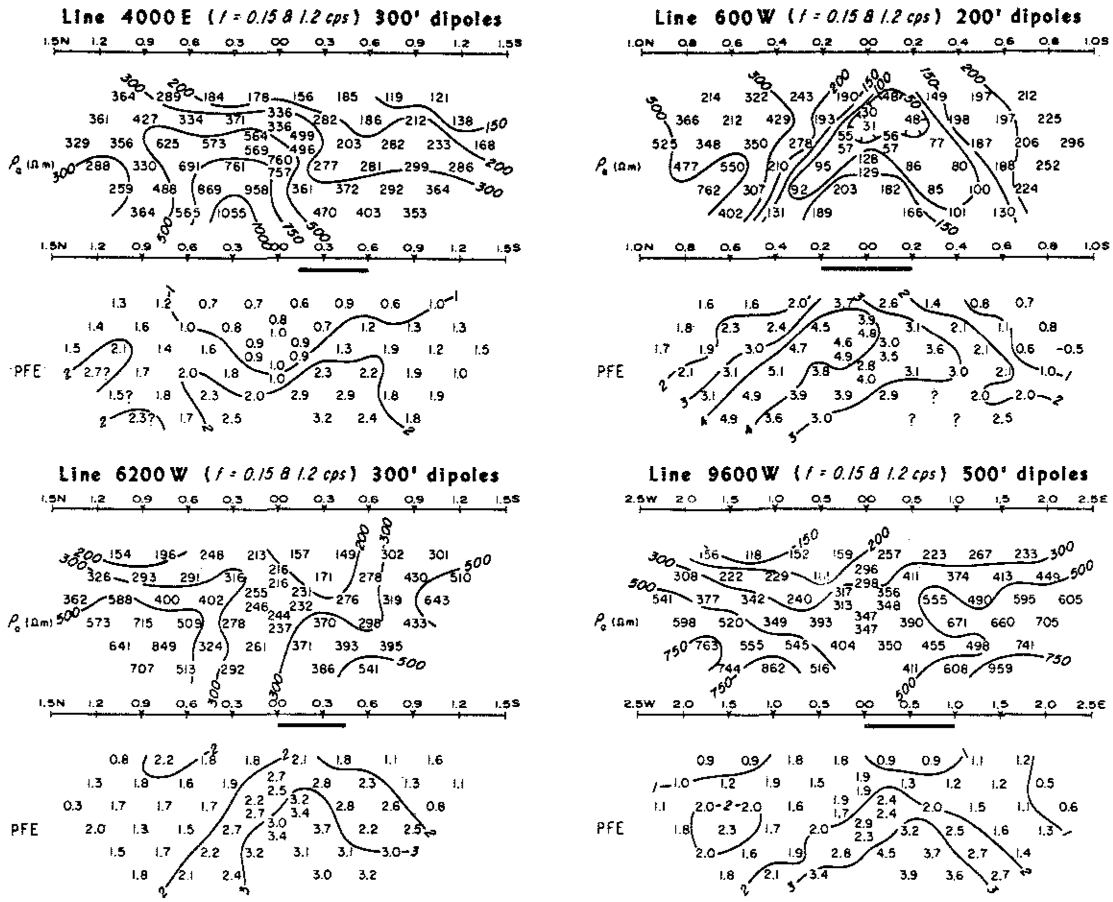


FIGURE 12. INDUCED POLARIZATION PROFILES

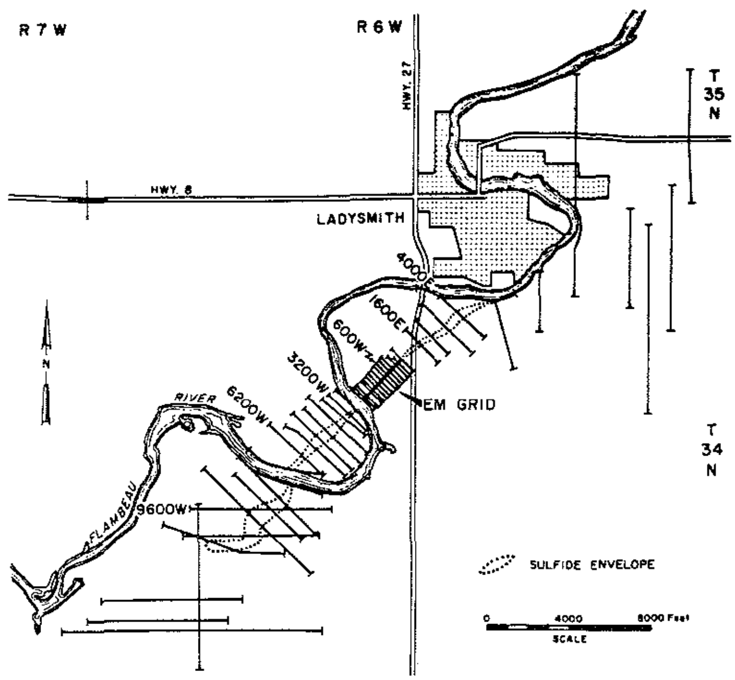


FIGURE 13. INDUCED POLARIZATION PLAN MAP

The sulfide envelope was mapped for an additional mile to the northeast and about two miles to the southwest. The complete IP anomaly is sketched in plan view on Figure 13. This interpretation has been borne out by numerous drill tests which intersected disseminated sulfides bearing minor amounts of metallic mineralization.

