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Mineralogical and elemental trends in the Lucky Friday Mine Mullan Idaho

Thomas Scott Bryan

The University of Montana

MINERALOGICAL AND ELEMENTAL TRENDS

IN THE LUCKY FRIDAY MINE, MULLAN, IDAHO

by

Thomas Scott Bryan

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Approved by:

Don M. Lange

Chairman, Board of Examiners

John M. Stewart

Dean, Graduate School

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CHAPTER I

INTRODUCTION AND PURPOSE

The Coeur d'Alene District of northern Idaho is one of the best known mining districts in the United States. The district was discovered in 1884, and, from that time through 1965, it has produced more than 700,000,000 ounces of silver, 112,000 tons of copper, 6,900,000 tons of lead, and 2,450,000 tons of zinc (Hobbs and Fryklund, 1968). Production at many of the mines continues, and, because of the recent advances in metal prices, these mines have become more profitable. In addition, numerous old, inactive mines have been reopened and exploration for new ore bodies continues.

The Lucky Friday Mine is located in the eastern portion of the Coeur d'Alene District. It is operated by the Hecla Mining Company. In general, the ore consists of galena, tetrahedrite, sphalerite, chalcopyrite, and pyrite in a quartz-siderite gangue. These minerals form a replacement vein within the St. Regis and Revett Formations of the Precambrian Belt Supergroup metasedimentary rocks.

Both the location of the Coeur d'Alene District in Idaho and of the Lucky Friday Mine within the district are shown on Figure 1.

This study was undertaken in an attempt to understand the nature of the zoning in the Lucky Friday Mine revealed by the assay data of the Hecla Mining Company. Of special interest was the distribution

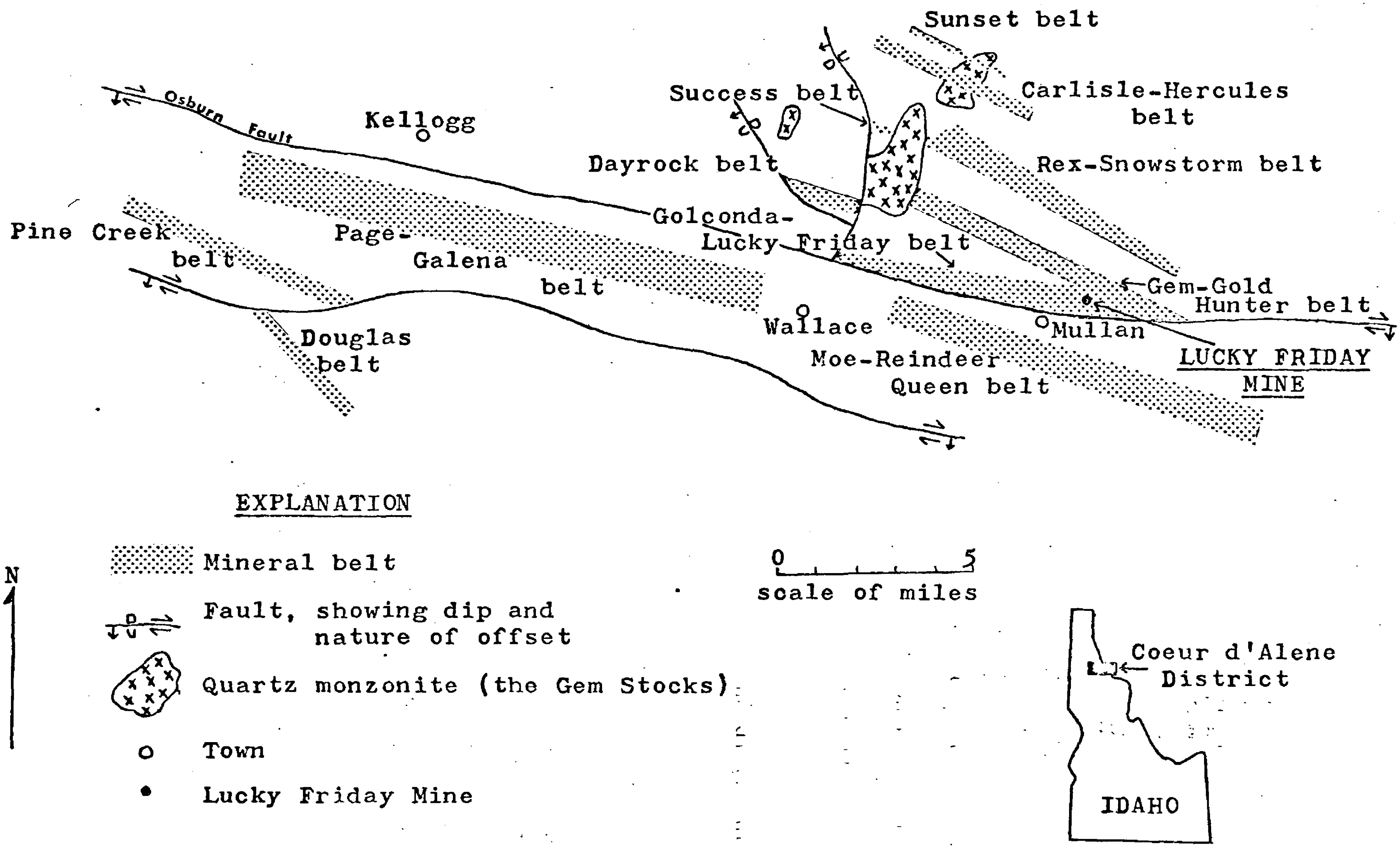

Fig. 1. The Coeur d'Alene District, Idaho, showing mineral belts, major faults, and the location of the Lucky Friday Mine.

of silver and bismuth in the westernmost portions of the Lucky Friday Vein. The ores were examined megascopically, microscopically, and chemically to 1) study the physical and textural relationships of the minerals, 2) identify all minerals present, 3) study the chemistry of the minerals, 4) study the distribution of silver, and all other major metals present, and 5) to determine how these relationships relate to the mode of formation of the ore body.

CHAPTER II

GENERAL GEOLOGY OF THE COEUR d'ALENE DISTRICT

Only the general geologic framework of the Coeur d'Alene District will be covered here. A detailed study of the geology of the district may be found in Hobbs and others (1965); a study of the ore deposits of the district may be found in Fryklund (1964).

The Coeur d'Alene District, located within northern Idaho and extreme western Montana, lies within the Northern Rocky Mountain physiographic province. Local relief in the district exceeds 3,000 feet (Hobbs and Fryklund, 1968).

The rocks of the district are primarily metasedimentary rocks of the Precambrian Belt Supergroup. These rocks are dominated by quartzites and argillites and, within the district, have been divided into six formations. Five of these formations are ore bearing (the Striped Peak Formation is not). These rocks have been intruded by several small quartz monzonite stocks (the Gem Stocks) and by diabase and lamprophyre dikes. All of these intrusive rocks are of late Cretaceous to early Tertiary age (Hobbs and Fryklund, 1968).

The Coeur d'Alene District lies at the intersection of the Lewis and Clark lineament (here represented mainly by the Osburn Fault) and a broad antiformal arch which extends at least as far as Kimberly, British Columbia some 230 kilometers to the north (Wallace and others, 1961). The Osburn Fault dominates the structure of the area (Figure 1). It has experienced right-lateral offset of perhaps as much as 25 kilometers (Wallace and others, 1961).

The age of the ore deposits has been, and still is being, debated. Several periods of mineralization have been recognized. Primary uraninite mineralization in undeformed veins in the Sunshine Mine gives an "age" of 1,250 million years (Eckelmann and Kulp, 1957). Apparently, major folding ceased before then. However, some major "Main Period" ore bearing veins cut the 100 million year old Gem Stocks (Wallace and others, 1961). Also, the diabase and lamprophyre dikes yield apparent Tertiary ages. Some of the diabase dikes appear to be associated with minor occurrences of the latest mineralization period (Hobbs and Fryklund, 1968). Thus, the physical geologic relationships suggest that the ore deposits are younger than the Gem Stocks, and, therefore, no older than late Cretaceous in age. However, geochemical data, including absolute age determinations, indicate a Precambrian mineralization. The conflicts presented by these data have not been resolved.

The veins of the district are found in elongate groups called "mineral belts" (Fryklund, 1964; Hobbs and Fryklund, 1968). These belts are shown on Figure 1. They may have originated as zones of shearing and fracturing that extended to great depth (Fryklund, 1961). The fractures subsequently served as channels along which migrating hydrothermal solutions passed and deposited the sulfide minerals.

The source of the ore forming metals is uncertain. The ore deposits are not syngenetic; they are not strata-bound and they commonly occur in clean, cross-bedded or thinly-bedded quartzites representative of a high energy, oxidizing environment. Lateral secretion is favored by some workers. Sorensen (unpublished Hecla Mining Company report, 1967) found evidence for lateral secretion while studying wallrock geochemistry and silicification-sericitization processes in the Silver Summit Mine (in the Page-Galena belt) and in the Lucky Friday Mine. The general lack of ore body zoning and the fine grained nature of the ores in the mines of the Coeur d'Alene District argue in favor of lateral secretion as the ore forming process because of the homogenizing nature of that mode of ore formation. Disseminated sulfide concentrations found in the country rocks of the district are the source of the metals in the lateral secretion hypothesis. An epigenetic origin for these deposits is suggested by the vertical elongation of the deposits and ore shoots on both large and small scales (Hobbs and Fryklund, 1968 and this study).

Many of the ore deposits of the Coeur d'Alene District are called "blind ore bodies;" e.g., they were not exposed or were barely exposed at the surface. The Lucky Friday Vein is one of these. The length of the vein exposed at the surface was only a few feet, yet on the 2600 level a total ore length of over 1,700 feet was mined (M. W. Hutchinson, pers. comm., 1973). (Figure 2). The Lucky Friday Vein probably represents a very old fault which has been deformed and mineralized since its last movement. The vein is enclosed within the quartzite of the St. Regis Formation; at depth, the absence of argillite interbedded with the quartzite indicates the possible

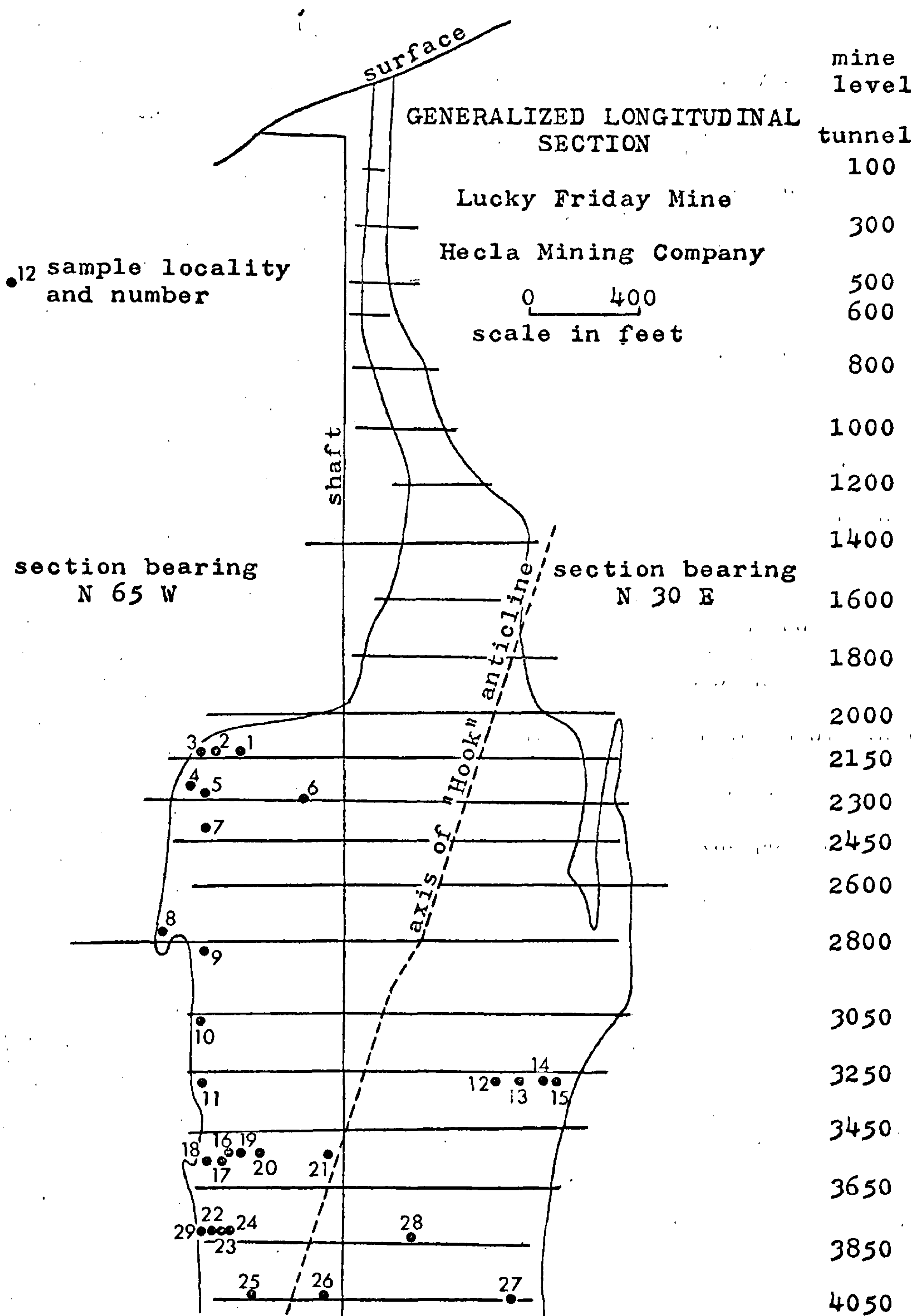

Fig. 2. Longitudinal section of the Lucky Friday Mine showing the sample localities and the axis of the "Hook" syncline.

presence of the Revett Formation (Hutchinson, 1961). A highly generalized plan view of the vein at the 3250 level of the mine illustrates the sinuosity of the vein and its relationship to the enclosing rocks (Figure 3).

The Lucky Friday Vein varies from a few inches to 14 feet in width, but averages about 6 feet. It is dominated by galena, quartz, and siderite. It also contains local concentrations of tetrahedrite, sphalerite, chalcopyrite, pyrite, and other less abundant sulfides. These minerals with their compositions are listed in Table III. It has been known from the examination of assay data that the vein is at least crudely zoned. Tetrahedrite-rich ore dominates the extreme western end of the vein; sphalerite seems to be concentrated about the "Hook" anticline (Figures 2 and 3). Also, the assay data indicate that the extreme western portion of the vein may consist of a series of small, physically and chemically distinct ore bodies called ore shoots.

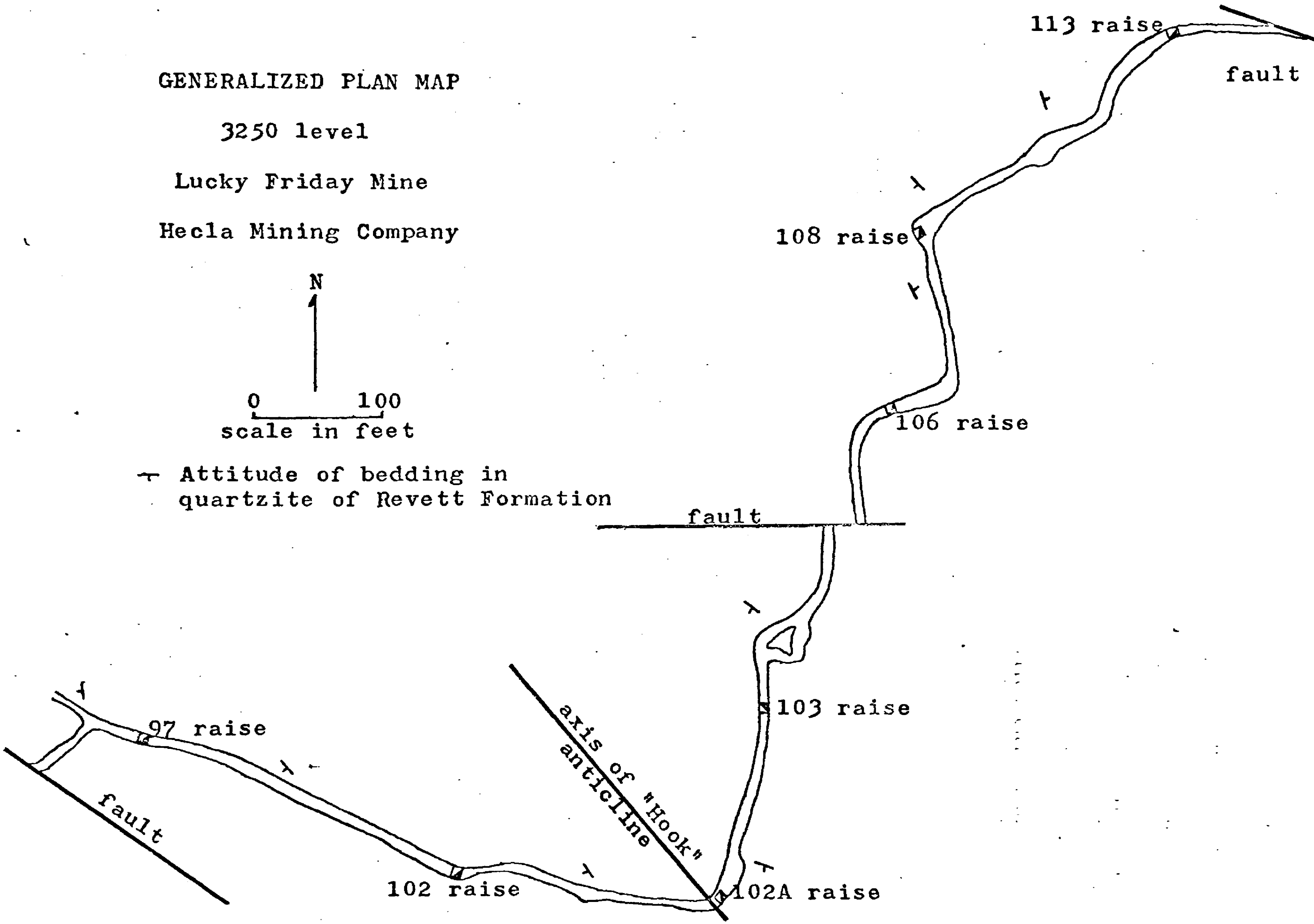

Fig. 3. Generalized plan map of the 3250 level of the Lucky Friday Mine.

CHAPTER III

PROCEDURE

All samples were collected in the Lucky Friday Mine by the author. The sample sites are located on Figure 2. The samples are described in Appendix A. In the upper portion of the vein sampling was restricted to the westernmost tetrahedrite-rich portion of the vein. Because the vein is mostly mined out above the 3250 level sampling was necessarily somewhat spotty in this area. Below the 3250 level samples were collected mainly from the western portion of the vein. A few samples were obtained from the central and eastern portions of the vein in order to provide information about the mineralogy and chemistry of those areas.

The mineral textures and physical relationships were studied in hand specimens and in polished slabs. These textures are shown in photomicrographs (Appendix C). X-ray diffraction and/or qualitative microchemical tests were used to confirm the mineral identifications.

Because of the fine grain size of many of the samples, the mineral separations for chemical analysis proved to be a long and aggravating process. A general separation procedure is outlined below because each sample required much experimentation in order to achieve the final pure mineral samples. This procedure is summarized in Figure 4. The final mineral separates analyzed are listed in Table I.

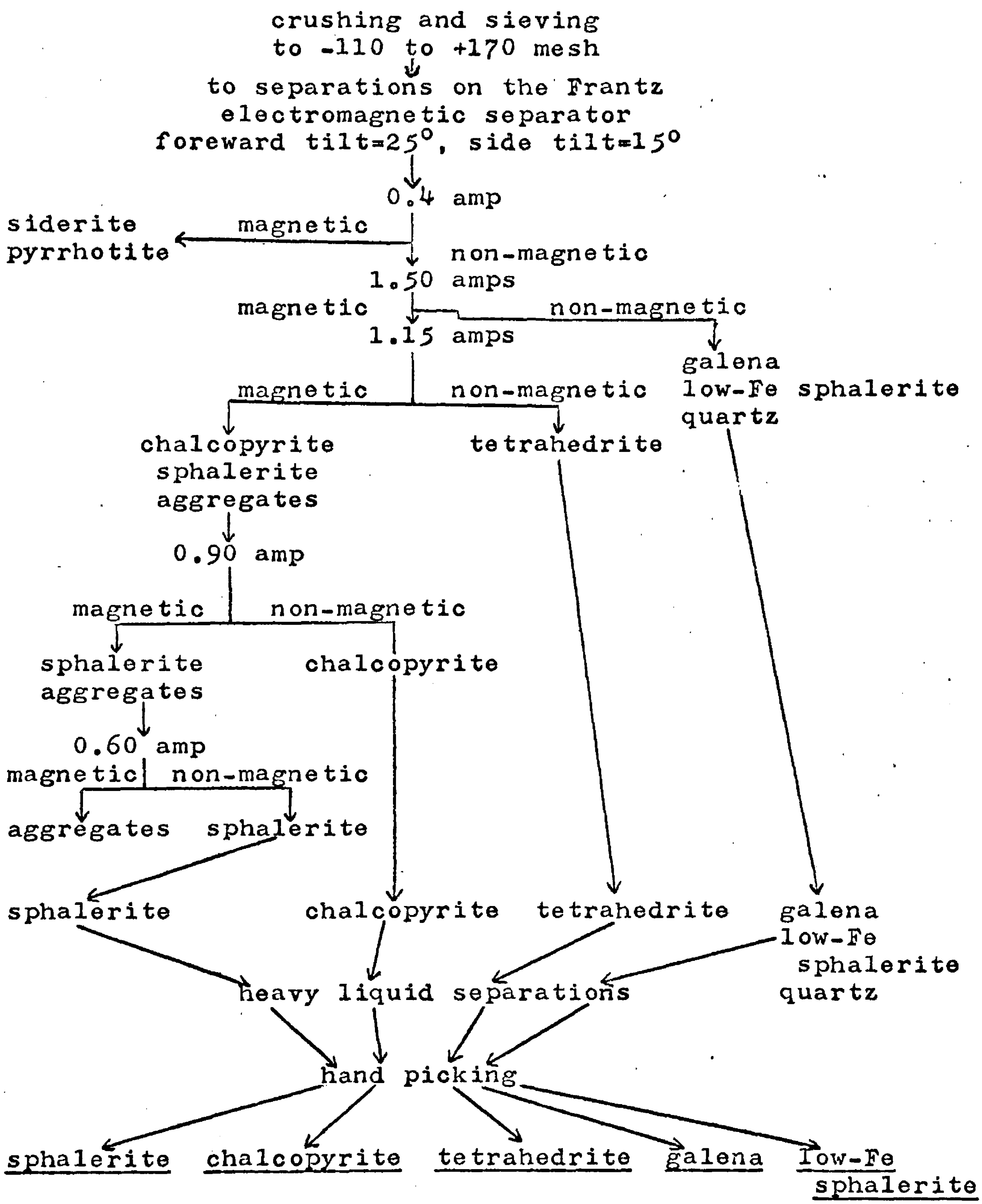

Fig. 4. Flowchart showing generalized mineral separation procedure.

TABLE I

LUCKY FRIDAY ORE SPECIMENS AND MINERAL SEPARATES ANALYZED

Sample number	Sample locality*	Mineral Separates Analyzed** gn	sp	td	sid
1	2150-95AR	X		X	X
2	2150-95AR-W65	X		X	
3	2150-95AR-W115	X	X	X	
4	2300-94R-W30	highly oxidized, no mineral analyzed			
5	2300-94R	X	X	X	
6	2300-100R	X		X	
7	2450-94R-W30	X		X	X
8	2800-94R-W65	X			
9	3050-96ER			X	
10	3250-96R	X			
11	3450-97R-W65			X	
12	3450-109R-W120	X	X		
13	3450-109R-W25	X	X		X
14	3450-109R-E80	X	X		
15	3450-109R-E133	X	X	X	
16	3650-95R	X	X	X	
17	3650-95R-W30	X	X	X	
18	3650-95R-W78	X		X	
19	3650-99R-W120	X			
20	3650-99R-W70	X	X	X	
21	3650-99R-E146	X	X		
22	3850-94R-W10	X		X	X
23	3850-94R	X		X	
24	3850-94R-E30	X		X	
25	4050-99R	X	X	X	
26	4050-101R	X	X		
27	4050-40 vn	X	X	X	
28	3850-105R	X	X	X	
29	3850-94R-W50	X		X	

** gn = galena; sp = sphalerite; td = tetrahedrite; sid = siderite.

* Sample localities: 3850-94R-W50, collected on the 3850 level in the active stope at a point 50 feet west of the number 94 raise.

The separation was begun by crushing and grinding a portion of each specimen. Whenever possible, the rough pieces were separated by hand according to the dominant mineral species present. The ground ore was sifted through nylon sieves; the -110 to +170 mesh fraction was saved for further treatment. This fraction was then separated on the Frantz electromagnetic separator: at 0.4 amp to remove the highly magnetic siderite and pyrrhotite; at 1.5 amps to remove the non-magnetic galena and quartz; at 1.15 amps to remove the tetrahedrite; at 0.9 amp to remove the chalcopyrite; and at 0.6 amp to remove the iron-rich sphalerite. Because of the presence of quartz and quartz-bearing aggregates, the various fractions were purified using heavy liquids (tetrabromethane, specific gravity = 2.96 and diiodomethane, specific gravity = 3.31). Because of the highly variable iron content of the sphalerite (some of which was non-magnetic at 1.7 amps), the final purity was achieved by hand picking the remaining quartz, siderite, and sphalerite impurities under a binocular microscope. Because of fine grained exsolutions, some chalcopyrite is present in both the tetrahedrite and sphalerite separates. Some tetrahedrite is present in the galena separate. However, on the basis of the chemical analyses, these separates are estimated to be at least 95% pure. The average purity of the individual samples is approximately 98%. The method of arriving at these estimates is described individually by mineral in Chapter 4.

The chemical compositions of the minerals were determined with a Varian AA-6D atomic absorption spectophotometer. Single element hollow-cathode lamps were utilized. All elements investigated were analyzed in an acetylene-air flame according to the parameters shown in Table II. In each case the instrument was operated in the direct-concentration readout mode with either a 3 or 10 second integrate function. Both the unknown solutions and the standard solutions were prepared so that the relationship between concentration and absorbance was linear.

Pure elements and analytical grade compounds were used to make the analytical standards. These materials are listed in Table II. Each of the standards was constructed so that the anion concentrations in the standards were similar to those in the unknown solutions. Two standards, one of high concentration and one of low concentration, were prepared for each element analyzed. These concentrations bracketed the range of concentrations in the unknown solutions.

The pure mineral samples were prepared for analysis following the procedures of Rubeska and others (1967). These procedures involved the use of concentrated nitric and sulfuric acids and a 10% solution of tartaric acid for the dissolutions. The sulfuric acid was omitted from the decomposition of galena in order to prevent the precipitation of large amounts of insoluble lead sulfate. Mercury (II) nitrate was added in every case to prevent the formation of colloidal silver chloride.

TABLE II

OPERATING PARAMETERS FOR THE VARIAN AA-6D ATOMIC ABSORPTION SPECTROPHOTOMETER

Element analyzed	Lamp current	Wavelength analyzed (nm)	Slit width (nm)	"Standard" material used
Cu	3ma	324.7	0.17	$CuSO_4.5H_2O$
Ag	3ma	338.3	0.20	$AgNO_3$
Fe	5ma	248.3	0.20	$FeNO_3$
Zn	5ma	213.9	0.20	$ZnSO_4$
Cd	3ma	228.8	0.50	$CdSO_4.8H_2O$
Bi	8ma	223.1	0.33	Bi metal

CHAPTER IV

MINERALOGY AND CHEMISTRY OF THE LUCKY FRIDAY ORES

Polished slabs of the ore samples were studied in order to fully describe the mineralogical composition and textures of the ores. All minerals identified in the Lucky Friday ore samples are listed with their compositions in Table III. The individual ore samples are described according to ore type and mineralogy in Appendix A.

The Lucky Friday ore specimens have been classified into three types. "Type-1" ore is fine grained. Galena is the dominant sulfide present and is associated with variable amounts of tetrahedrite, sphalerite, and chalcopyrite in a quartz-siderite-pyrite gangue. The galena crystals in the type-1 ore seldom exceed 0.5 mm in maximum dimension. The minerals found in the galena are generally rounded in outline. They are often slightly irregular in form; if so, they are interlocked with one another and the enclosing galena, forming a very tough rock. Plate 1 shows the texture of a type-1 sample.

Most of the mineral crystals in the "type-2" ore are coarse grained. Crystals average about 2 mm, and may exceed 1 cm, in maximum dimension. However, the galena may be fine grained in places. Galena is the dominant sulfide present. The associated tetrahedrite, sphalerite, chalcopyrite and quartz-siderite-pyrite gangue are more apt to occur as large masses rather than as inclusions in other minerals. Small

TABLE III

MINERALS IDENTIFIED IN THE LUCKY FRIDAY ORE SAMPLES

Name	Formula
galena	PbS
matildite(?)*	$AgBiS_2$
sphalerite	ZnS
pyrite	FeS_2
chalcopyrite	$CuFeS_2$
tetrahedrite	$(Cu,Ag,Fe,Zn)_{12}(Sb,As)_4S_{13}$
pyargyrite(?)*	Ag_3SbS_3
polybasite(?)*	$(Ag,Cu)_{16}Sb_2S_{11}$
bournonite(?)*	$CuPbSbS_3$
pyrrhotite	$Fe_{1-x}S$
arsenopyrite	$FeAsS$
siderite	$FeCO_3$
quartz	SiO_2
secondary minerals:	
greenockite	CdS
cerussite	$PbCO_3$
"limonite"	hydrous iron oxides
previously identified in Lucky Friday ores but not observed in the course of this study:	
jamesonite	$Pb_4FeSb_6S_{14}$

*tentatively identified

amounts of pyrrhotite, arsenopyrite, matildite(?), bournonite(?), and pyrargyrite(?) form minute grains in the galena, tetrahedrite and chalcopyrite. The texture of the type-2 ore is illustrated by Plate 2.

The "type-3" ore is composed of fine grained tetrahedrite in a coarse grained siderite-quartz gangue. Galena, chalcopyrite, and pyrite are present in small amounts. The texture of the type-3 ore is illustrated by Plate 3.

The characteristics of the three ore types are summarized on Table IV. The distribution of the ore types is shown in Figure 5. The type-2 and type-3 samples were confined to the western portion of the vein. The type-3 ore may be confined to ore shoots separate from the main portion of the ore body.

Fryklund (1964) describes the deposition of the Coeur d'Alene ore deposits as occurring in a series of "stages." According to this theory, the ore forming fluids were differentiated at the sulfide source. This differentiation resulted in a series of fluids of different compositions, each of which deposited a different mineral. Such a differentiation may or may not have occurred; the observed paragenesis (Figure 6) can be ascribed to a single solution which deposited the minerals under a changing set of physiochemical conditions. The beginning and end of each stage is sharp with no overlap with other stages (excepting pyrite of which several generations are known). The early formed minerals show successive replacement by the later minerals. If the replacement process was completed, the new mineral

TABLE IV

CHARACTERISTICS OF THE THREE ORE TYPES

Ore Type	Grain Size	Mineralogy
1	fine grained	ore: galena with lesser amounts of tetrahedrite, high-iron sphalerite, chalcopyrite gangue: quartz, siderite, pyrite
2	coarse grained	ore: galena with lesser amounts of tetrahedrite, low-iron sphalerite, chalcopyrite ± pyrrhotite, arsenopyrite, bournonite(?), matildite(?), pyrargyrite(?)
3	fine grained sulfides coarse grained gangue	ore: tetrahedrite ± galena, chalcopyrite gangue: siderite ± quartz, pyrite

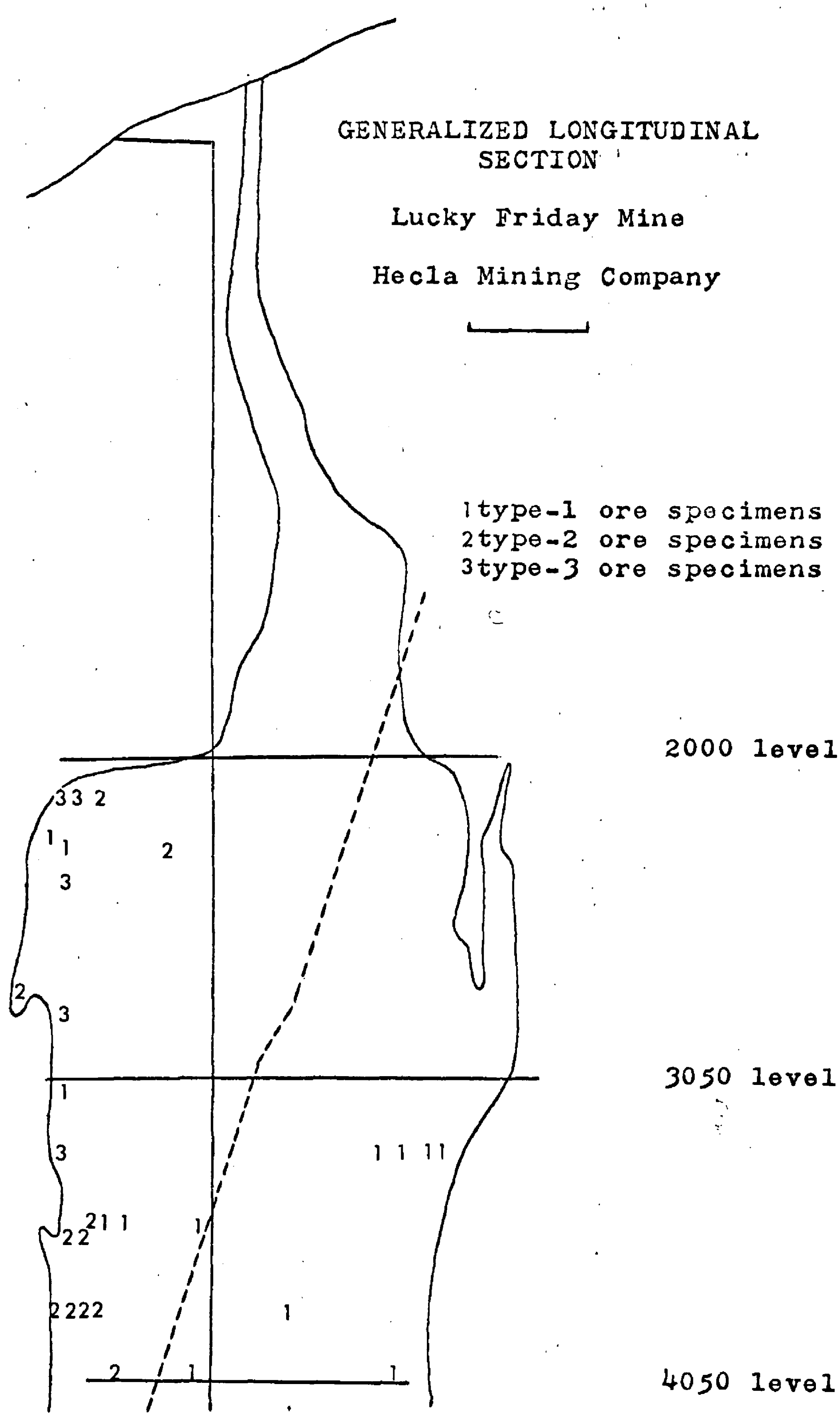

Fig. 5. Distribution of type-1, type-2, and type-3 ore specimens.

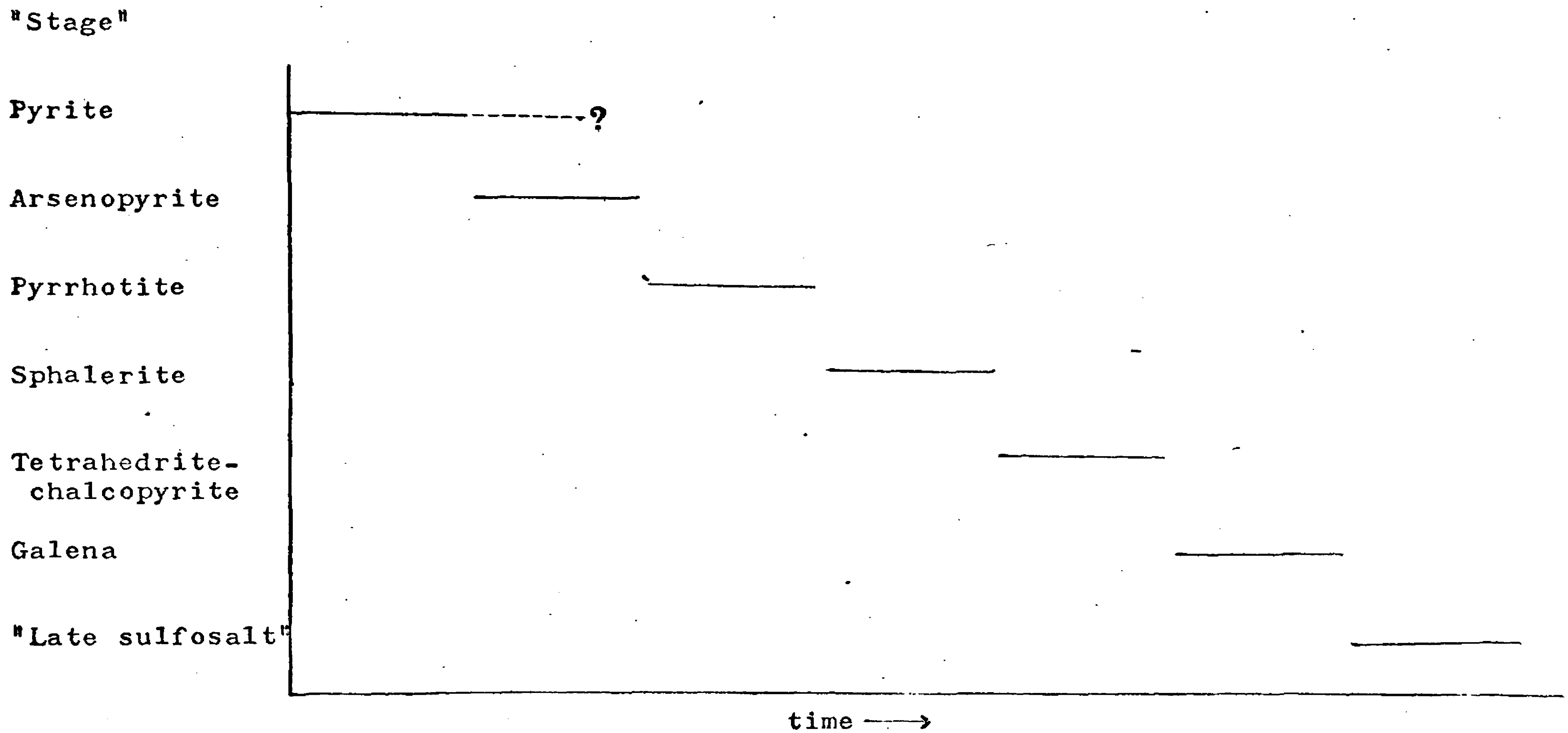

Fig. 6. The paragenesis of Coeur d'Alene sulfide deposition.

occurs as as a pure, monomineralic mass. Usually, however, the replacement process did not go to completion. In these cases, remnants of the earlier minerals occur as rounded inclusions in the later minerals. Most of the rounded inclusions seen in the Lucky Friday ore specimens represent such replacement remnants. Some, especially such examples as chalcopyrite in sphalerite, unquestionably represent exsolution of the inclusion from the host mineral.

The genesis of the type-1 and type-2 ores is problematical. The type-3 ore, restricted to a fringe along the westernmost portion of the vein, clearly formed under a different set of physiochemical conditions. Except for the type-3 ore, the galena dominated ore probably formed as fine grained type-1 ore and has since locally recrystallized to the coarse grained type-2 ore.

The Coeur d'Alene District was one of the first in which a post-ore deformational episode was recognized (Bateman, 1925). Such post-ore deformation may be necessary before ore recrystallization can occur. The deformation forms defects in the crystals which act as sites for the nucleation of the recrystallization (Stanton and Willey, 1972). Schistose (deformed) galena was found in two of my samples (3650-95R-W78 and 4050-99R). Arnold and others (1962) studied the equilibrium recrystallization of sphalerite-pyrrhotite assemblages from the Highland-Surprise Mine (located in the Pine Creek belt in the south-western part of the district (Figure 1)). The sphalerite-pyrrhotite binary is of little or no use as a geothermometer, being nearly insensitive to temperature (Barton and Skinner, 1967).

Therefore, the results of the Highland-Surprise study cannot be accepted with confidence. That study indicated post-deformational temperatures of 370°C to 490°C. Recrystallization begins in galena at about 300°C and in sphalerite at about 400°C (Stanton and Willey, 1971). If the evidence from the Highland-Surprise Mine can be taken to indicate that temperatures in excess of 400°C were attained in the Coeur d'Alene District, then certainly the recrystallization of the Lucky Friday ores was possible. Stanton and Willey (1971) stated that the extensive development of narrow twin lamellae in sphalerite may be evidence of recrystallization. This statement is not entirely supported by Ramdohr (1969). Nonetheless, such twinning is common in the coarse grained sphalerite masses of the type-2 ore, but it is not seen in the fine grained sphalerite of the type-1 ore. The iron content of sphalerite is strongly temperature dependent (for example, Ramdohr, 1969). A high iron sphalerite recrystallized at a temperature lower than that of its original formation will exolve excess iron as pyrrhotite or, in the presence of copper, chalcopyrite. The larger, iron-poor sphalerite from the type-2 ore contains abundant chalcopyrite as exsolutions and microveinlets and, also, is associated with pyrrhotite. The fine grained sphalerite of the type-1 ore contains none and chalcopyrite is uncommon in those ores. Information concerning the recrystallization of tetrahedrite is sparse. Tetrahedrite does recrystallize, but simple glide plane deformation is more common (Ramdohr, 1969).

The evidence supports a deformation-recrystallization history for the Lucky Friday ore. All type-2 specimens collected for this study were taken from west of the "Hook" anticline. It may be that the deformation was controlled by the attitude of the vein; the two portions of the vein differ in strike by about 90 degrees with the western limb nearly parallel to the regional fault pattern (Figures 1 and 3). A directed regional stress, resulting in the faulting, might well have sheared the easily deformed sulfides in the western (parallel) portion of the vein. This shearing could have caused the development of defects in the sulfide crystals, which in turn provided the sites for the nucleation of the recrystallization. In addition, those type-1 specimens taken from west of the "Hook" anticline often (but not always) contain large quantities of inclusions, especially quartz, in the galena. This might have been capable of preventing or limiting deformation.

Galena

Galena (PbS) is the most common sulfide mineral in the Lucky Friday ores. It is found most often as the fine grained type-1 ore. The coarse grained type-2 ore is dominant in the western portions of the vein along with smaller amounts of type-3 ore in which galena is a minor constituent.

Galena is always found in nature as nearly pure lead sulfide. Substitutions by other elements for the lead are very limited. The most common substitution is by silver. In galena formed under "ordinary conditions" (presumably at moderate temperature and pressure) the maximum substitution of silver for lead is only about 0.087% (Ramdohr, 1969). Bismuth may also substitute for the lead, but few studies have been made as to the maximum amount of such substitution. Ramdohr (1969) notes one example with 11% bismuth. In the case of nearly equivalent silver and bismuth contents (that is, with a one to one atomic ratio or one to two weight ratio), these elements are present at least in part as matildite ($AgBiS_2$) "molecules" either mixed with or unmixed from the host galena. Zinc, cadmium, iron, gold, platinum, and copper have also been reported to replace part of the lead in galena, but such substitutions involve only very small amounts of those elements (Palache, 1944; Hurlbut, 1959; Ramdohr, 1969). Also, the sulfur may be replaced by small quantities of selenium and tellurium (Ramdohr, 1969).

The galena samples were analyzed for silver, bismuth, and copper. The results of the analyses are presented in Table V. Because significant quantities (>0.01%) of copper do not occur in galena, the copper analyses provide an indication as to how much tetrahedrite is included as an impurity in the samples. Inclusions of sphalerite and chalcopyrite were easily removed and did not present a problem.

The copper content of the tetrahedrite is approximately 30% (Table VII). Therefore the percent impurity must be very close to the copper content of the sample multiplied by a factor of 3.3. Calculations of this sort, while approximate, show the minimum purity of the galena samples to be about 95.3% and the average purity to be about 98.3%. The silver contents presented in Table V have been

TABLE V

ANALYSES OF LUCKY FRIDAY GALENA SAMPLES*

sample number	ore type	constitutent in weight percent Ag	Bi	Cu
1	2	0.18	0.010	0.58
2	3	0.66	0.029	1.56
3	3	0.12	0.220	0.67
5	1	0.91	0.008	1.08
6	2	0.41	0	0.73
7	3	0.99	0.038	1.12
8	2	0.19	0.102	0.74
10	1	0.24	0.033	0.86
12	1	0.38	0.004	0.18
13	1	0.32	0.022	0.10
14	1	0.34	0.003	0.16
15	1	0.37	0.008	0.20
16	2	0.52	0.008	0.01
17	2	0.42	0.015	0.66
18	2	0.22	0.006	0.37
19	1	0.31	0.039	0.30
20	1	0.27	0.003	0.53
21	1	0.20	0.008	0.16
22	2	0.86	0.188	1.17
23	2	0.36	0.200	0.07
24	2	0.09	0.057	0.24
25	2	0.23	0.004	0.03
26	1	0.23	0.012	0.93
27	1	0.19	0.004	0.03
28	1	0.27	0.007	0.86
29	2	0.22	0.470	0.19

*corrected for included mineralogical impurities.

corrected with the amount of silver attributable to the included tetrahedrite (Table VII) subtracted from the analyses. In every case, the amount of bismuth attributable to the included tetrahedrite is negligible (maximum 0.00003%).

The silver values determined for the galena samples are plotted on Figure 7. Values in all but the extreme western portion of the vein are quite constant, ranging from a low of 0.20% to a high of 0.41%. The richest samples were obtained from the extreme western portion of the vein. In this region silver contents ranging from only 0.09% to 0.99% were found. No regular distribution of these values can be positively identified. The representation of Figure 7 does indicate the possible existence of a zone "lean" in silver along the extreme western margin of the vein, followed, inward, by a narrow zone of high values, and then the moderate values of the interior portion of the vein. The relationship between silver content and ore type is shown on Graph 1 of Appendix B. The silver content of the type-1 galena is quite restricted, ranging between 0.19% and 0.38% with one sample at 0.91%. The silver content of the type-2 samples is highly variable, ranging from 0.09% to 0.86%. The type-3 samples, of which only three were available, also show highly variable silver contents (0.22% to 0.99%).