ORE RESERVES

During 1969-1970 an extensive drilling campaign was undertaken to evaluate ore reserves. Simultaneously, a saturation gravity program utilizing 507 stations was completed to permit excess mass calculations. This was accomplished with a Lacoste & Romberg, model G gravimeter which provided data we considered accurate to 0.1 milligal. True sea level elevations were determined by transit and stadia. The residual gravity contour map (Figure 14) shows that a maximum anomaly of 1.2 milligals was detected. By applying the Gauss Theorem (Hammer, 1945) a total excess mass of 6.33×10^6 tons was calculated to lie inside the boundary of the zero contour level.

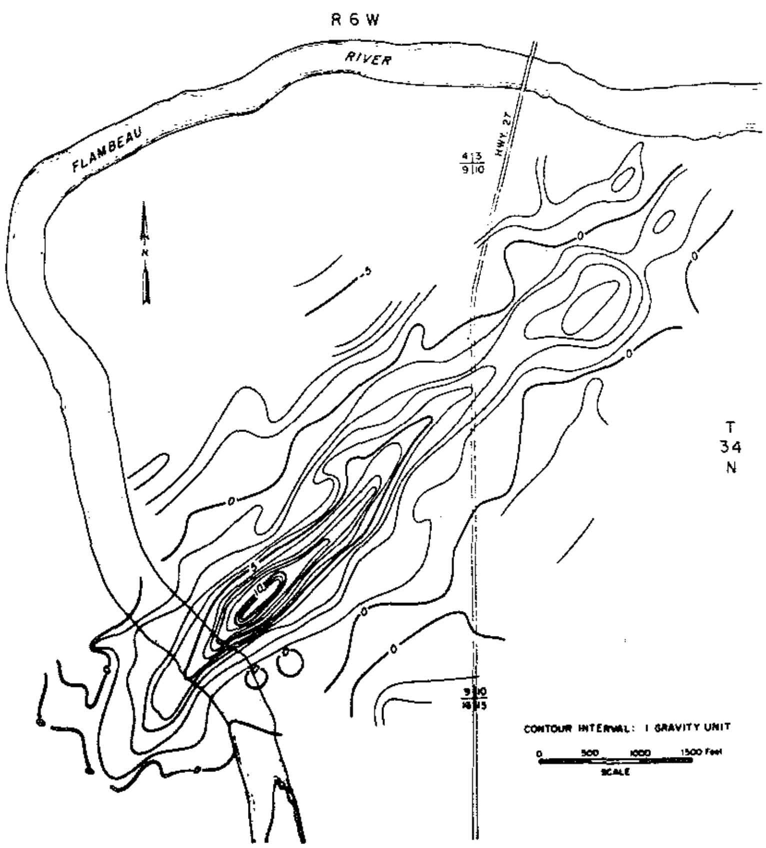


FIGURE 14. RESIDUAL GRAVITY PLAN MAP

Drilling information, however, defined the economic limits as the interval between Lines 200 E. and 2100 W. (mine sections 424 to 401). This interval includes approximately one-half of the total excess mass, or 3.12×10^6 tons. Density measurements of the host rock and near-surface ore average 2.6 and 4.3 gm/cc, respectively. Using these densities we projected a total of 8×10^6 tons of ore.

A thorough investigation of Flambeau has now been made to a depth of 800 feet by 135 inclined and vertical drill holes. The dimensions of the deposit, as it is now recognized, fit the geophysical description well. Figures 15 and 16 illustrate a simplified geologic cross section and plan map of Flambeau.