The bismuth values in galena, which provide information as to the presence or absence of matildite, are shown on Figure 8. The bismuth values show a distribution similar to that of silver. The values are generally higher in samples collected in the extreme western portions

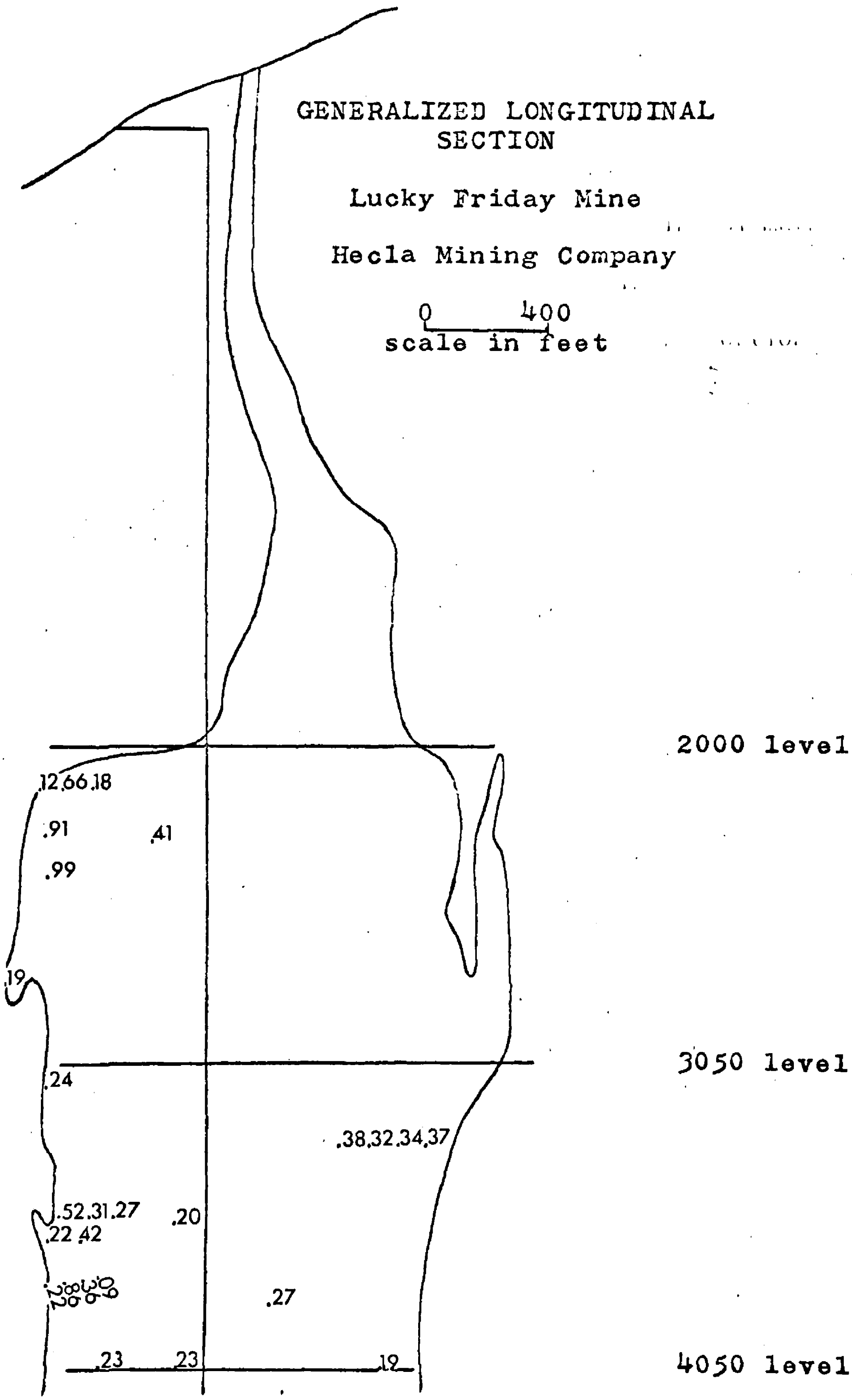

Fig. 7. Longitudinal section showing silver values in galena samples (in percent).

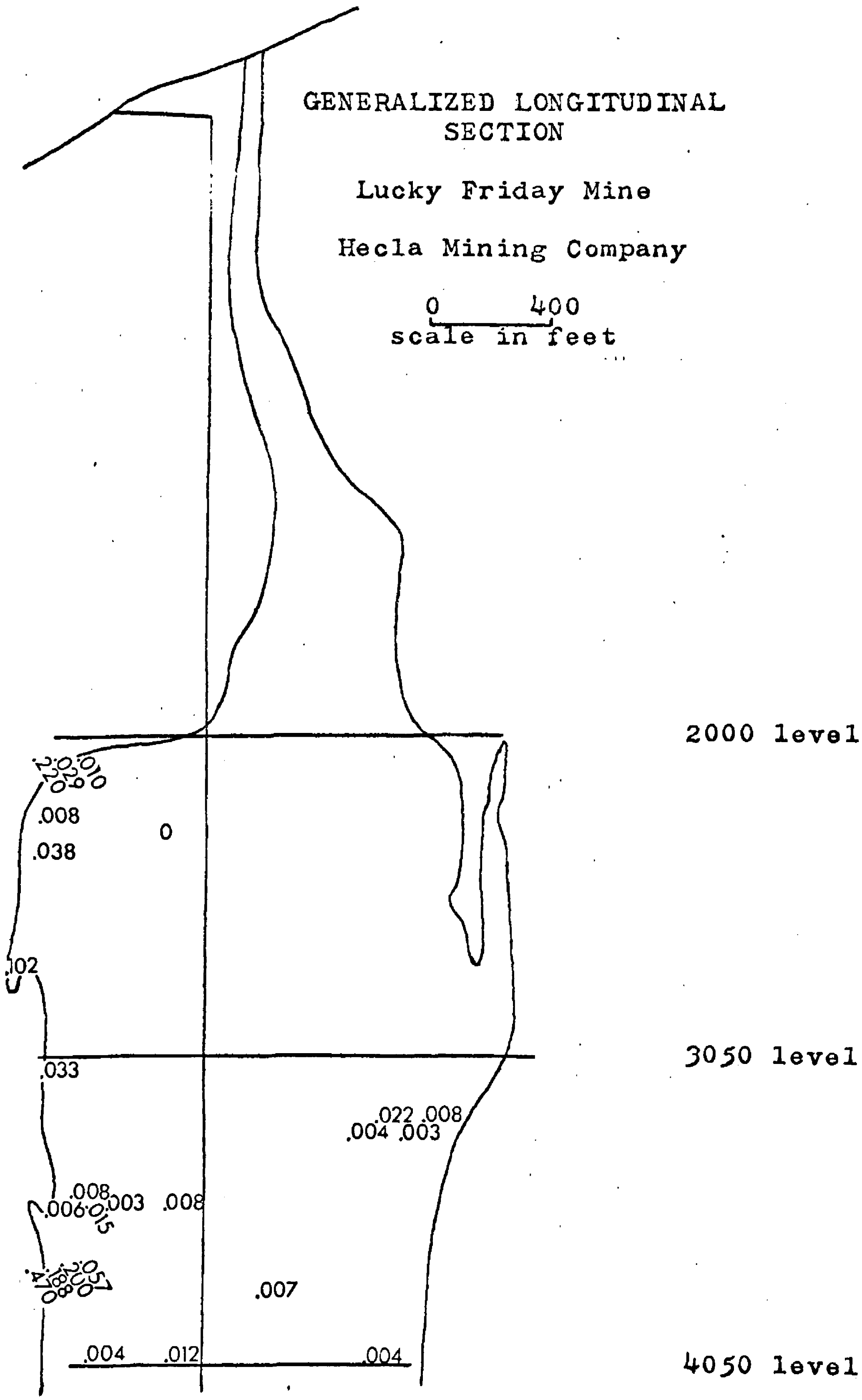

Fig. 8. Longitudinal section showing bismuth values in galena samples (in percent).

of the vein. The highest bismuth content (0.470%) was in a sample collected from the last few feet of ore on the 3850 level. Eastward, the bismuth contents drop sharply to near-zero values. Graph 1 of Appendix B illustrates the relationship between the bismuth content and the ore type. By far the highest values are found in type-2 (and one type-3) ore samples. Such samples, however, do not always contain high bismuth contents. None of the type-1 ore samples contained significantly high amounts of bismuth.

The relationship between the silver and bismuth contents is shown by Graph 1. While the distributions of the two elements within the mine seem to coincide, large amounts of silver and bismuth seem to be mutually exclusive in the individual galena samples.

Matildite

Matildite ($AgBiS_2$) is a very rare mineral. World-wide, it has been observed in small amounts in the mines of several mining districts. When found, it is always included in (or at least associated with) galena. Matildite has been tentatively identified in the Lucky Friday ores on the basis of electron microprobe examinations of three ore samples (R. Lillibridge, pers. comm.). Although it was only tentatively identified in the course of this study, matildite is discussed because of its bearing on the silver-bismuth relationships observed in the galena samples. A full discussion of its properties, chemistry, and occurrences may be found in Ramdohr (1969).

A complete solid solution series of matildite in galena is possible at elevated temperatures (above 225°C). Upon cooling below the inversion temperature matildite becomes orthorhombic and may exolve from the host galena. These exsolutions usually form very fine lamellae parallel to the (111) direction of the galena. However, the matildite does not always exolve, especially when it is present in concentrations below three or four percent (Ramdohr, 1969). Although the maximum solid solution of Ag_2S (argentite) in galena amounts to only 0.1%, "relatively considerable amounts" of $AgBiS_2$ may remain dissolved at low temperatures (Ramdohr, 1969). "In the case of essentially equivalent Ag- and Bi-contents in galena of high to intermediate temperature of formation, you will search in vain with the microscope for the silver-bearing material" (Ramdohr, 1969).

A re-examination of my samples which analyzed high in bismuth revealed a few lamellae of what may be matildite only in sample 2800-94R-W65. (Plate 2). Microchemical etch tests were of no value as an aid in the identification because of the very small size of the lamellae and the strong reaction of the galena to the reagents. However, the moderate silver and high bismuth contents of this sample indicate that the existence of matildite is possible, in this case at least.

Part of the silver and bismuth may occur as $AgBiS_2$ "molecules." Most probably remain dissolved in the galena, but some may have exsolved as very small but discrete lamellae. In either case, the matildite is probably restricted to the extreme west end of the vein.

Sphalerite

Sphalerite (ZnS) is common in the Lucky Friday ores, but is nowhere abundant in the main portion of the vein. Sample 4050-40 vn, number 27, taken from a large wall vein, is about 52.6% sphalerite (by modal analysis).

Two distinct varieties of sphalerite were observed. Most widely distributed but less common in volume is a dark, opaque iron-rich variety. Although it is found in both the type-1 and type-2 ores, it may be locally abundant in the type-1 ore (Plate 1) but is uncommon in the type-2 ore. The second variety of sphalerite is light colored, generally yellow- to red-brown, and is relatively iron poor. It is found only in the coarse grained type-2 ore and is itself coarse grained.

Assay data provided by the Hecla Mining Company shows a zone enriched in zinc (>1.5%) centered about the "Hook" anticline and other zones impoverished in zinc (<0.5%) in the extreme western and eastern parts of the vein. These zones are illustrated on Figure 9. The boundaries of these zones are approximate. They were selected at those points in the assay data where the zinc values change suddenly; the average ore grade over any 20 feet or more will fall into the specified ranges of zinc content. Because of the emphasis of the elemental distribution in the mine, samples were collected in order to provide examples of as many minerals as possible from each locality. Therefore, the amount of sphalerite obtained from each locality was inordinate, and no mineralogical zonation of sphalerite similar to the

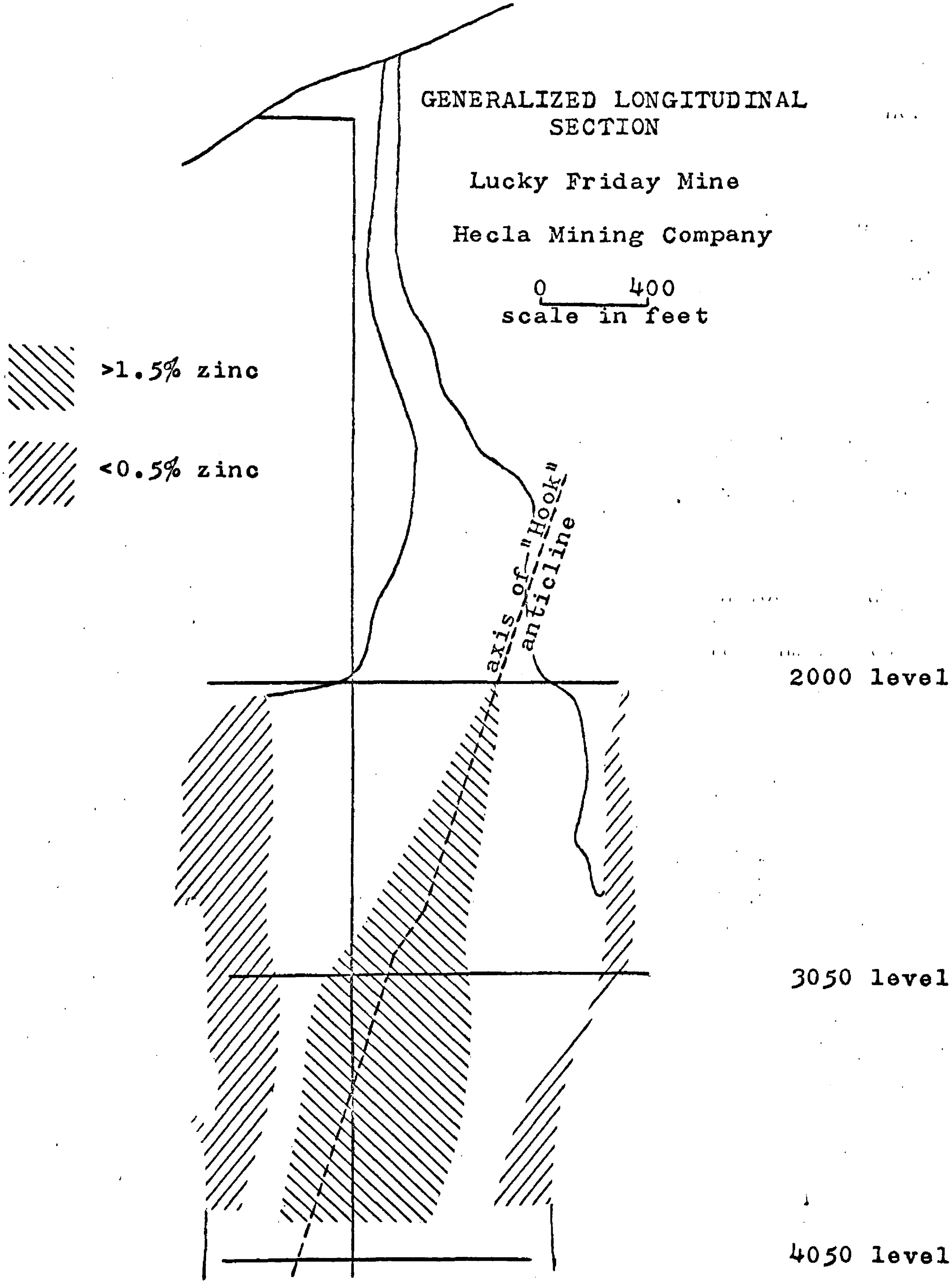

Fig. 9. Distribution of zinc in ore as determined from assay data.

chemical zonation of zinc (as revealed by the assay data) could be observed in this study.

Sphalerite (ZnS) can contain up to 67% zinc, but it almost always contains some iron. The sphalerite structure can accommodate as much as 36.5% iron (Hurlbut, 1959). Cadmium to a maximum of 1.66% and manganese to a maximum of 5.81% may also replace zinc (Palache and others, 1944). Germanium, indium, gallium, cobalt, mercury, and other elements may also be present in small amounts (Fryklund, 1964). Copper may be present at high temperatures but always exsolves, depending upon the elements present, as chalcopyrite, tetrahedrite, and other rarer minerals upon cooling (Ramdohr, 1969).

The sphalerite samples were analyzed for zinc, iron, cadmium, and copper. The results of the analyses are presented in Table VI Because copper exsolves from sphalerite as chalcopyrite and tetrahedrite, it was analyzed as a check on the purity of the samples.

The copper content of tetrahedrite is about 30% (Table VII) and of chalcopyrite about 34.5% (Hurlbut, 1959). Because most of the impurity in the Lucky Friday samples is chalcopyrite, an "average" figure of 33.3% was used in determining the purity of the sphalerite samples. The percent impurity in the sphalerite samples will be close to the copper content multiplied by a factor of 3. Calculations show the minimum purity of the sphalerite samples to be about 95.2% and the average purity to be about 98.5%. Chalcopyrite is about 30.5 wt % iron. Therefore the iron content attributable to the included chalcopyrite is considerable. The iron contents presented

TABLE VI

ANALYSES OF LUCKY FRIDAY SPHALERITE SAMPLES*

sample number	ore type	constituent in weight percent Zn	Fe	Cd	Cu
3	3	65.48	1.42	0.23	0.12
5	1	61.19	5.38	0.23	0.21
12	1	63.13	2.21	0.20	0.24
13	1	58.97	7.92	0.17	0.37
14	1	59.07	7.17	0.34	0.18
15	1	64.56	0.67	0.31	0.12
16	2	64.29	2.42	0.08	0.15
17	2	63.43	3.44	0.27	1.58
20	1	64.51	2.57	0.22	0.09
21	1	57.83	9.46	0.26	1.07
25	2	65.01	1.82	0.28	0.25
26	2	59.00	7.70	0.24	0.53
27	2	64.92	1.39	0.30	1.40
28	1	65.21	1.47	0.20	0.55

*corrected for included mineralogical impurities.

in Table VI have been corrected with the amount of iron attributable to the included chalcopyrite subtracted from the analyses.

The iron values determined for the Lucky Friday sphalerite samples are plotted on Figure 10. This shows that the iron contents of the sphalerite are not regularly distributed; high values are found alongside low values in all parts of the mine. The relationship between iron content and ore type is shown on Graph 2 of Appendix B. The iron content clearly tends to higher values in the fine grained type-1 ore samples and to lower values in the coarse grained type-2 ore samples. Exceptions to this generalization are present, however, and no predictions of iron contents can be made on the basis of ore type. Variations in the cadmium content of the sphalerite are slight. Graph 2 shows both the relationship between cadmium content and ore type and between the cadmium content and iron content. In neither case was any correlation found, possibly due to the small number of samples.

Pyrite

Pyrite (FeS_2) is ubiquitous in the Lucky Friday ores; it was observed in every sample. It is most common in the fine grained type-1 ore where it occurs as abundant rounded inclusions in the galena (Plate 1). There it may constitute as much as 50% of the whole rock (by modal analysis); in most cases it is present to a few percent only.

Large idiomorphic crystals containing oriented inclusions of tetrahedrite were found in three type-2 ore specimens from the west end of the 3850 level (Plate 9). Nickel and cobalt may replace much

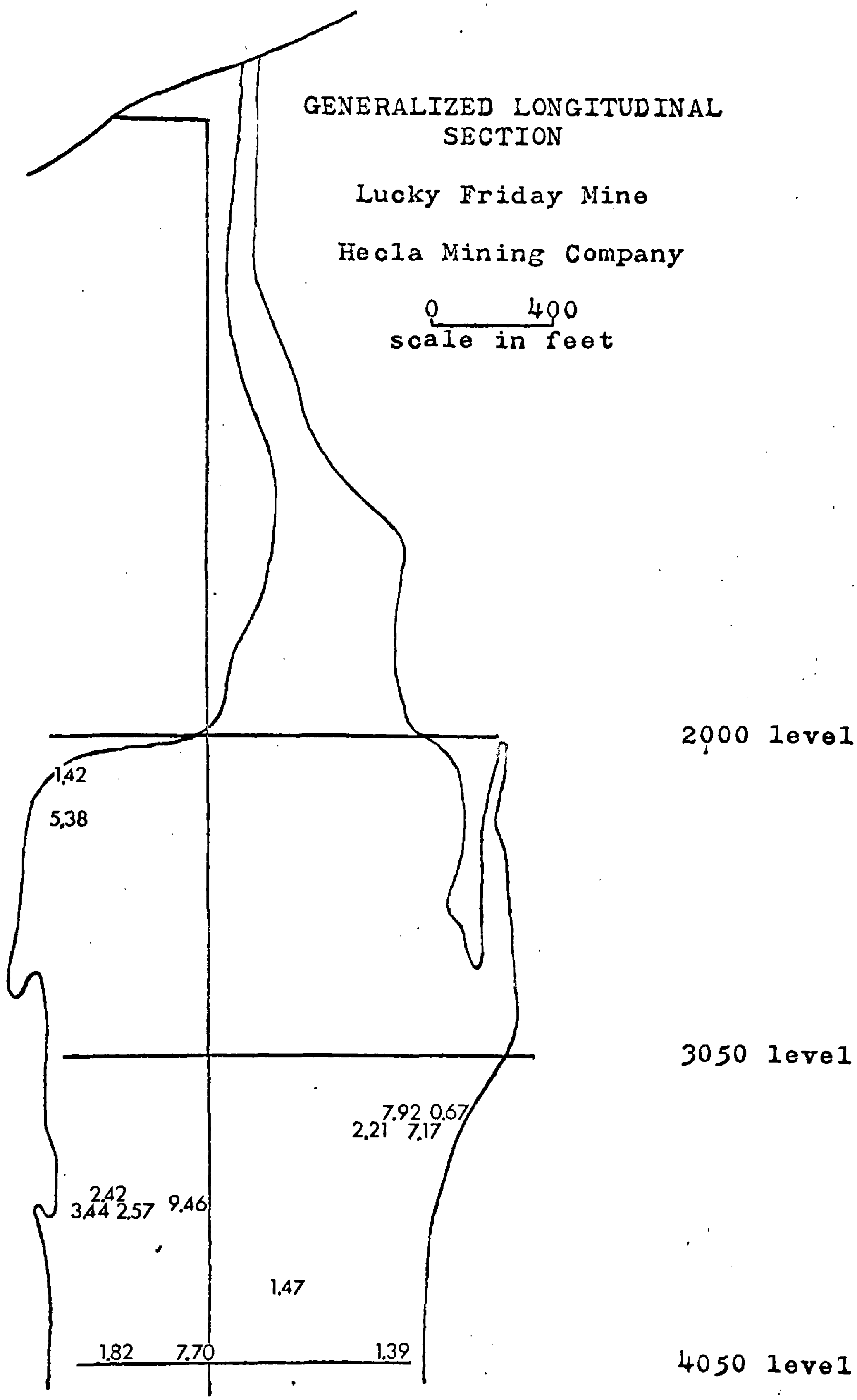

Fig. 10. Longitudinal section showing iron values in sphalerite samples (in percent).

of the iron in pyrite, but the miscibility of other elements, including those found in tetrahedrite, is very low. The inclusions seen here are probably replacement remnants of the tetrahedrite by the pyrite or simply oriented intergrowths (Ramdohr, 1969). Parallel intergrowths of pyrite and tetrahedrite have been found previously. In these, the {111} and {001} forms of the pyrite are parallel to the {111} and {001} forms of the tetrahedrite (Palache and others, 1944).

Chalcopyrite

Small amounts of chalcopyrite ($CuFeS_2$) are common in the Lucky Friday ores, especially in the more tetrahedrite-rich type-2 specimens. There it is common as both rounded grains in the tetrahedrite and as large polycrystalline masses in galena.

"Classic" exsolution lamellae of chalcopyrite within sphalerite were seen in several specimens. An example is shown in Plate 4. For unknown reasons, most such features were found near concentrations of tetrahedrite in the sphalerite; elsewhere the chalcopyrite exsolutions formed rounded grains.

Tetrahedrite

Tetrahedrite (approximately $Cu_8Sb_2S_7$) is common in the Lucky Friday ores. Rounded grains and masses, ranging from a few microns to 1.5 cm in maximum dimension, are dispersed through the galena of both the fine grained type-1 and coarse grained type-2 ores (Plates 1, 2, and 5).

It is most common in the type-1 ores where it may constitute as much as about 35% of the whole rock. Tetrahedrite is a major component of the ores from the western portion of the vein. In some areas it and siderite are present to the near exclusion of other minerals, forming the type-3 ore (Plate 3). The distribution of the three ore types is shown on Figure 5.

Tetrahedrite is a chemically complex mineral. Its composition is not fixed and a considerable range (approximately 5%) in copper content is known. Its formula is usually within the range of $Cu_8Sb_2S_7$ and $Cu_{12}Sb_4S_{13}$. The copper is always partially replaced by any of several other metals in varying proportions. Palache and others (1944) indicated the following substitutions by other metals to be possible: iron up to 13%; zinc up to 8%; silver up to 18%; mercury up to 17%; "lead" up to "16%(?);" nickel up to 4%; cobalt up to 4%; and bismuth up to 4%. The bismuth replaces the antimony which may be in turn replaced in major amounts by arsenic and lesser amounts of tin, germanium, molybdenum(?), and tungsten(?). The sulfur may be slightly replaced by antimony, tellurium, and selenium (Ramdohr, 1969).

Two different varieties of tetrahedrite were identified in the polished slabs of six type-1 specimens. One of these is the "normal" grayish-green colored tetrahedrite. The second type is very pale yellowish-green colored, weakly anisotropic type which shows lamellar twinning. Plate 6 shows a specimen containing the two types; Plate 7 shows the twinning under partially crossed polarizers. Ramdohr (1969) suggests that the paler tetrahedrite probably contains more silver and/or bismuth and less iron than the darker variety. This theory is supported by sample 3850-105R (number 28) in which the pale variety is dominant. The tetrahedrite in this sample carries 6.78% silver and 0.208% bismuth but only 2.14% iron, the lowest iron content observed in this study. The samples in which the pale variety was observed are indicated on Figure 11.

The Lucky Friday tetrahedrite separates were analyzed for copper, silver, iron, zinc, cadmium, and bismuth. The analytical results are presented in Table VII. All of the elements analyzed (as well as lead) are present in the tetrahedrite structure. Therefore no element could be analyzed as a check on the purity of the separates. Similar separation procedures were used in obtaining the tetrahedrite separates and the galena and sphalerite separates. Based on this, microscopic examinations, and X-ray diffraction analyses, the purity of the tetrahedrite samples is believed to be at least that of the final galena and sphalerite samples. The sums of the cations determined seem to be low, even when the wide range (5%) of possible sums is considered. Because the variations and not the absolute amounts of the elements are of interest, this discrepancy does not affect the results presented below.

Copper is the major component of the Lucky Friday tetrahedrite samples. In these samples it ranged from 26.49% to 33.40%. This range is compatible with the concurrent variations in the other metals present, as must be the case. The variations in copper content could

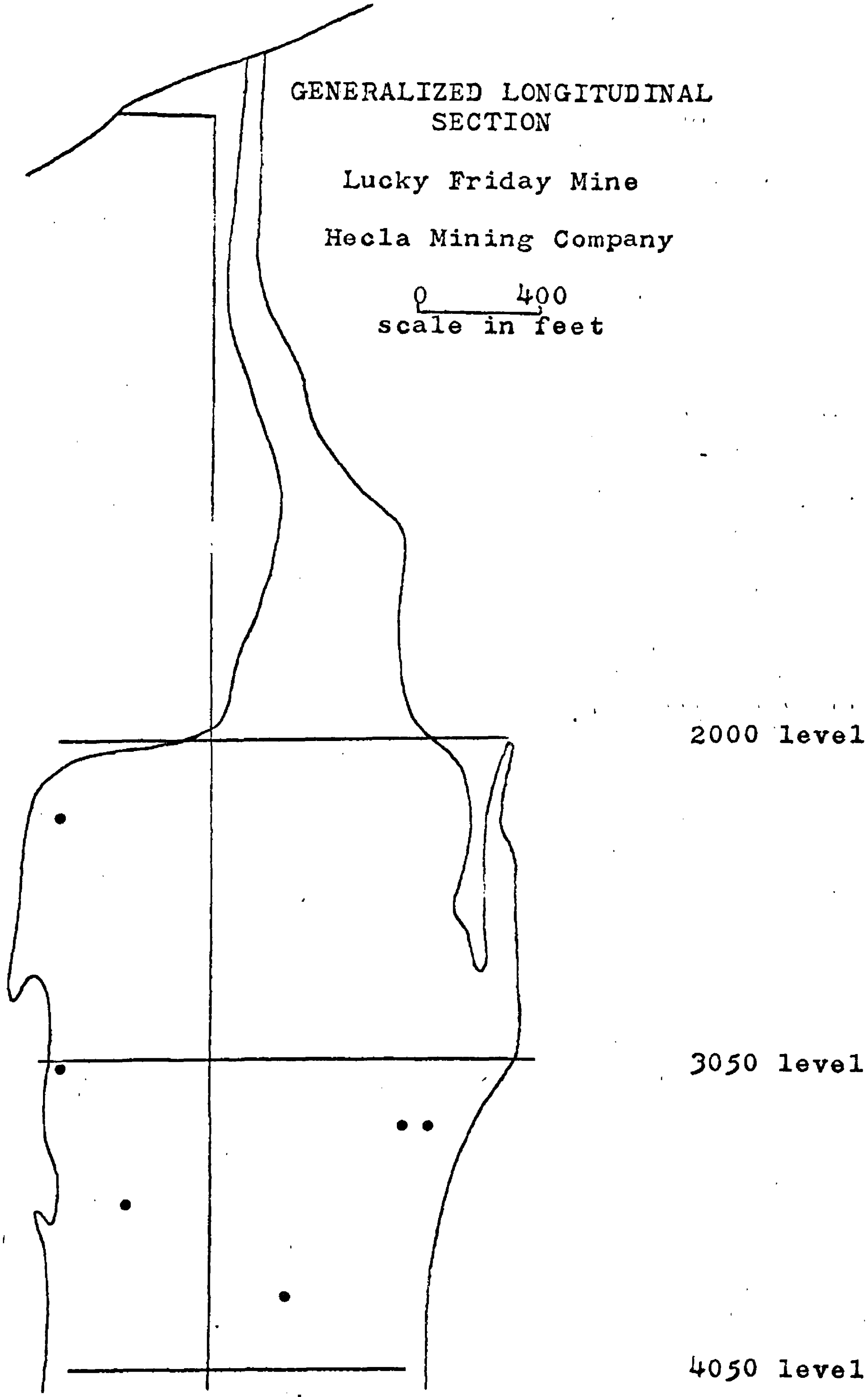

Fig. 11. Distribution of specimens containing two varieties of tetrahedrite.

TABLE VII

ANALYSES OF LUCKY FRIDAY TETRAHEDRITE SAMPLES*

sample number	ore type	constituent in weight percent CU	Ag	Fe	Zn	Cd	Bi
1	2	31.41	3.78	3.11	3.82	0.029	0.057
2	3	33.40	3.33	2.97	4.11	0.036	0.035
3	3	31.65	3.29	3.54	3.84	0.033	0.052
5	1	26.49	3.82	3.43	7.16	0.080	0.053
6	2	26.86	8.39	2.32	5.49	0.069	0.101
7	3	26.62	8.67	2.92	4.09	0.027	0.057
9	2	27.54	4.64	2.56	4.26	0.036	0.084
11	3	29.62	5.67	2.58	4.49	0.059	0.803
15	1	30.98	3.12	2.68	3.77	0.032	0.032
17	2	31.74	2.90	3.07	4.33	0.036	0.231
18	2	29.40	4.21	3.63	4.71	0.035	0.057
20	1	29.68	3.39	2.81	4.28	0.039	0.108
22	2	32.44	2.42	3.12	2.54	0.024	0.130
23	2	29.24	2.28	2.82	3.51	0.030	0.085
24	2	30.26	1.84	3.23	4.61	0.042	0.054
25	2	28.13	4.31	2.53	4.48	0.034	0.058
27	1	29.69	2.37	3.08	8.02	0.093	0.061
28	1	29.74	6.78	2.14	3.65	0.031	0.203
29	2	31.68	2.52	2.46	5.19	0.062	0.068

*not corrected for included mineralogical impurities.

not be coupled to variations in any single one of the other elements analyzed, as shown on Graphs 3-7 of Appendix B. There are weak relationships between the copper content and the silver content and between the copper content and the zinc content of the Lucky Friday tetrahedrite samples. These relationships have correlation coefficients of only -0.61 and -0.40 respectively. The relationships between the copper contents and the contents of the other elements analyzed are very weak with correlation coefficients of less than 0.20.

The silver values analyzed in the Lucky Friday tetrahedrite separates are plotted on Figure 12. These values show no regular distribution similar to those of the galena samples. High values were found in the extreme western portion of the vein, but not exclusively so. The high values do not necessarily correspond to the type-1 samples containing the pale, silver-rich variety of tetrahedrite. In fact, high values were found in separates from all three ore types. The relationship between silver content and ore type is shown on Graph 3 of Appendix B. The silver content of the tetrahedrite samples cannot be predicted on the basis of ore type. Graphs 3 and 8-11 illustrate the relationship of the silver contents to the other elemental contents. Only the weak correlation between silver and copper (previously noted) can be seen; the other correlations are very weak.

The distribution of bismuth is shown on Figure 13. High values were found in samples from all portions of the vein, and no predictable variation can be seen. Graph 11 shows the relationship between bismuth

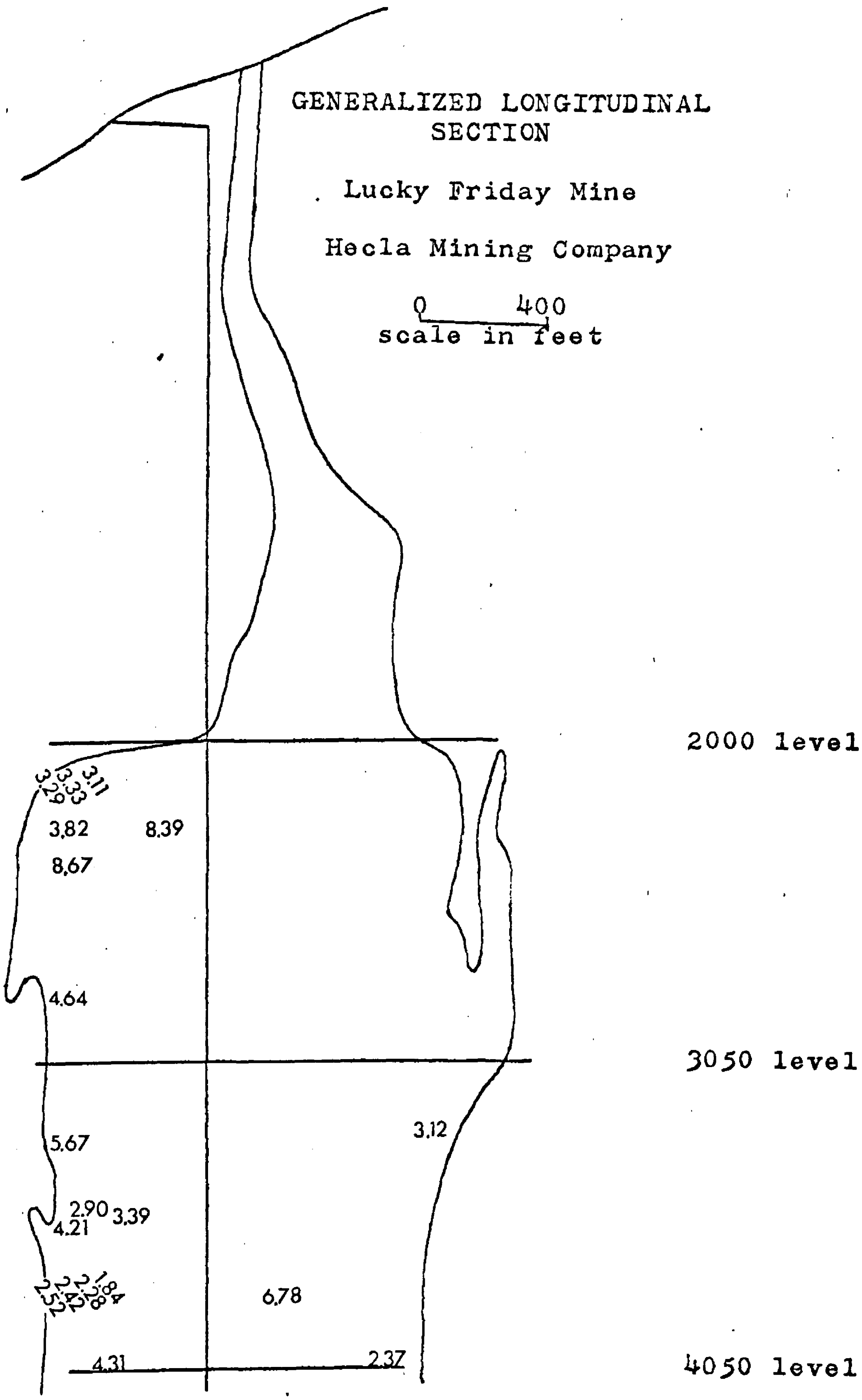

Fig. 12. Longitudinal section showing distribution of silver values in tetrahedrite samples (in percent).

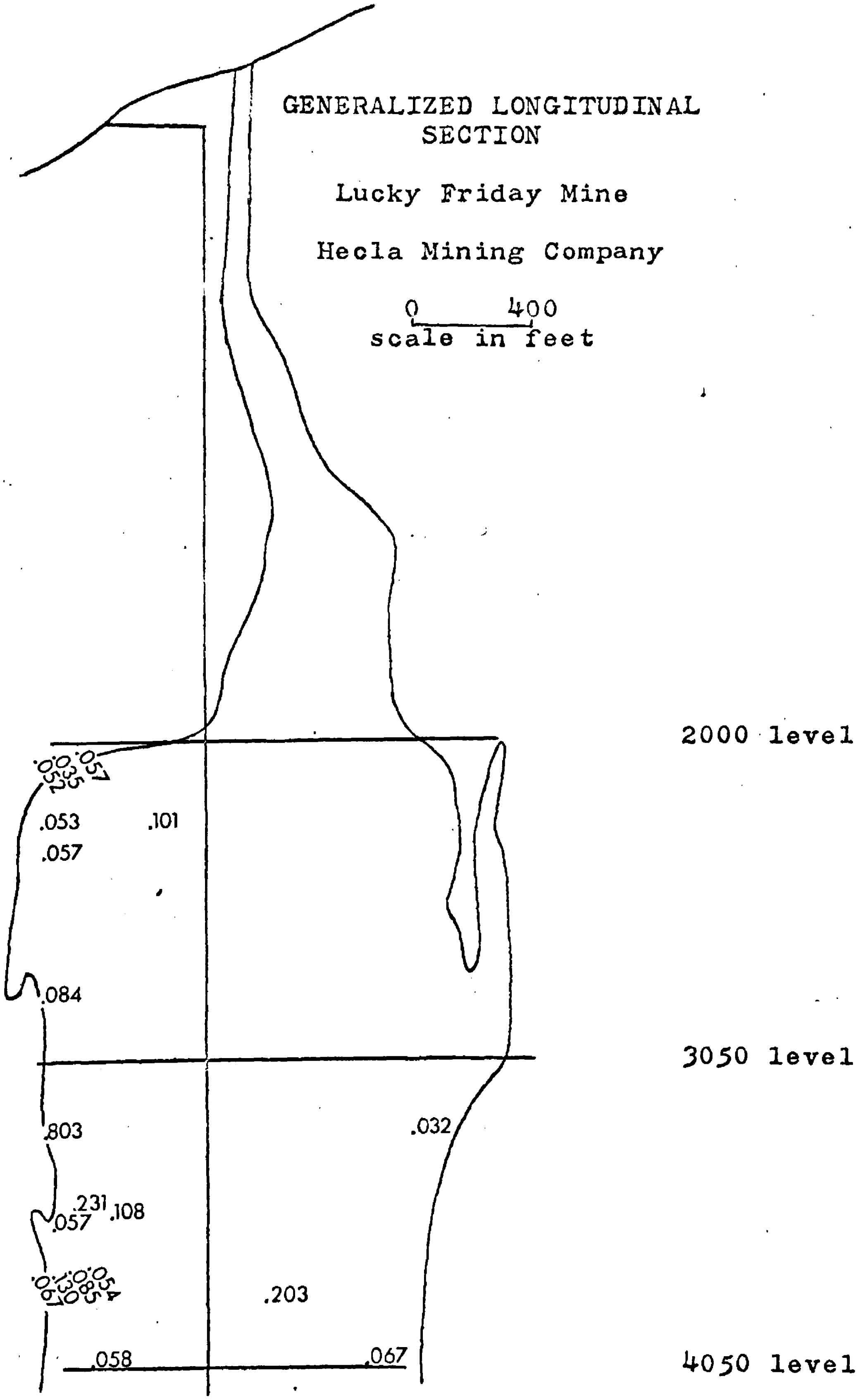

Fig. 13. Longitudinal section showing distribution of bismuth values in tetrahedrite samples (in percent).

content and ore type. High values (>0.200%) were found in one sample of each of the three ore types. There is no observable relationship between the bismuth content and the ore type. There is no correlation between the bismuth and silver contents (Graph 11).

Graphs showing the relationships between iron, zinc, cadmium, and bismuth are shown on Graphs 12-17. These relationships are similar to those between copper and silver and these elements. The only observed correlation of any significance is that of zinc to cadmium where the correlation coefficient is +0.72. This relationship is to be expected considering the chemical similarities of cadmium and zinc (Barton and Skinner, 1967).

The results of these analyses are in accord with those of other studies involving tetrahedrite. Because of the multitude of interchangeable element substitutions in tetrahedrite, significant correlations between the elements present are seldom found.

"Late Sulfosalts"

Several so-called "late sulfosalts" have been found in minor amounts in the mines of the Coeur d'Alene District. All sulfosalts identified here are antimony-bearing and contain very little arsenic (Fryklund, 1964). Three sulfosalts (in addition to tetrahedrite) were identified in the Lucky Friday ores; insufficient quantities were available to permit either positive identification or chemical analysis.

Pyrargyrite (Ag_3SbS_3) has been previously reported in the Lucky Friday Mine (T. J. Smolik to M. W. Hutchinson, pers. comm.). None was seen in the polished slabs during the course of this study. However, during the magnetic separation procedures, brilliant red grains were sometimes found in the non-magnetic fractions. These grains were not sphalerite. They were probably pyrargyrite (or, perhaps, some other "ruby silver" mineral).

Polybasite ($(Ag,Cu)_{16}Sb_2S_{11}$) has not been previously identified in the Lucky Friday ores. It was tentatively identified in the Coeur d"Alene District from the Silver Summit Mine by Fryklund (1964). A few small grains in sample 3650-95R-W78, were tentatively identified, using microchemical etch tests and optical properties, as polybasite.

Bournonite ($CuPbSbS_3$) was questionably observed in association with tetrahedrite in sample 2800-94R-W65. As is often the case with bournonite (Anderson, 1940), these grains appeared to be a product of reaction between tetrahedrite grains and the enclosing galena. The identification was made using microchemical etch tests and optical properties.

<u>Pyrrhotite</u>

Pyrrhotite ($Fe_{1-x}S$) was found in several type-2 ore samples, always as small rounded grains resembling and in association with pyrite (Plate 8). These grains were always wholly or partly enclosed within either tetrahedrite or chalcopyrite.

The pyrrhotite was observed only in specimens from the westernmost portions of the vein on the 3850 level. These same specimens contained idiomorphic pyrite (see under "Pyrite"), extensively replaced and deformed siderite (see under "Siderite"), little tetrahedrite, and very little sphalerite. Chemically, the galena of these specimens was relatively silver-poor and bismuth-rich.

Arsenopyrite

A few rounded grains of arsenopyrite (FeAsS) were seen in sample 2800-94R-W65. Measuring up to 0.5 mm in diameter, they were enclosed in a very coarse grained galena. Also occurring in this specimen were the bournonite(?), matildite(?), and large quantities of chalcopyrite; tetrahedrite was rare and sphalerite was absent. Chemically, the galena of this sample was relatively silver-poor and bismuth-rich, similar to the other mineralogically unusual samples from the 3850 level.

Siderite

Siderite ($FeCO_3$), together with quartz and pyrite, forms the gangue of the Lucky Friday ores. It was present in all samples studied. The siderite grains range in size from a few microns to several mm in diameter (Plates 1, 3, 8, and 10). Four siderite samples were analyzed for iron, manganese, magnesium, and calcium by qualitative wet-chemical methods. All four samples proved to be "true" siderite although all contained small amounts of the other analyzed elements.

In most cases where the siderite was enclosed in the sulfide minerals it formed small rounded grains. Shown on Plate 10 is one of many large siderite masses which were observed in the samples from the western end of the 3850 level. They are extensively being replaced by galena along cleavage surfaces and have been extensively deformed (twinning visible under crossed polarizers). These same samples contained idiomorphic pyrite, pyrrhotite, little tetrahedrite, and very little sphalerite. These type-2 samples were also relatively silver-poor and bismuth-rich.

Quartz

Quartz (SiO_2) is nearly as abundant as siderite in the gangue of the Lucky Friday ores. In several cases it was the dominant gangue mineral. The quartz probably entirely represents recrystallized country rock (Fryklund, 1964). Some of the quartz encountered in this study was virtually unaltered quartzite (of the Revett Formation?) of the country rock, and all gradations from that to clear, glassy crystals were seen.

Secondary Minerals

Secondary minerals were found as fracture fillings and coatings in several specimens from the Lucky Friday Mine.

Greenockite (CdS) is a rare mineral in ore deposits, but is quite commonly found as an alteration on sphalerite specimens from old mine workings and dumps. Greenockite itself is always remarkably pure with only minute quantities of zinc and iron present in the structure, but in the occurrences of secondary nature it is nearly always contaminated by small quantities of other secondary minerals (such as malachite, smithsonite, and cerussite) (Palache and others, 1944).

A few small and thin bright yellow-orange stains and incrustations were observed on fracture surfaces on sample 3450-109R-W25. A small amount of this material was qualitatively tested for the presence of cadmium, zinc, copper, and iron. Cadmium was a major constituent, but the other three elements were also present in major amounts. The high cadmium content and bright color of the incrustation and the fact that the specimen contains considerable (about 19.6%) sphalerite indicate the greenockite is a component of the incrustations. The other elements are probably present as the carbonates malachite ($Cu_3(OH)_2CO_3$), smithsonite ($ZnCO_3$), siderite ($FeCO_3$), and, perhaps, other more complex minerals.

No references could be found in the literature of greenockite having been found in the Coeur d'Alene District. Fryklund (1964) does not mention it. Although the bright color makes its presence obvious, it is present in extremely small amounts only. The occurrence on fracture surfaces and the great depth from which the sample came indicate that the greenockite must have formed as a secondary product after the ore was exposed by mining.

Cerussite ($PbCO_3$) was observed in the most highly oxidized samples, especially 2300-94R-W30. A mixture of it and "limonite" formed crusts on exposed surfaces and small amounts were seen as an alteration along fractures in galena.

"Limonite", or, more properly, hydrous iron oxides, was found on the exposed surfaces of several samples. It was usually associated with small amounts of cerussite.