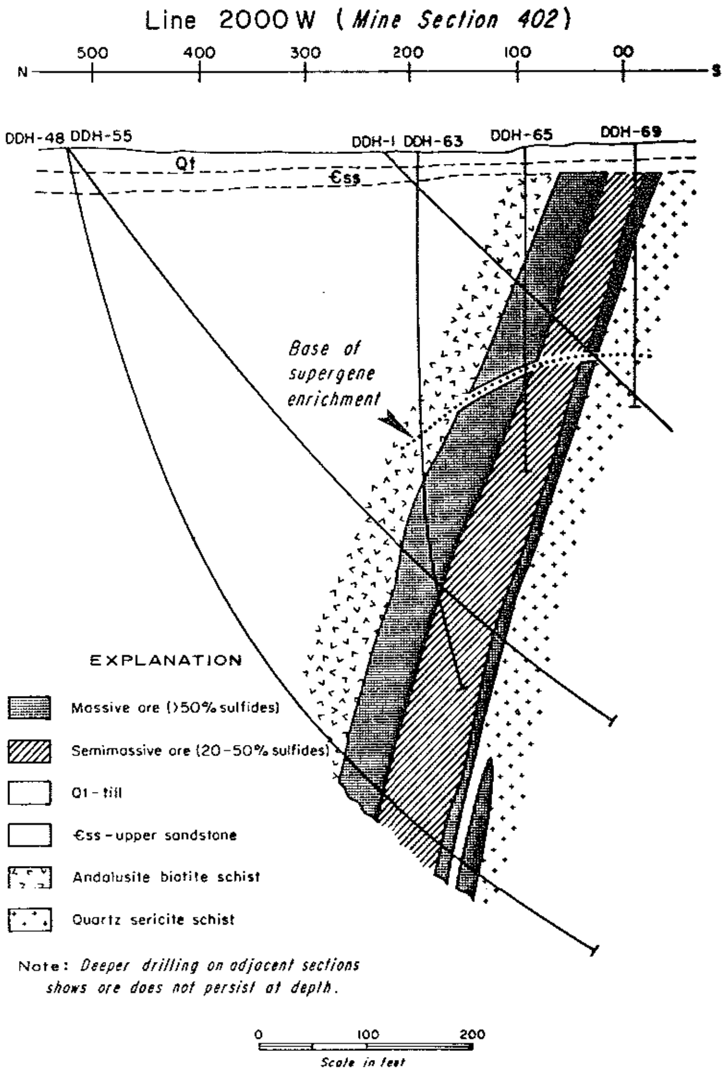


FIGURE 15. GEOLOGIC CROSS SECTION

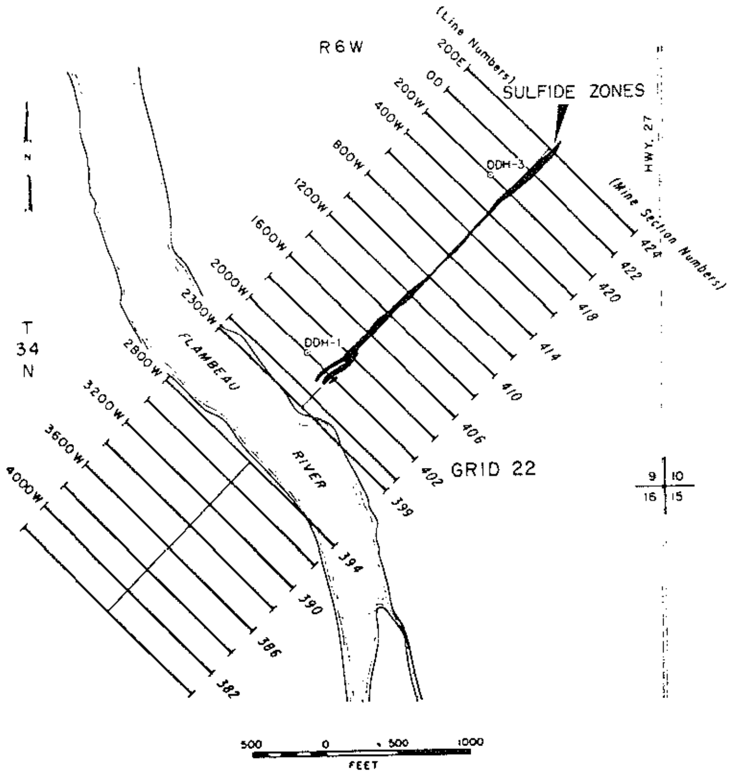


FIGURE 16. GEOLOGIC PLAN MAP

The mineralized horizon has been interpreted to be metamorphosed, felsic, fragmental volcanic rock with some siliceous chemical sediment. Several sulfide lenses, bounded by a quartz-sericite schist on the footwall and an andalusite-biotite schist on the hanging wall, have been defined. Mineralogic zoning studies suggest that this sequence has been overturned and that the south side is the stratigraphic top. This explains why the uphole wall rock (the geologic footwall) reflects the better IP response.

The most unusual and economically attractive feature of the Flambeau deposit is the extensive enrichment blanket in the upper 100 to 200 feet of the horizon. The principal mineralogy consists of supergene chalcocite and bornite. Below the enrichment zone primary pyrite, chalcopyrite, and lesser amounts of sphalerite predominate. Total reserves are now estimated to be 6 x 10^6 tons which deviate from our gravity solution by 25 percent. A detailed geologic description of the Flambeau deposit (May, 1976) is discussed in the accompanying paper.

ACKNOWLEDGMENTS

The author wishes to acknowledge the many contributions to this study that have been made by others. Particular recognition is in order for the following personnel of Kennecott Exploration, Inc. or Bear Creek Mining Company: Messrs. R. MacDougall and H. Fleming, for their persistent support of the Wisconsin exploration program; Messrs. E. May and H. Sichermann, who provided the geologic description; Mr. C. Topping, and numerous other Geophysics Division personnel, for their assistance in obtaining creditable field data; Messrs. N. Lutz and M. Wright, for helpful editorial advice. In addition, I would like to thank Mr. A. Rattew, of Geoterrex, Ltd., for valuable counsel regarding the INPUT system.

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