CHAPTER V

SUMMARY AND CONCLUSIONS

The Lucky Friday ores are composed of relatively few minerals. The ores are dominated by galena, sphalerite, and tetrahedrite in association with a quartz-siderite-pyrite gangue. These minerals, together with some rarer sulfides are found in three ore types. These ore types are defined on the basis of mineralogy and texture. The fine grained type-1 ore is the most common. The coarse grained type-2 ore was probably formed by the recrystallization of the type-1 ore; evidence for this includes specimens of deformed galena, the large grain size, twinning in sphalerite, the low iron content of the sphalerite, and the presence of pyrrhotite and relative large amounts of chalcopyrite in the type-2 specimens. The recrystallized specimens are confined to the area west of the "Hook" anticline where the vein nearly parallels the regional fault pattern. The type-3 ore is dominated by tetrahedrite and siderite.

The silver content of the galena is quite constant with most values lying between 0.2 and 0.5% silver. The highest silver contents occur in samples from the western-most portions of the vein. Here the analyses suggest inwardly successive zones of low, high, and intermediate silver values. There is no predictable relationship between the silver content and the ore type. The distribution of bismuth in the galena, at least part of which is probably associated with silver as matildite, is similar to that of silver. However, even though the distributions of silver and bismuth are similar, there is no relationship between high silver and high bismuth contents in the individual galena samples. In fact, such high values are generally exclusive of one another. The bismuth values are very high in type-2 galena samples from the extreme western portion of the vein, and high in most type-2 samples. Values are quite low in the type-1 samples.

Matildite, judging by the distributions of silver and bismuth in galena, is probably restricted to the extreme western end of the vein.

No regular distribution of either iron or cadmium exists in the sphalerite. The cadmium contents are quite constant and no correlation between the iron and cadmium contents can be seen. High iron contents tend to be found in the fine grained type-1 sphalerite samples, but the type-1 samples may have low iron contents. The coarse grained type-2 sphalerite samples usually have low iron contents. A mineralogical zonation in accord with that suggested by the assay data was not found.

Two varieties of tetrahedrite, one pale in color and comparatively rich in silver and bismuth and poor in iron, were found. The rarer, pale variety was found only in type-1 samples. The only regular distribution of any constituent of the tetrahedrite is that of silver. Higher values tend to be found in the west, but high silver values were also found in the pale tetrahedrite-bearing samples from the interior portions of the vein. There is no predictable variation of the bismuth contents. Reasonably good correlations exist between the copper and silver contents and, as expected, between the cadmium and zinc contents of the tetrahedrite samples; a poorer correlation exists between the copper and zinc contents. The differing relationships of the silver and bismuth contents of the tetrahedrite and galena can be explained by the two minerals having formed under slightly different physiochemical conditions.

Large idiomorphic crystals of pyrite, pyrrhotite, arsenopyrite, large amounts of chalcopyrite, and large, extensively replaced and deformed masses of siderite were found in five type-2 samples from the extreme western portion of the ore body. Chemically, the galena of these same samples analyzed relatively silver-poor and bismuth-rich. These features all suggest that the physiochemical conditions governing the formation of this ore were somewhat different from those of most of the vein. One of these samples (2800-94R-W65) was obtained from what may be an ore shoot separate from the main ore body of the Lucky Friday Vein. It came from the bottom of that ore shoot. The presence of mineralogically and chemically similar specimens from the 3850 level suggests that a second ore shoot is bottoming-out in that region (Figure 14). The apparent ore shoot in the eastern portion of the mine was not sampled.

The lack of relationships between elemental contents and ore type eliminate the use of ore texture as an indication of ore grade. The type-1 and type-2 ores have the same original origin, and, therefore, similar elemental contents. The type-3 ore has highly variable elemental contents. Any such predictions of ore grade would be made at very low levels of confidence.

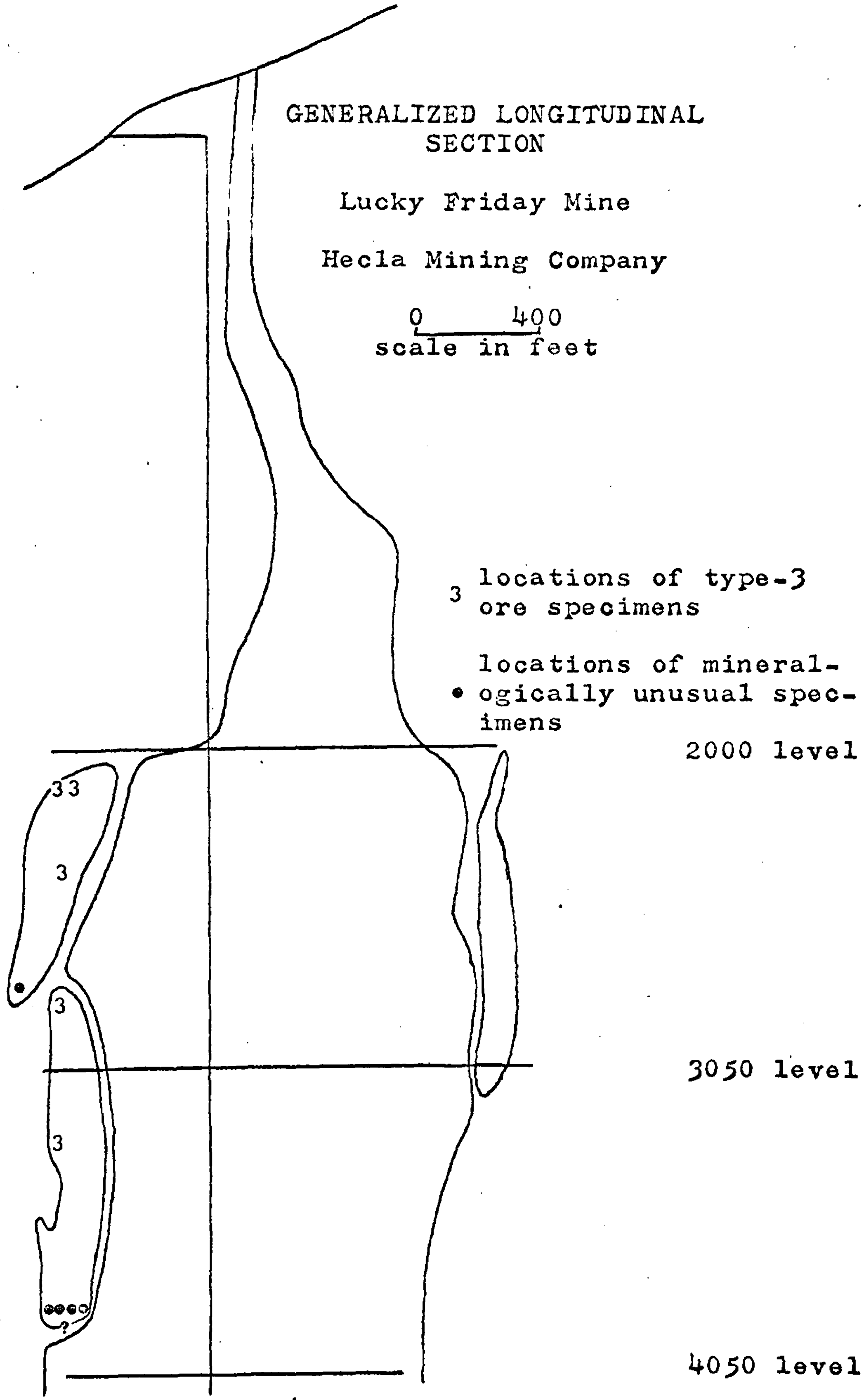

Fig. 14. Longitudinal section showing the location of ore shoots along the western margin of the Lucky Friday Vein.

Horizontal zonations of silver and bismuth are revealed by this study. Because of the limited number of samples involved in this study, these zonations can only be taken as suggestions. A more extensive sampling program in the western portion of the vein would probably prove these zonations. Such study might also reveal the boundaries of the ore shoots which are suggested by the distribution of the type-3 ore and assay data.

Vertical zonations of either mineralogical or chemical nature were not found in this study. Zinc values in the wholerock are zoned with generally increasing zinc contents with depth. From these data it can only be said that, with increasing depth, increasing amounts of zinc may be expected, but that no predictions concerning the copper, lead, silver, and cadmium contents of the ore may be made. There is no suggestion of any chemical or mineralogical trend of the ore body that can be used to predict the down dip extent of the ore. However, the lack of zoning does imply that the ore extends unchanged to greater depths.

The fine grained, homogeneous nature of the ores (this study), the wall-rock geochemistry (previous unpublished study by Sorensen, 1967), and the presence of disseminated sulfides in the country rock all support the formation of the Lucky Friday Vein by lateral secretion. The presence of vertically elongated and vertically zoned ore shoots along the margins of the vein support an epigenetic origin of the vein.

These results are in accord with those found by studies in other mines of the Coeur d'Alene District. These studies are summarized by Fryklund (1964). Mineralogical and chemical zoning of the veins is usually not found in the district; when found it is applicable only to the mine in which it was found.

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APPENDIX A

DESCRIPTIONS OF THE LUCKY FRIDAY ORE SPECIMENS

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DESCRIPTIONS OF THE LUCKY FRIDAY ORE SPECIMENS

#	sample locality	ore type[1]	Mineralogy[2]	Comments
1	2150-95AR	2	gn(maj), td(mod), cp(min), py(tr) w/ qtz(maj)-sid(min) gangue	galena is very coarse grained; cp as exsolution blebs in large td masses
2	2150-95AR-W65	3	td(75), gn(10), cp(5), py(5), in sid (95)-qtz(5) gangue	cp especially noted as reaction between td and sid; py is completely enclosed in sid
3	2150-95AR-W115	3	td(95), gn(5), py(tr), cp(r) in sid gangue	gn concentrated in a few small patches in td; otherwise td is nearly pure
4	2300-94R-W30	1	? gn(maj), td(min), sp(min), cp(min), py(min) w/ qtz gangue plus secondary mineral (cerussite, limonite) crusts	specimen highly oxidized, component minerals not analyzed; modes are approximate
5	2300-94R	1	gn(40), td1(35), td2(2), sp(20), py(5), cp(tr) w/ qtz(mod)-sid(mod) gangue	two varieties of tetrahedrite; chalcopyrite exosolutions from both sp and td; minor development of secondary minerals
6	2300-100R	2	gn(80), td(15), sp(5), cp(tr), py(tr) in qtz(maj)-sid(min) gangue	gn cleavage surfaces to 1 cm; td as large masses to 1 cm; cp as exsoln in low-Fe sp

7	24-94R-W30	3	td(maj), gn(min), cp(tr), py(tr) in sid(mod)-qtz(mod) gangue	gn as coarse cleavages in td; cp as exsol'n in td; py is enclosed in sid
8	2800-94R-W65	2	gn(maj), cp(mod), td(tr), py(r), arsenopyrite(r), matildite(vr), bournonite(vr) in sid (maj)-qtz(min) gangue	gn very coarse grained; cp as large isolated pure masses; ars as rdd grains in gn; mat as exsolution lamellae in gn; bour as rxns between td and gn
9	3050-96ER	3	td(95), gn(5), py(tr) in qtz gangue	py cubes to 3mm in qtz; gn as microveinlets in td
10	3250-97R	1	py(50), gn(40), td(5), cp(5) in qtzite gangue	py finely disseminated; gn very fine grained; two varieties of td; cp as exslo'n in td and a microveinlets in py
11	3450-97R-W65	3	td(100), gn(tr) in qtzite gangue; py in qtz	qtz is nearly unaltered qtzite of ctry rk(Revett Fm?)
12	3450-109R-W120	1	gn(maj), sp(mod) py(min), td(r), cp(r), py(r) w/ qtz(mod)-sid(mod) gangue	gn is v. fine grained; other minerals all as small rdd grains in gn
13	3450-109R-W25	1	gn(73.12), sp(19.63), td1 (3.87), td2(2.31), py(1.10), w/ qtz(mod)-sid(mod) gangue greenockite v. rare as secondary mineral	sp masses to 4 mm; two types of td; inclusions in gn v. small

14	3450-109R-E80	1	gn(maj), sp(mod), td(min), cp(r), py(r) w/ qtz(mod)-sid(mod) gangue	no large sp masses; otherwise like #13
15	3450-109R-E133	1	gn(70), sp(15), td(10), py(5) w/ qtz(maj)-sid(min) gangue	sample v. fine grained; sp is v low in iron, forms large grains
16	3650-95R	2	gn(95), sp(5), td(tr) in qtz(mod)-sid(mod) gangue; py cubes in sid	v. coarse grained; sp masses to 1 cm
17	3650-95R-W30	2	gn(maj), sp(min), td(min), py(min) w/ qtz(maj)-sid(min) gangue	rather fine grained for "type-1" but otherwise typical
18	3650-95R-W78	2	gn(80), td(15), cp(2) sp(2), py(1), polybasite?(vr) w/ qtz(r) gangue	gn is very schistose; td in large masses cut by cp veinlets; numerous red grains ("ruby silver" or polybasite?) seen in gn fraction; almost no gangue
19	3650-99R-W120	1	gn(95), td(2), sp(2), cp(1), py(r) w/ qtz(mod)-sid (mod) gangue	gn very fine grained; cp exsol'n lamellae in sp
20	3650-99R-W70	1	gn(mod), td(mod), sp(mod), cp(min), py(r) w/ qtz(maj)-sid(min) gangue	gn fine grained; sp grains to 1 mm; two varieties of td; td grains to 0.5 mm

21	3650-99R-E146	1	gn(95), sp(5), td(tr), py(r) w/ qtz(mod)-sid(mod) gangue	py as inclusions in sp; td in widely scattered concentrations of grains; specimen extremely fine grained
22	3850-94R-W10	2	gn(70), td(20), py(5) sp+cp+pyrr(5) w/ q(maj)-sid(min) gangue	specimen of different mineral-ogy, microtextures, and chem-istry; pyrite idiomorphic; sid as large replaced and deformed masses (see text)
23	3850-94R	2	gn(70), td(25), sp(2), py(2), cp(1), pyrr(tr) w/ qtz(mod)-sid(mod) gangue	Same as #22
24	3850-94R-E50	2	gn(90), cp(5), py(5), td(tr), w/ qtz gangue	chemistry similar to that of #s 22, 23, 29, 8; cp grains in gn and as exsol'n in td
25	4050-99R	2	gn(85.06); sp(9.64), td(5.31) cp(r), py(r) w/ qtz(maj)-sid (min) gangue	very coarse grained; some schistosity to the gn; sp as large polycrystalline grains to 1 cm; cp as exsol'n in sp
26	4050-101R	1	gn(mod), sp(mod), py(min), cp(min), td(tr) w/ qtz(mod)-sid(mod) gangue	gn is fine grained, sp is coarse grained forming veinlets to 5 mm thick in gn; py as both large cubes and fine dispers-ions; cp mostly as exsol'n in td; sample has a messy appear-ance in hand specimen

27	4050-40 vn	1	sp(52.62), gn(46.03), td(1.er), cp(tr), py(tr) w/ qtz(min) gangue	sample collected in large wall vein @150 feet from main vein; laminations resembling flow are cut by fine sp veinlets; masses of coarse grained sp are cut by gn veinlets; cp as exsol'n in sp
28	3850-105R	1	gn(52.59), td1(2.16), td2(8.89), sp(8.43), cp(1.06), py(0.70) w/ qtz-sid gangue (26.14)	gn very fine grained; two varieties of td; cp as exsol'n in sp, grains in gn
29	3850-94R-W50	2	gn(80), td(15), sp(2), py(2), cp(tr), pyrr(tr), w/ qtz(mod)-sid(mod) gangue	Similar to #22

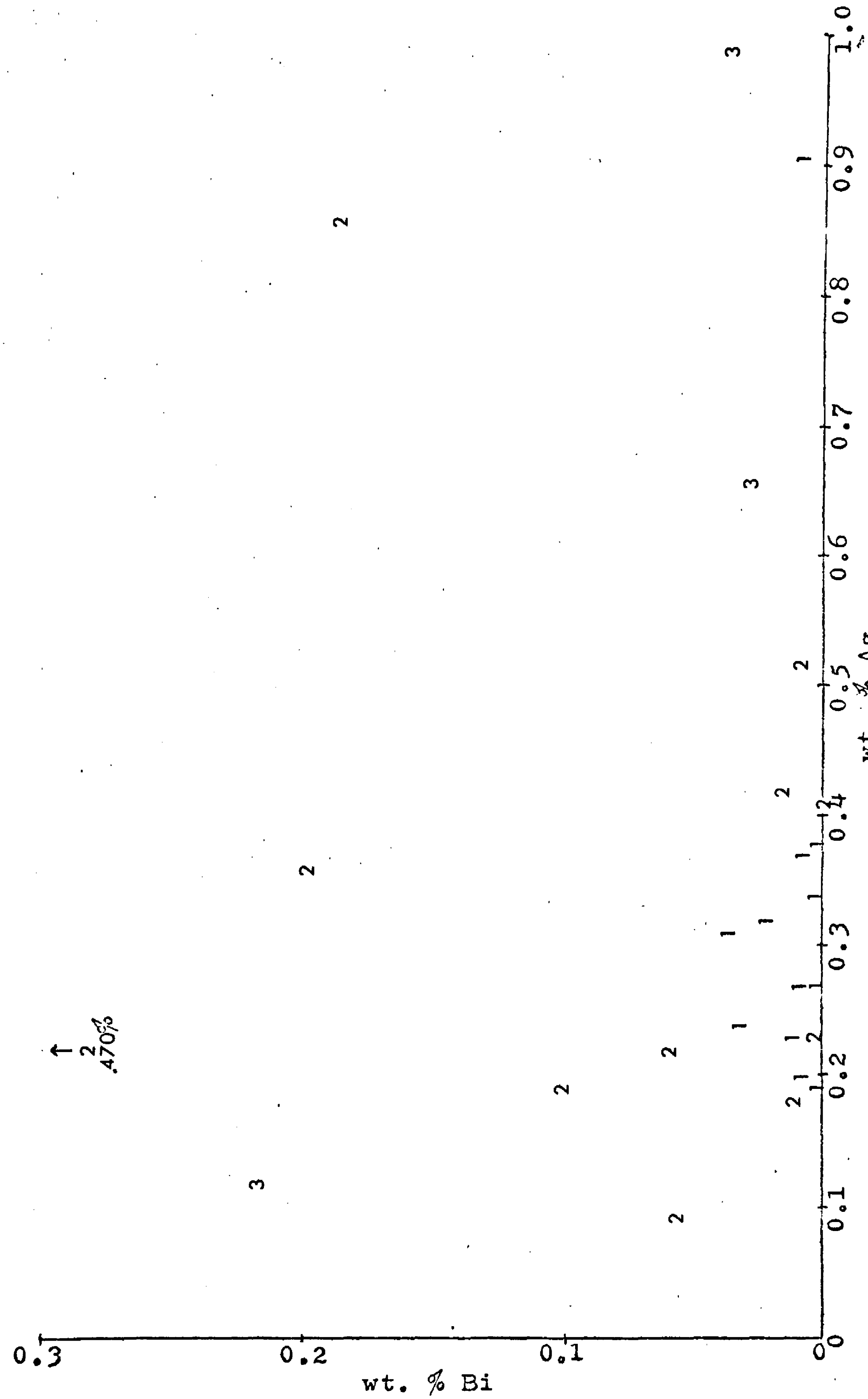
[1] sample localities: example, 3850-94R-W50: collected on the 3850 level in the active stope at a point 50 feet west of the number 94 raise.

[2] ore types: 1 = fine grained type-1 galena ore
2 = coarse grained type-2 galena ore
3 = tetrahedrite-siderite ore

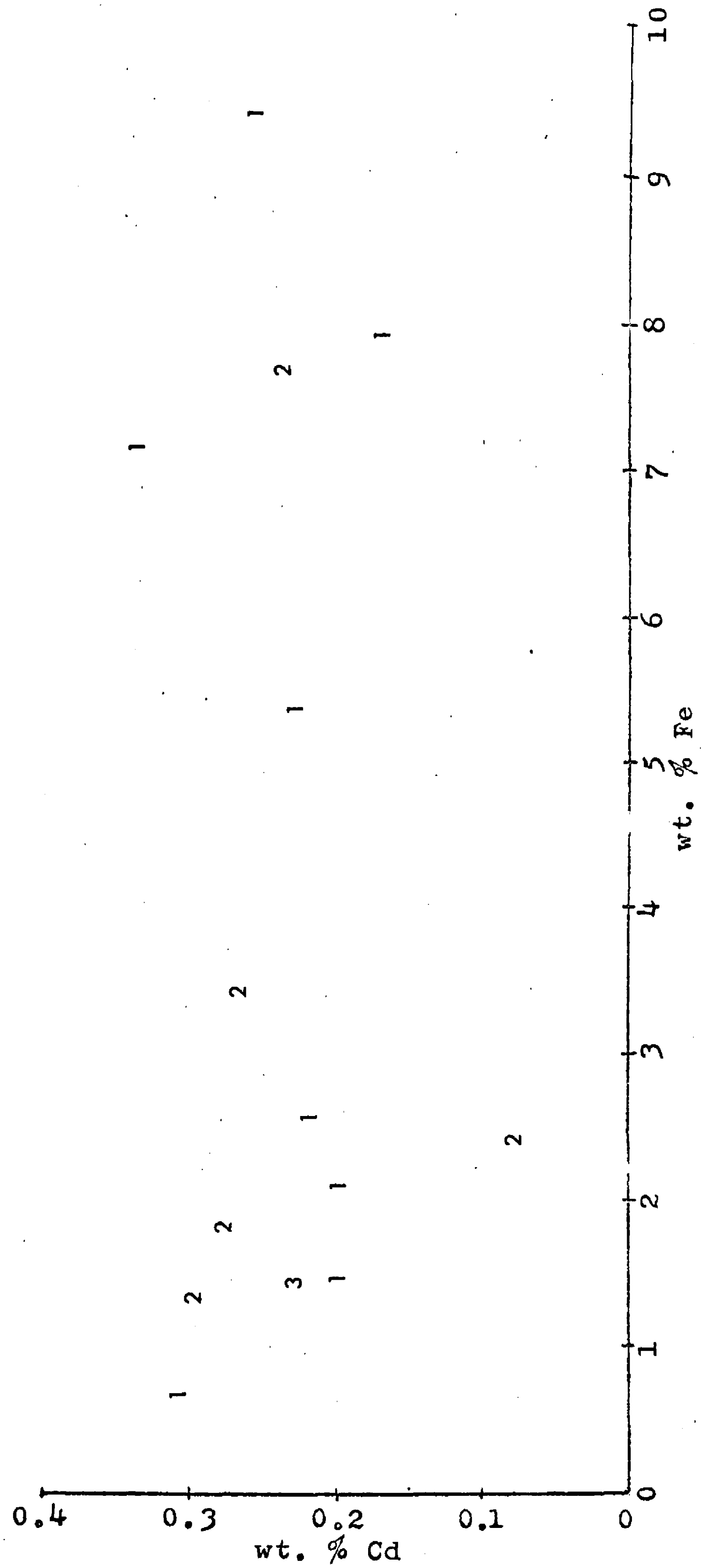
[3] gn = galena; sp = sphalerite; td = tetrahedrite; cp = chalcopyrite; py = pyrite;
sid = siderite; q = quartz
maj = major; mod = moderate; min = minor; r = rare; vr = very rare; tr = trace. These modal designations are estimates
Modal designations given in even percentages are approximations and were determined by comparison with slabs on which actual modal analyses were done.
Modal analyses were done by counting 1,500 points.

APPENDIX B

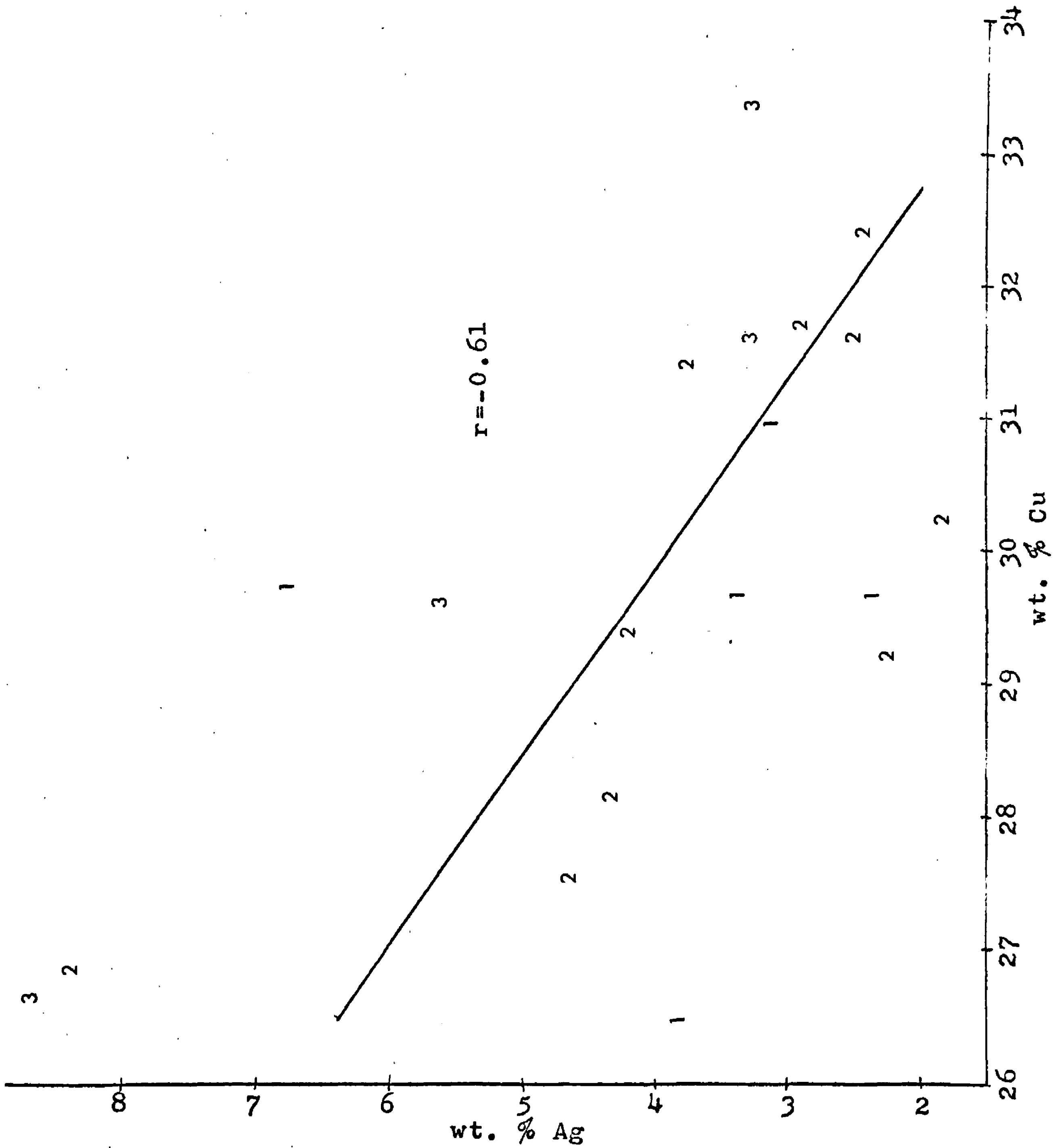
GRAPHS



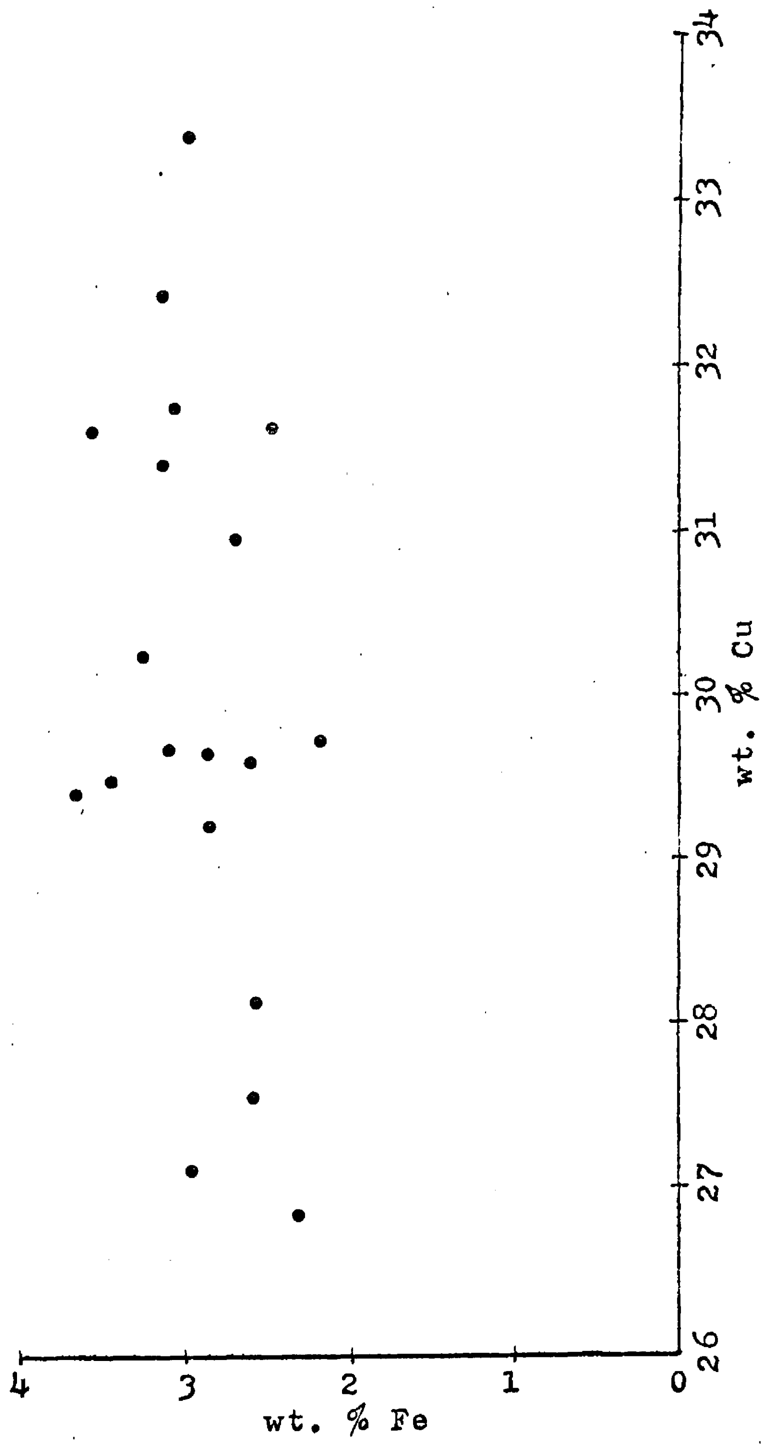
GRAPH 1 -- Graphical relationship between silver and bismuth values and ore type in Lucky Friday galena samples.



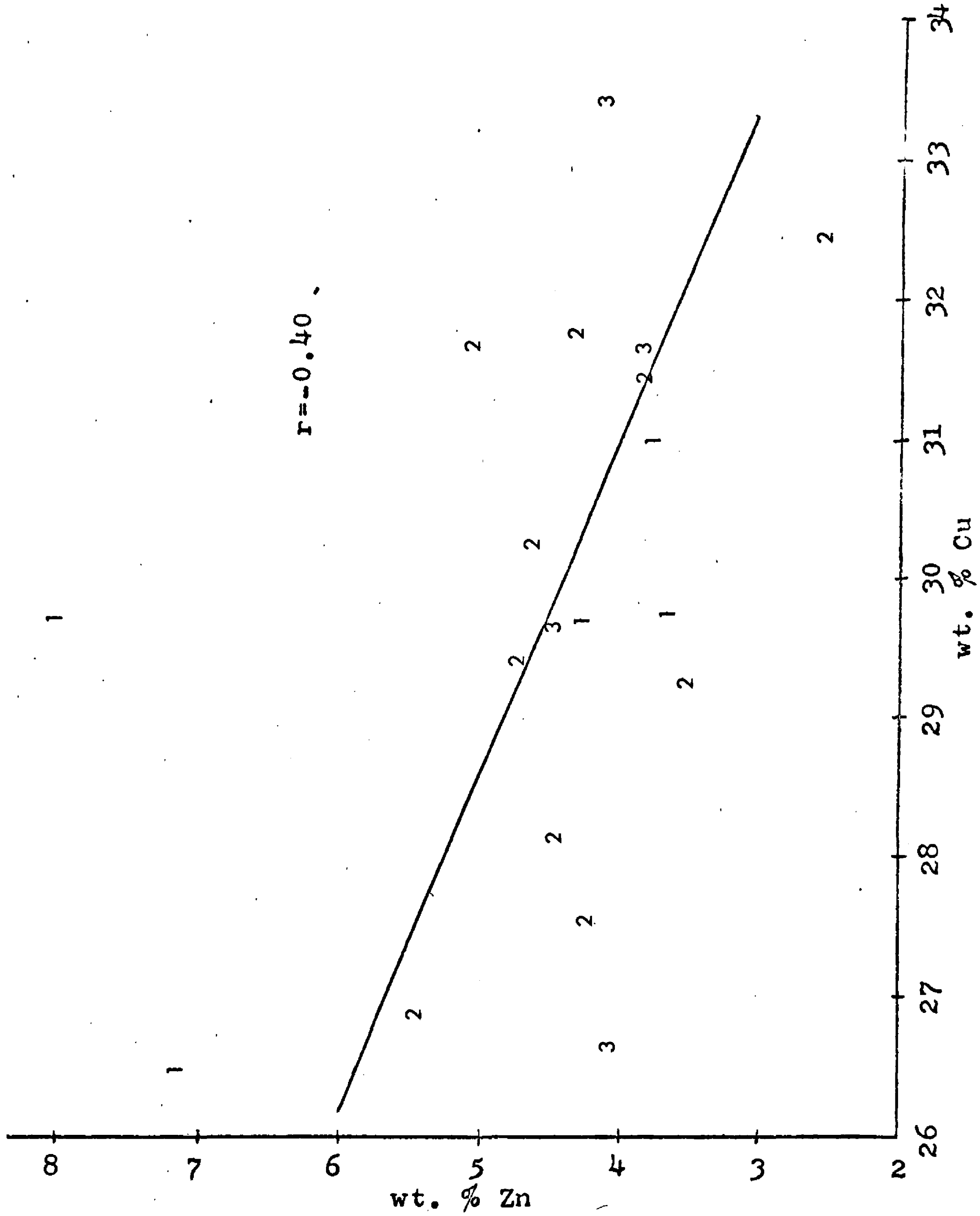
GRAPH 2 -- Graphical relationship between iron and cadmium values and ore type in Lucky Friday sphalerite samples.



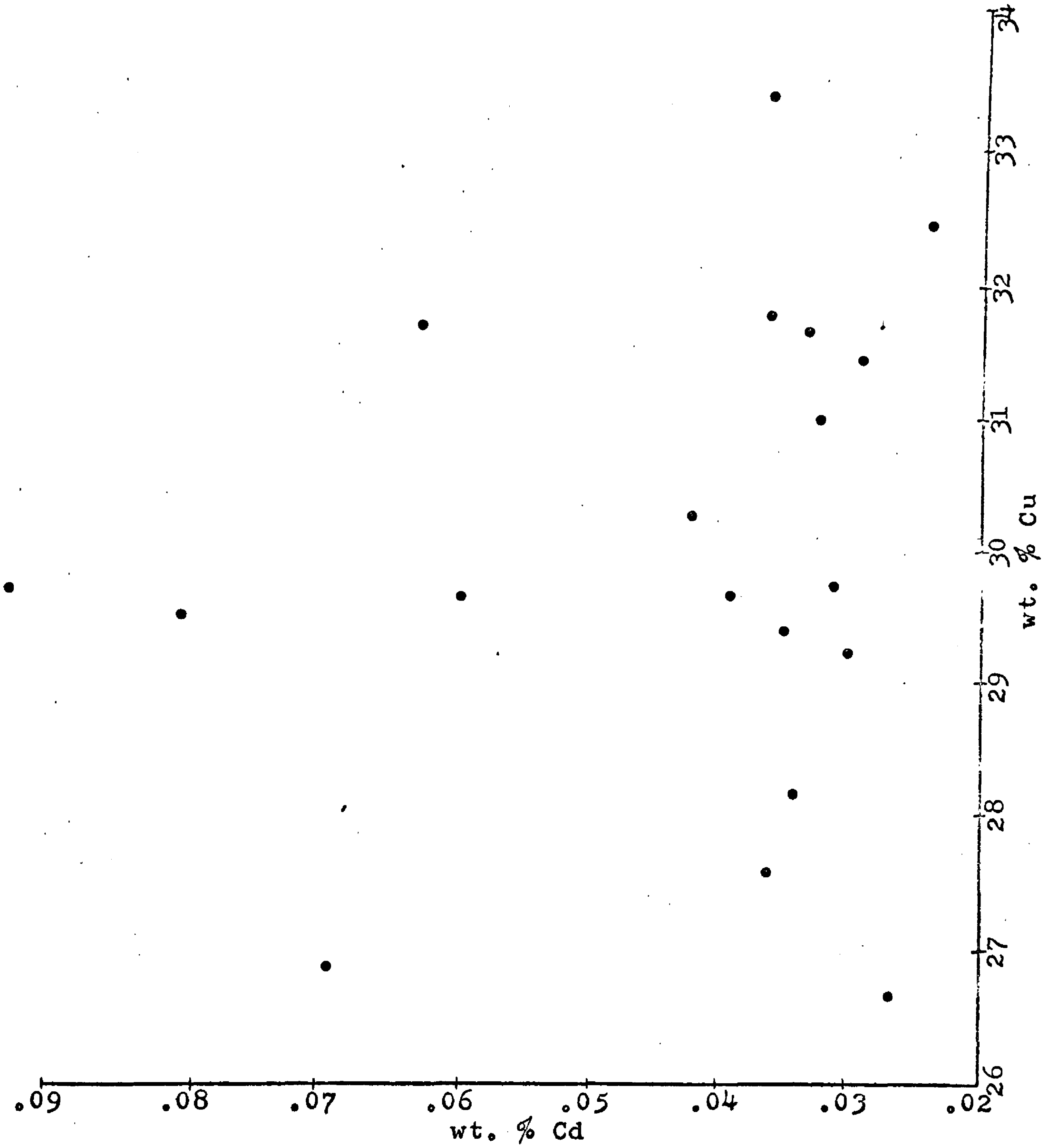
GRAPH 3 -- Graphical relationship between copper and silver values and ore type in Lucky Friday tetrahedrite samples.



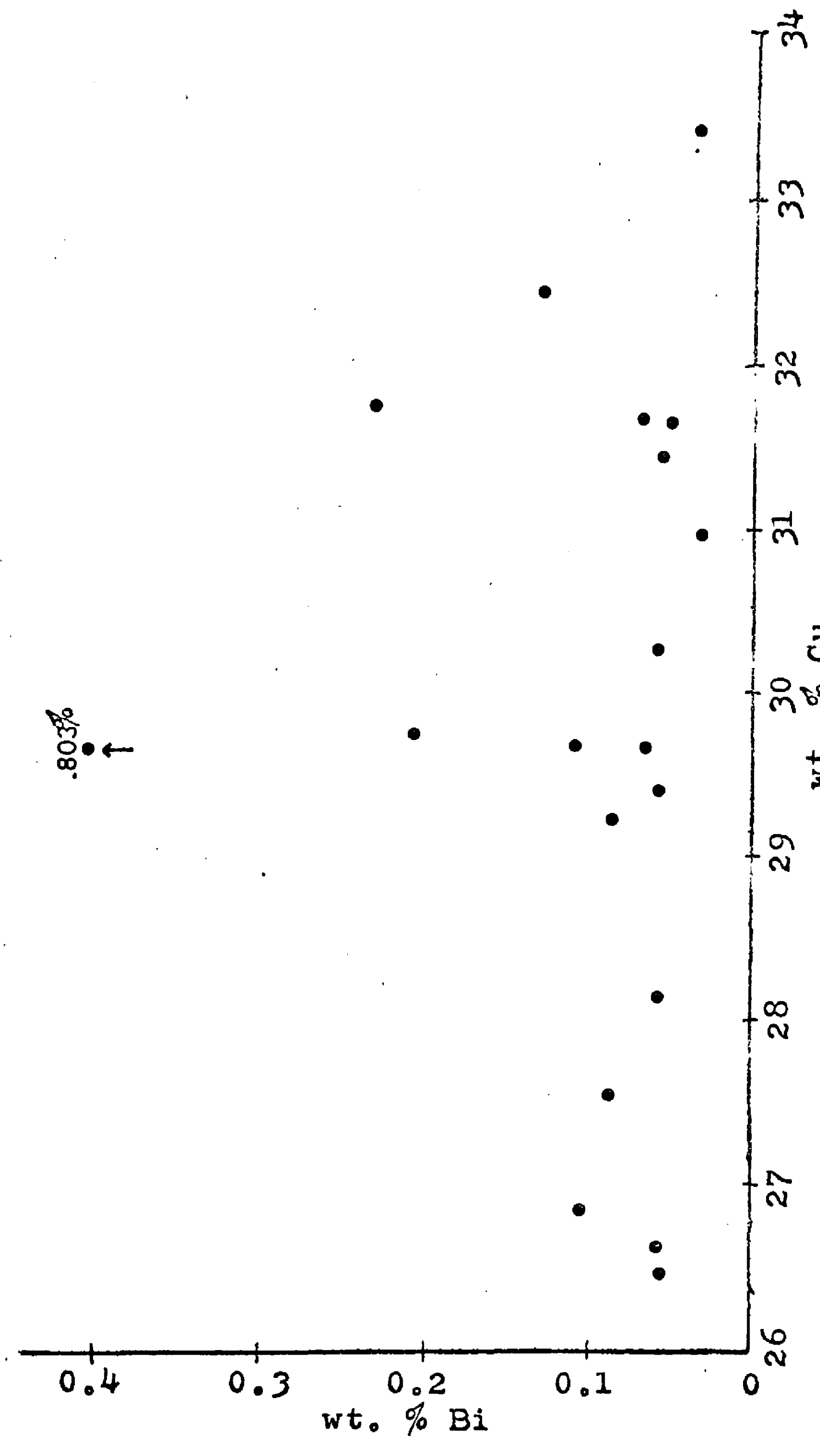
GRAPH 4 -- Graphical relationship between copper and iron values in Lucky Friday tetrahedrite samples.



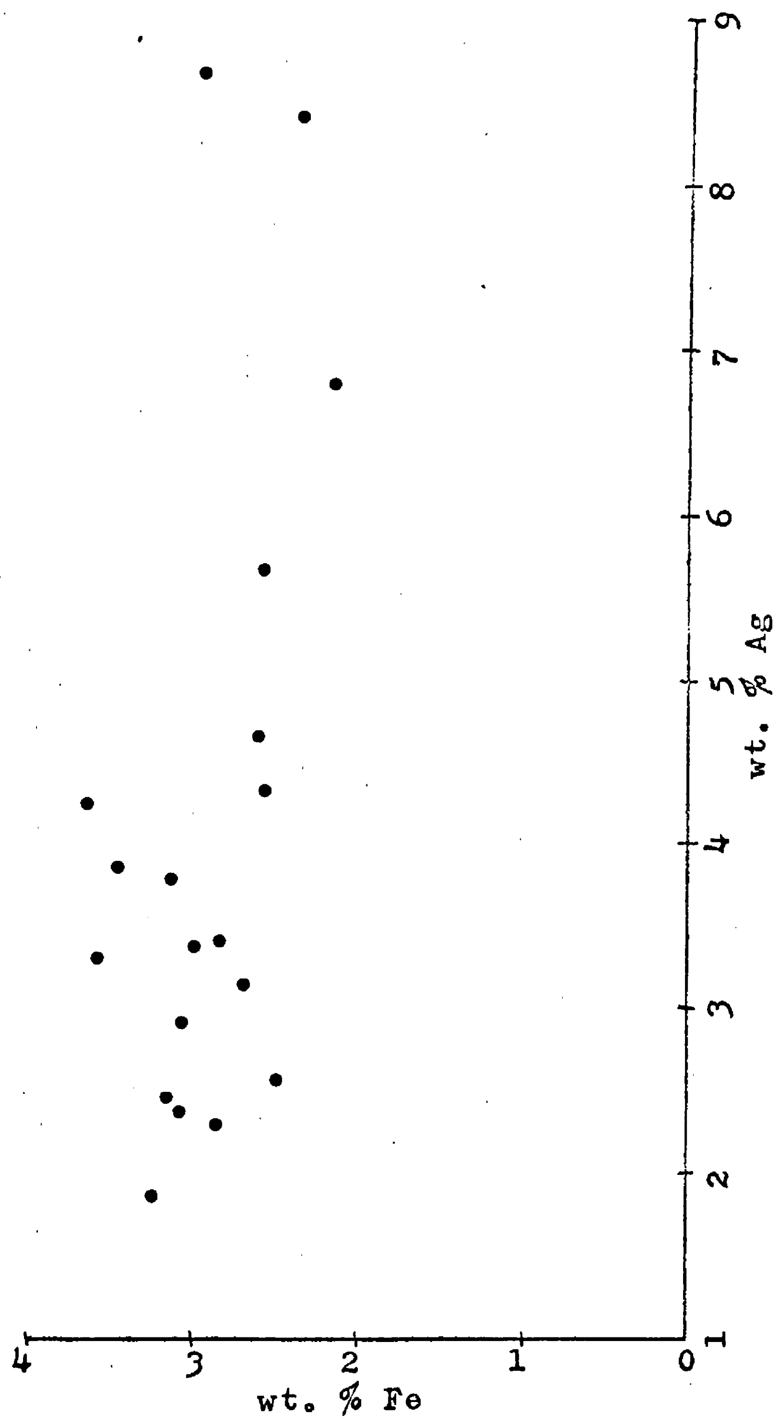
GRAPH 5 -- Graphical relationship between copper and zinc values and ore type in Lucky Friday tetrahedrite samples.



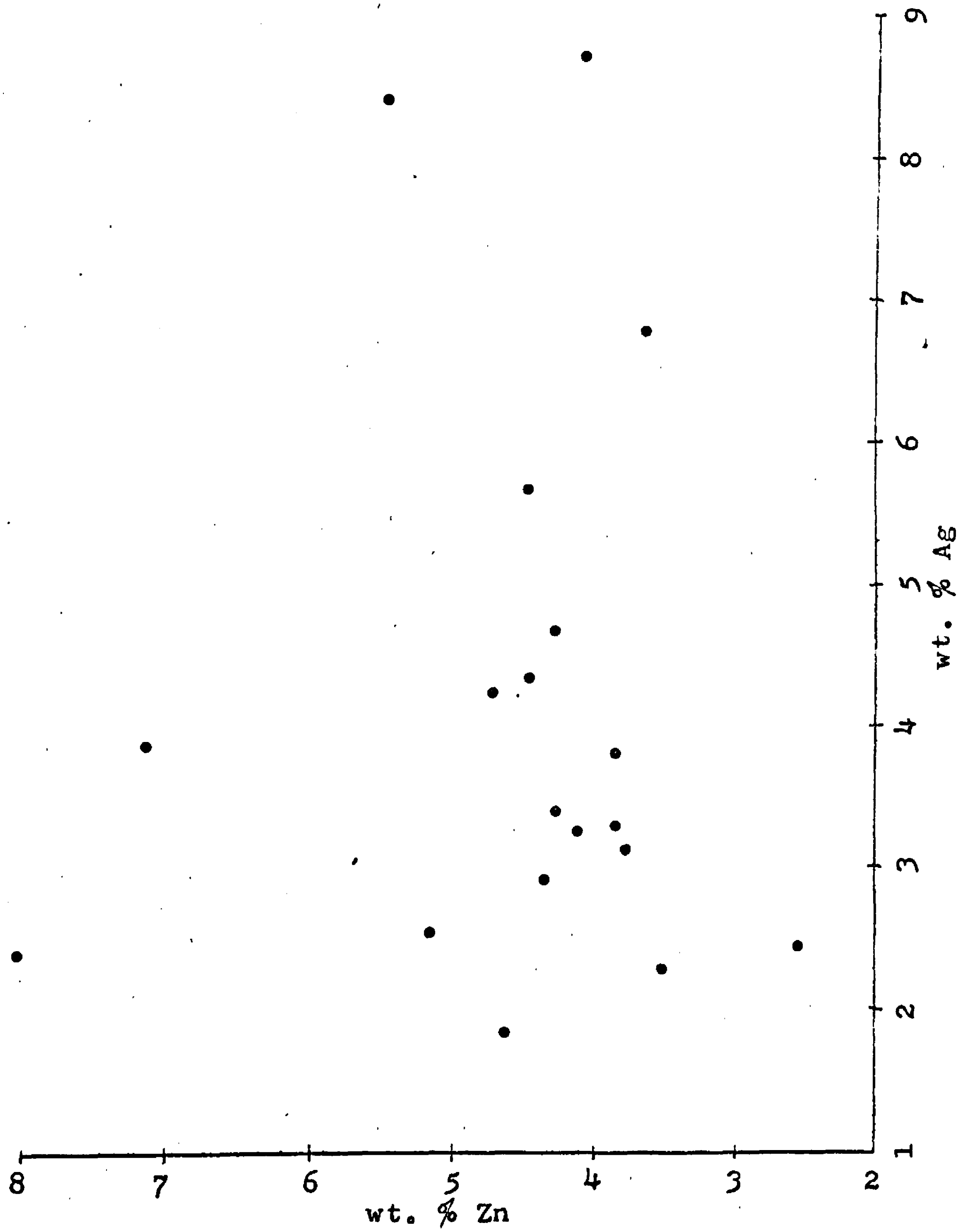
GRAPH 6 -- Graphical relationship between copper and cadmium values in Lucky Friday tetrahedrite samples.



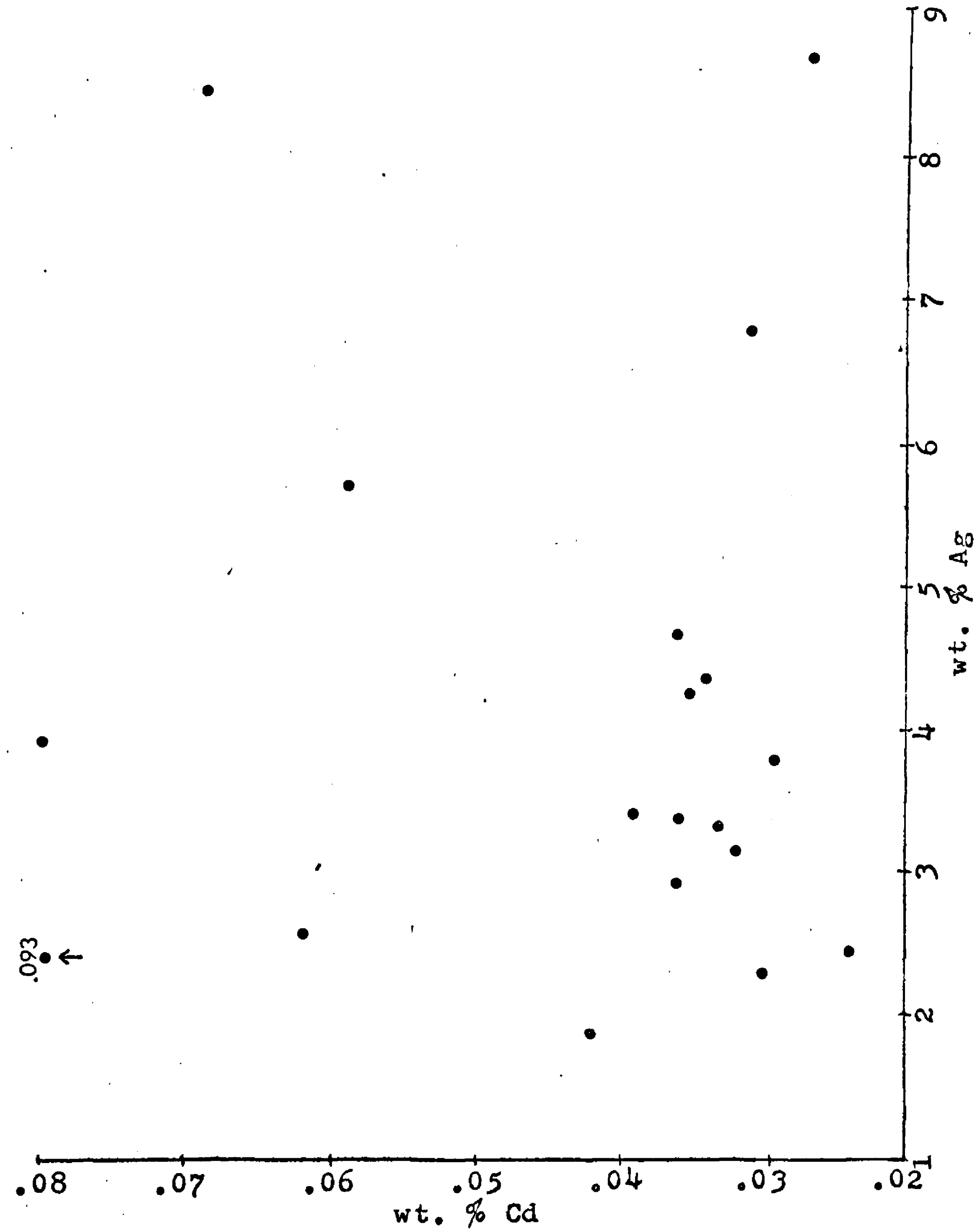
GRAPH 7 -- Graphical relationship between copper and bismuth values in Lucky Friday tetrahedrite samples.



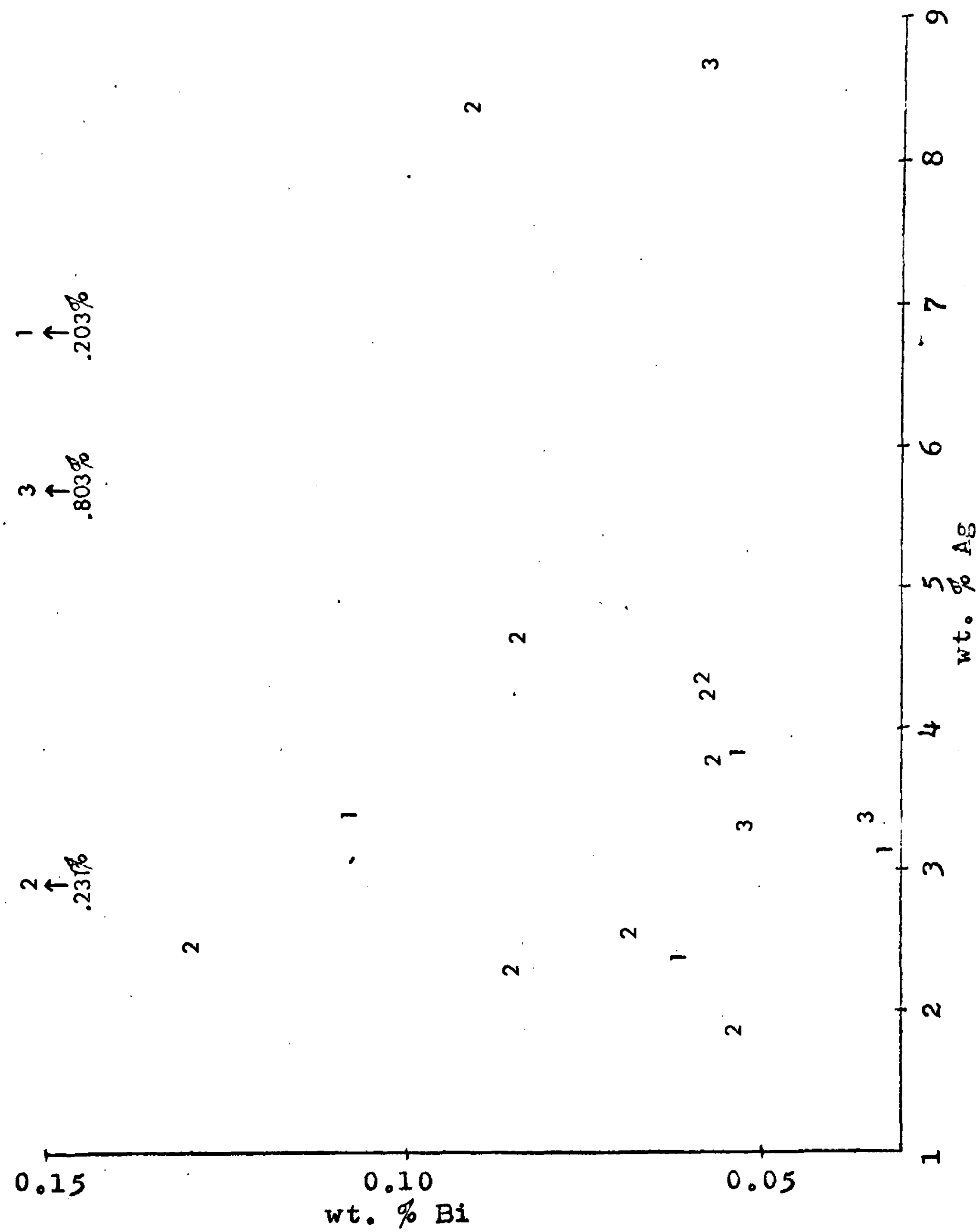
GRAPH 8 -- Graphical relationship between silver and iron values in Lucky Friday tetrahedrite samples.



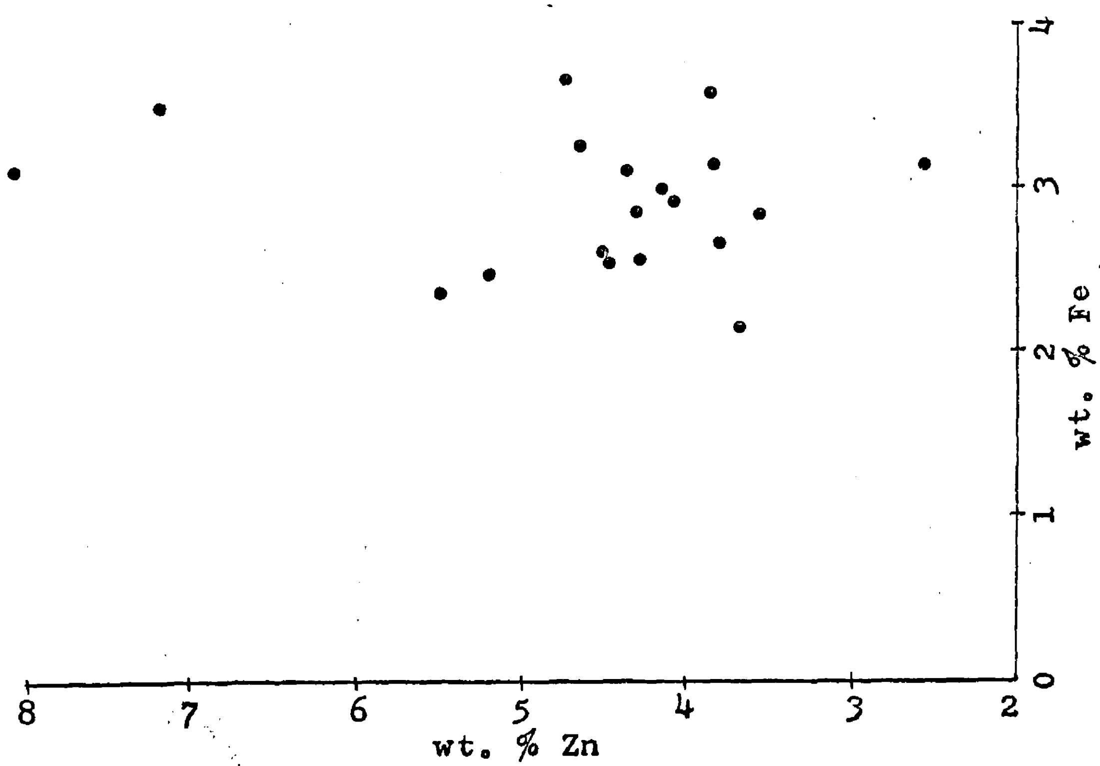
GRAPH 9 -- Graphical relationship between silver and zinc values in Lucky Friday tetrahedrite samples.



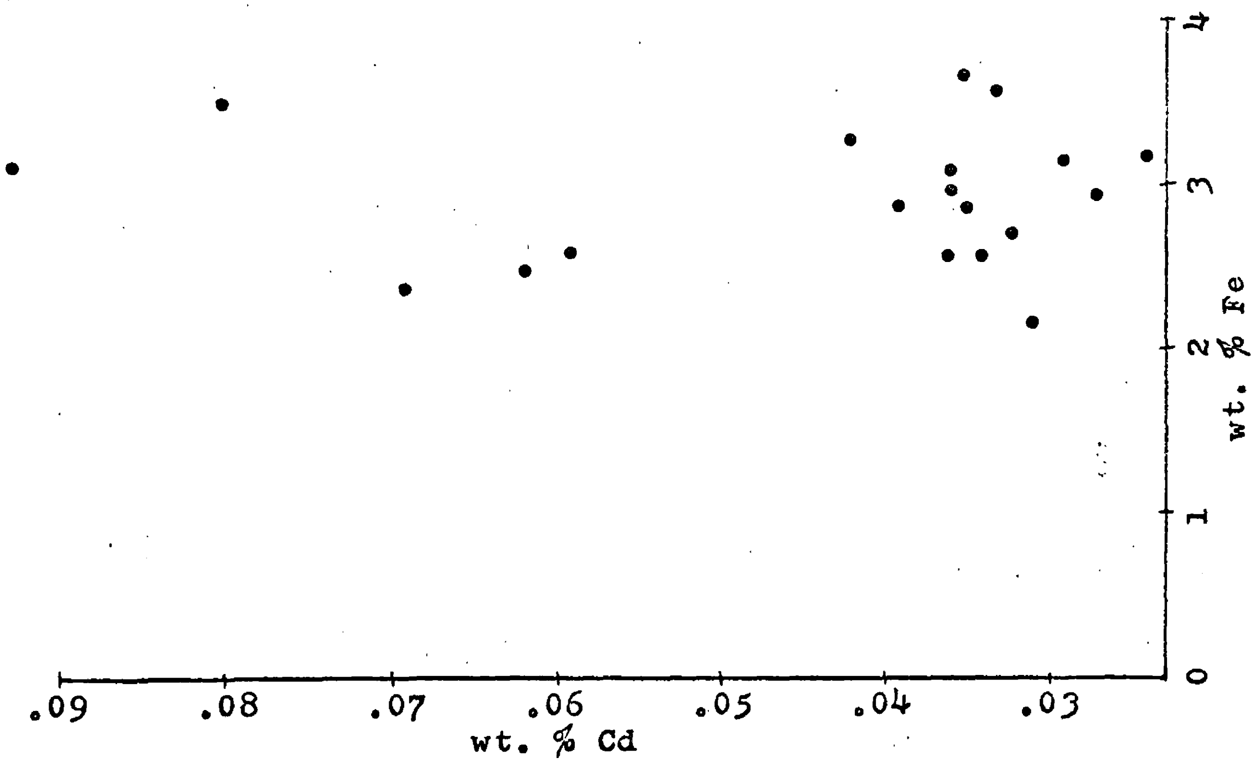
GRAPH 10 -- Graphical relationship between silver and cadmium values in Lucky Friday tetrahedrite samples.



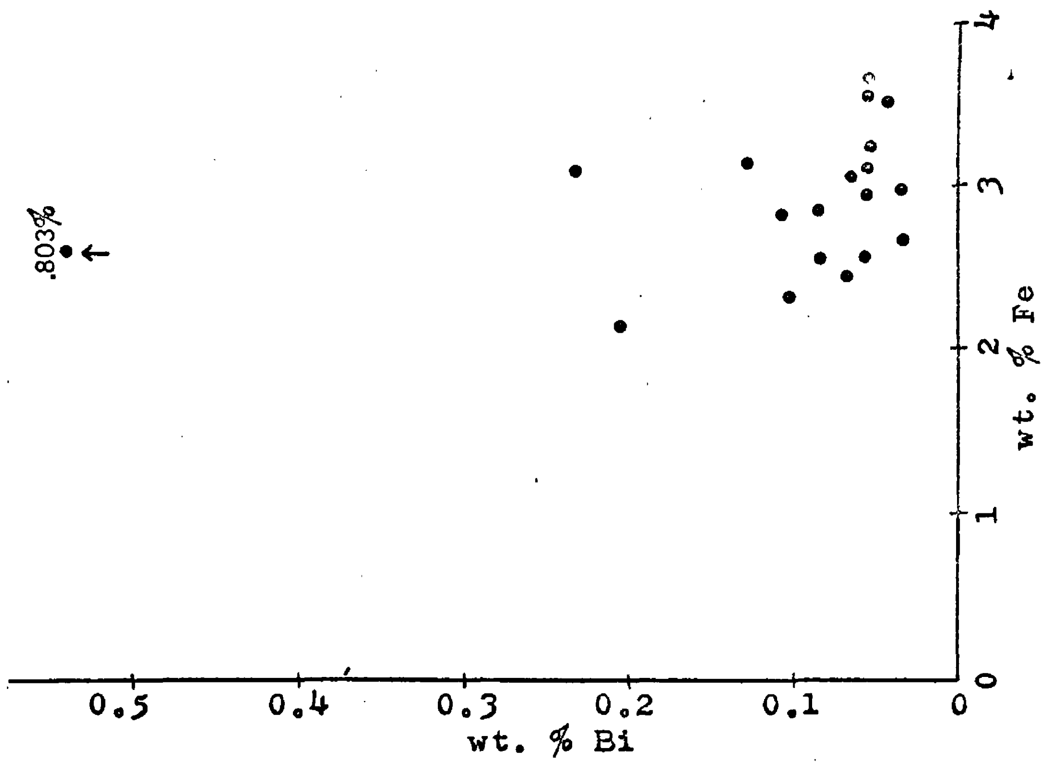
GRAPH 11 -- Graphical relationship between silver and bismuth values and ore type in Lucky Friday tetrahedrite samples.



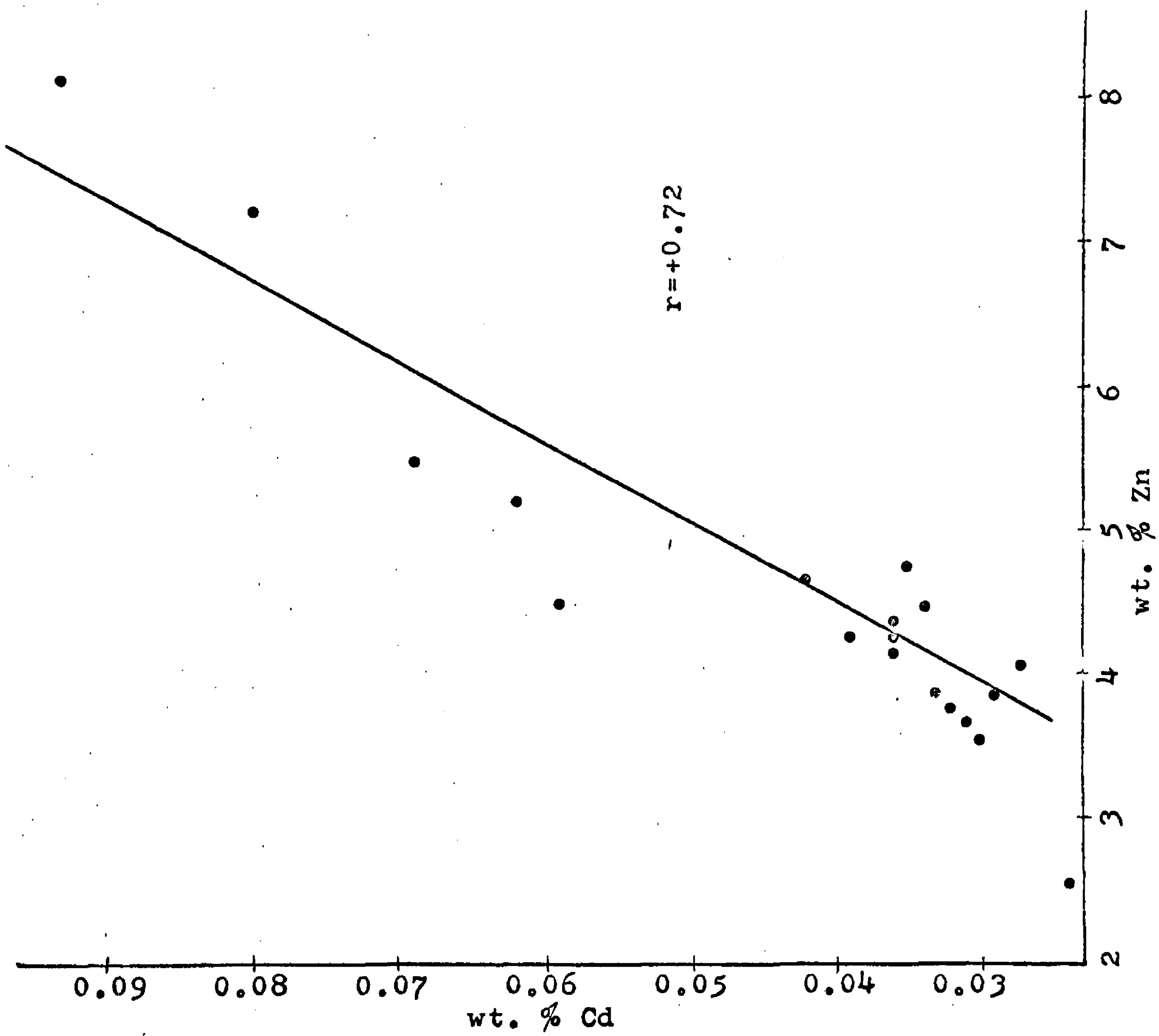
GRAPH 12 -- Graphical relationship between iron and zinc values in Lucky Friday tetrahedrite samples.



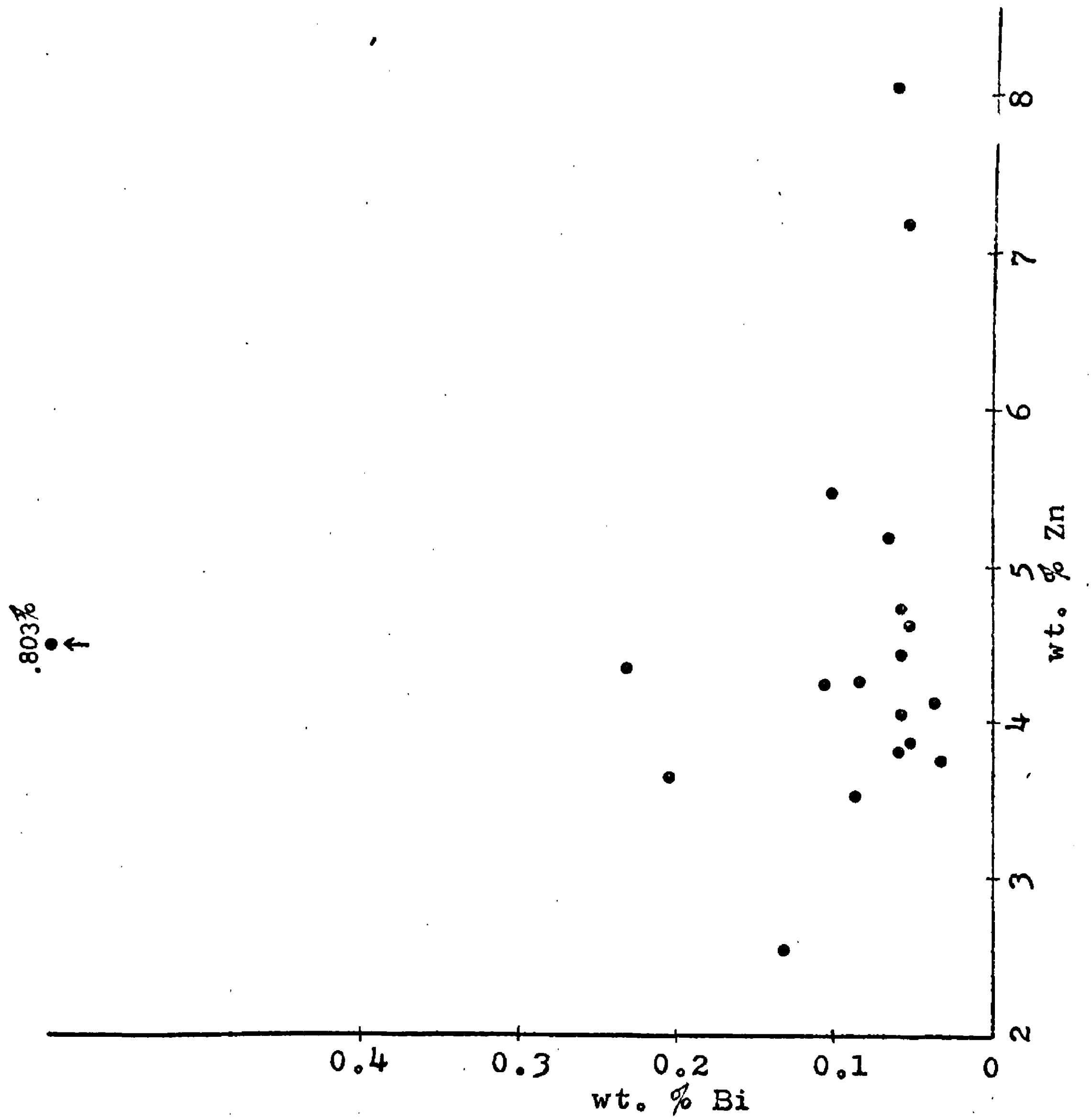
GRAPH 13 -- Graphical relationship between iron and cadmium values in Lucky Friday tetrahedrite samples.



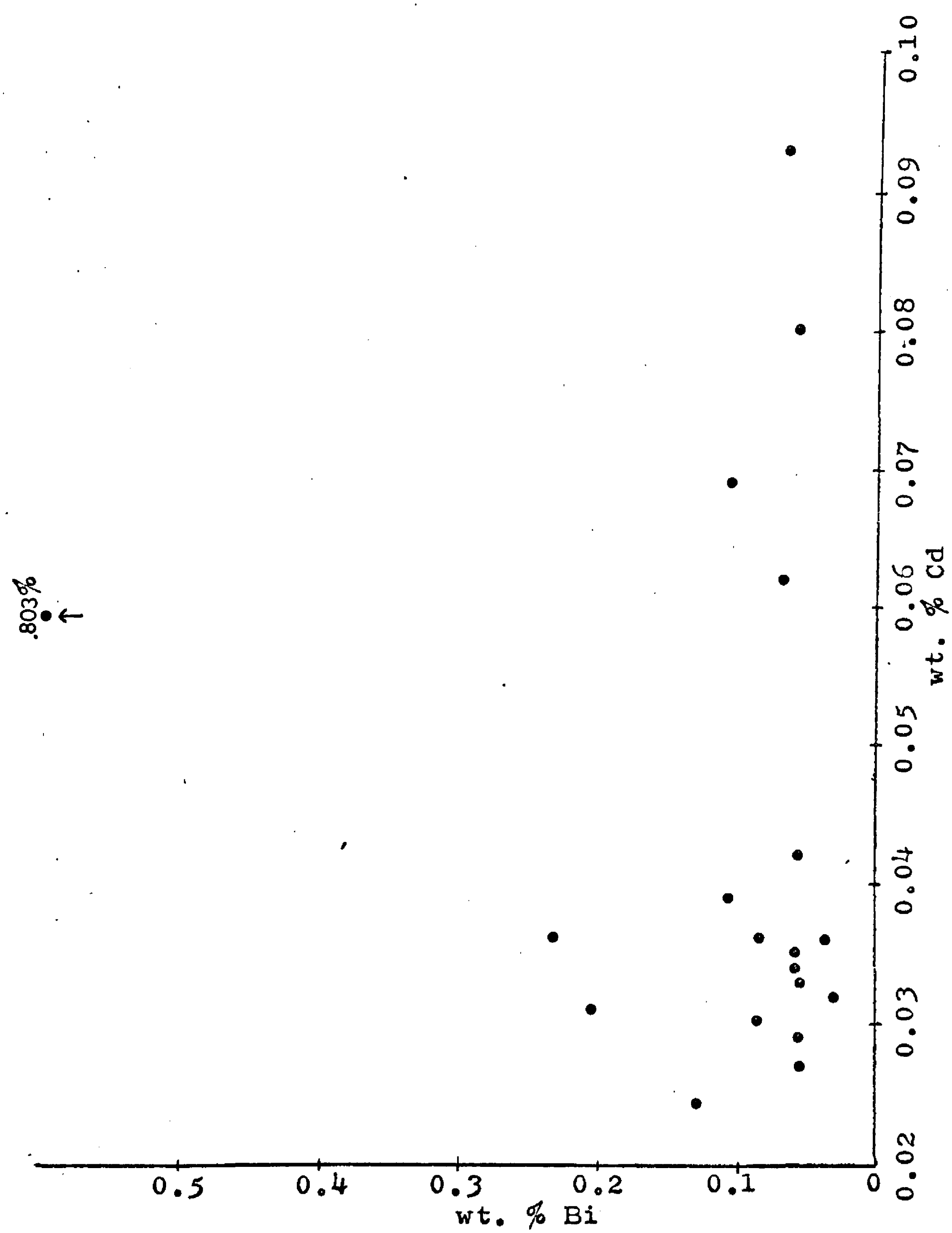
GRAPH 14 -- Graphical relationship between iron and bismuth values in Lucky Friday tetrahedrite samples.



GRAPH 15 -- Graphical relationship between zinc and cadmium values in Lucky Friday tetrahedrite samples.



GRAPH 16 -- Graphical relationship between zinc and bismuth values in Lucky Friday tetrahedrite samples.



GRAPH 17 -- Graphical relationship between cadmium and bismuth values in Lucky Friday tetrahedrite samples.

APPENDIX C

MICROPHOTOGRAPHS

(Plates 1-10)

PLATE 1 -- Example of the fine grained type-1 ore. Sphalerite (sp) grains are semi-rounded and partly interlocked (arrows) with the enclosing galena (gn). Associated with tetrahedrite (td, with grain boundaries dotted for clarity), pyrite (py), quartz (q), and siderite (sid). Sample 3450-109R-E80. Plane polarized light. Bar scale represents 0.2 mm.

PLATE 2 -- Possible matildite (mat) exsolution grain in coarse grained type-2 galena. Associated with minor tetrahedrite (td). Note polishing scratches on the galena surface. Sample 2800-94R-W65. Plane polarized light. Bar scale represents 0.05 mm.

PLATE 1

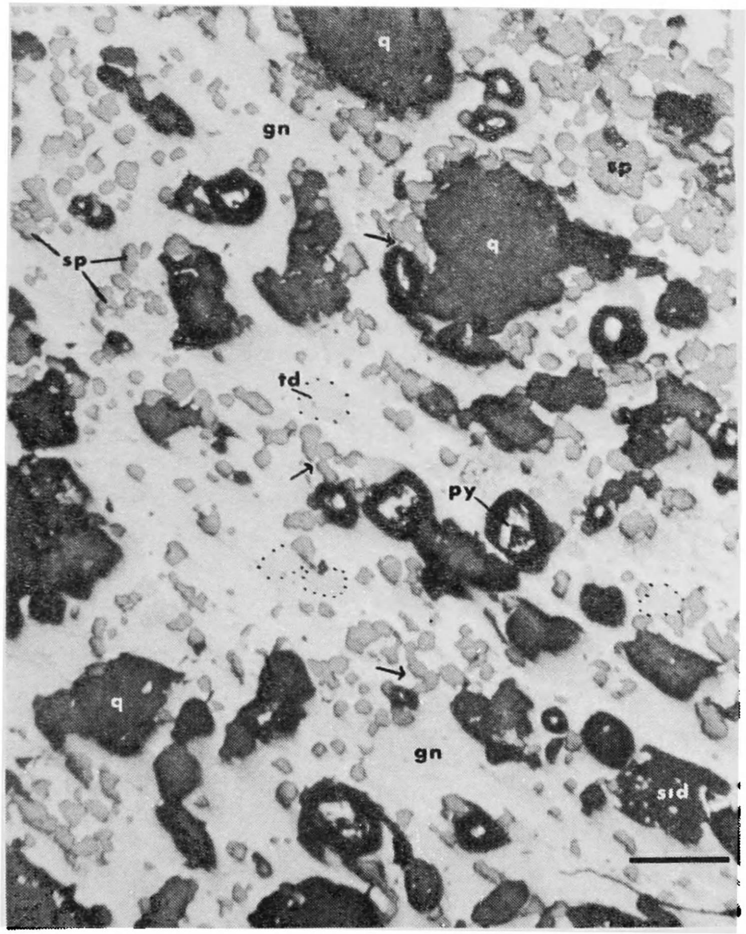


PLATE 2

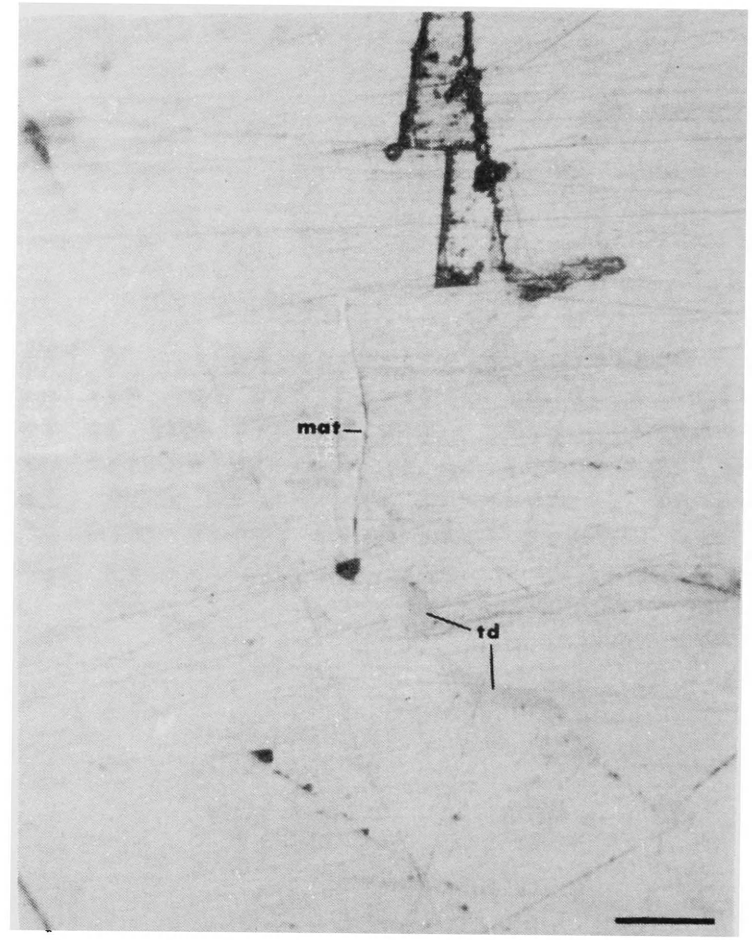


PLATE 3 -- Example of the tetrahedrite-rich type-3 ore. Tetrahedrite (td) replaces siderite (dark) and contains galena (gn) inclusions. Sample 2150-95AR-W115. Plane polarized light. Bar scale represents 0.1 mm.

PLATE 4 -- Chalcopyrite exsolution lamellae and grains (cp) in sphalerite (sp) of the type-2 ore. Associated with irregular grains of tetrahedrite (td). Dark areas are fractures. Sample 4050-99R. Plane polarized light. Bar scale represents 0.1 mm.

PLATE 3

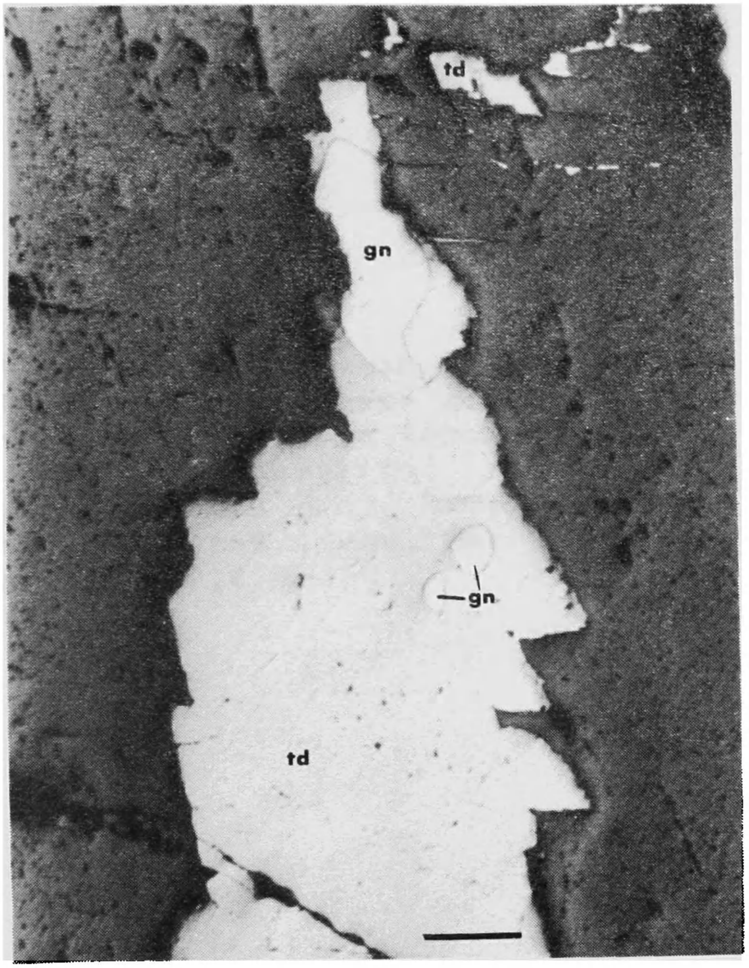


PLATE 4

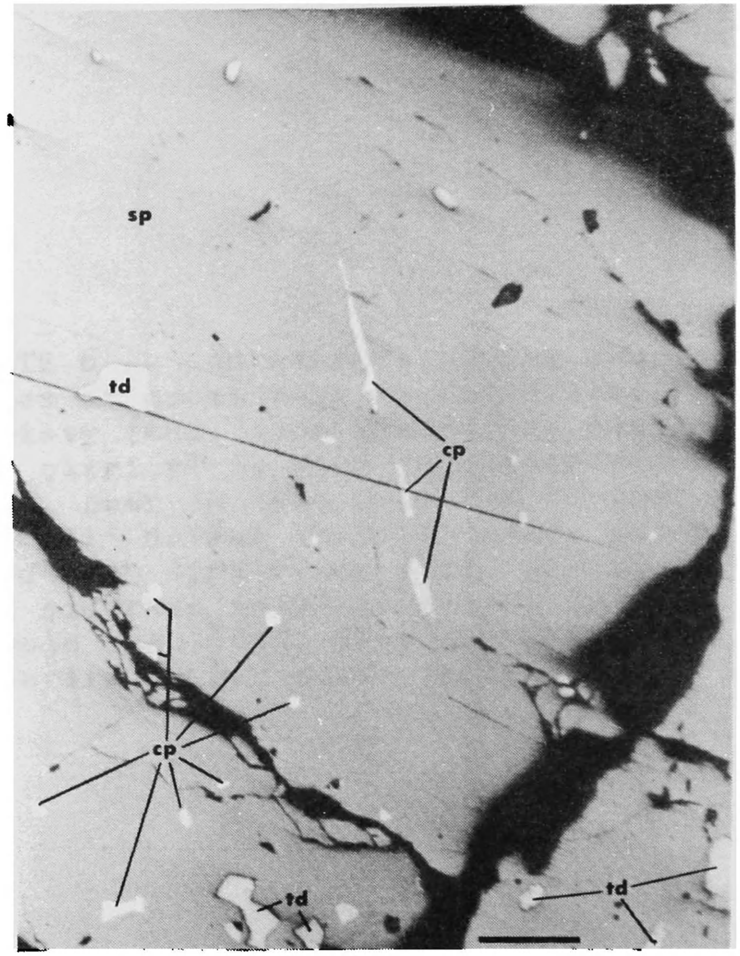


PLATE 5 -- The common habit of tetrahedrite (td) in coarse grained type-2 ore. Associated with sphalerite (sp), pyrite (py), quartz (q), and siderite (sid) in galena (gn). Sample 3850-94R. Plane polarized light. Bar scale represents 0.2 mm.

PLATE 6 -- An example of the two varieties of coexisting tetrahedrite. Pale variety (td2, some boundaries dotted for clarity) is rich in silver and bismuth, poor in iron compared to the "normal" darker variety (td1). Associated with sphalerite (sp), pyrite (py), and siderite (sid) in galena (gn). Sample 3850-105R. Slightly crossed polarizers. Bar scale represents 0.1 mm.

PLATE 5

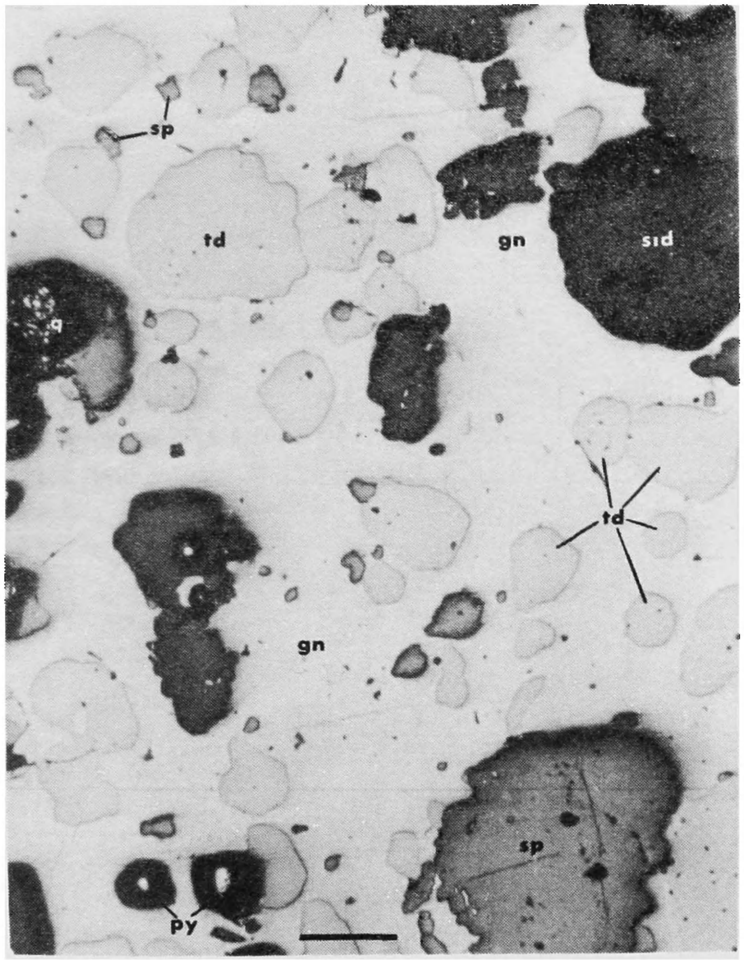


PLATE 6

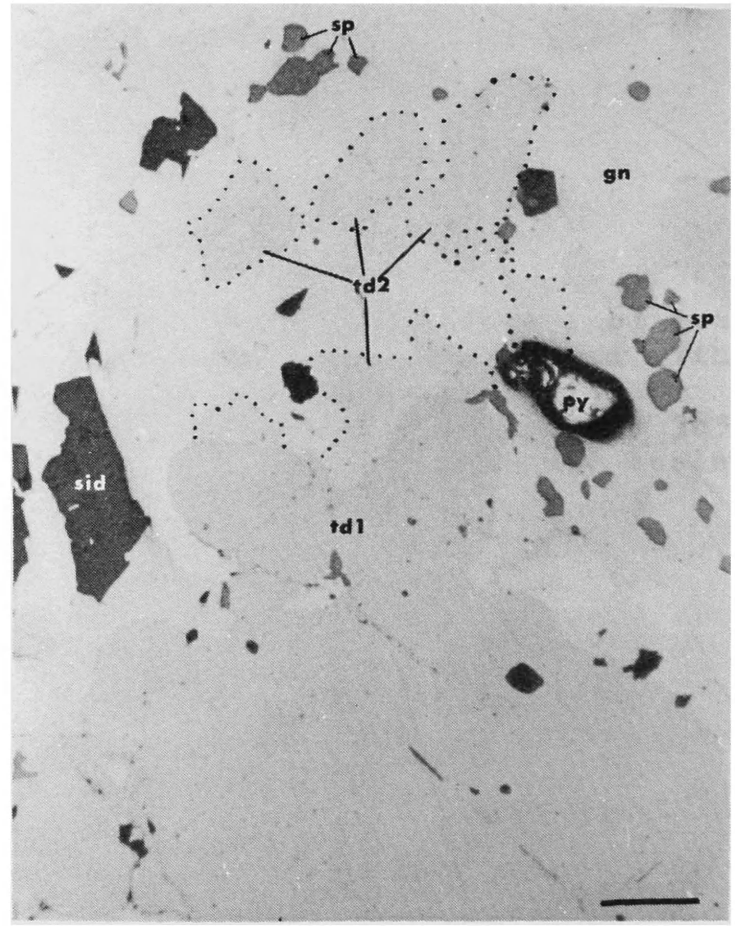


PLATE 7 -- Lamellar twinning in the pale, silver- and bismuth-rich, iron-poor variety of tetrahedrite (td). The slab was etched for 30 seconds with 1:1 nitric acid, darkening the enclosing galena. Associated with sphalerite (sp), siderite, and quartz. Sample 3850-105R. Polarizers slightly uncrossed. Bar scale represents 0.1 mm.

PLATE 8 -- Small pyrrhotite (po) grains in tetrahedrite (td). Associated with pyrite (py), chalcopyrite (cp), and quartz (q) in galena (gn). Sample 3850-94R. Plane polarized light. Bar scale represents 0.2 mm.

PLATE 7

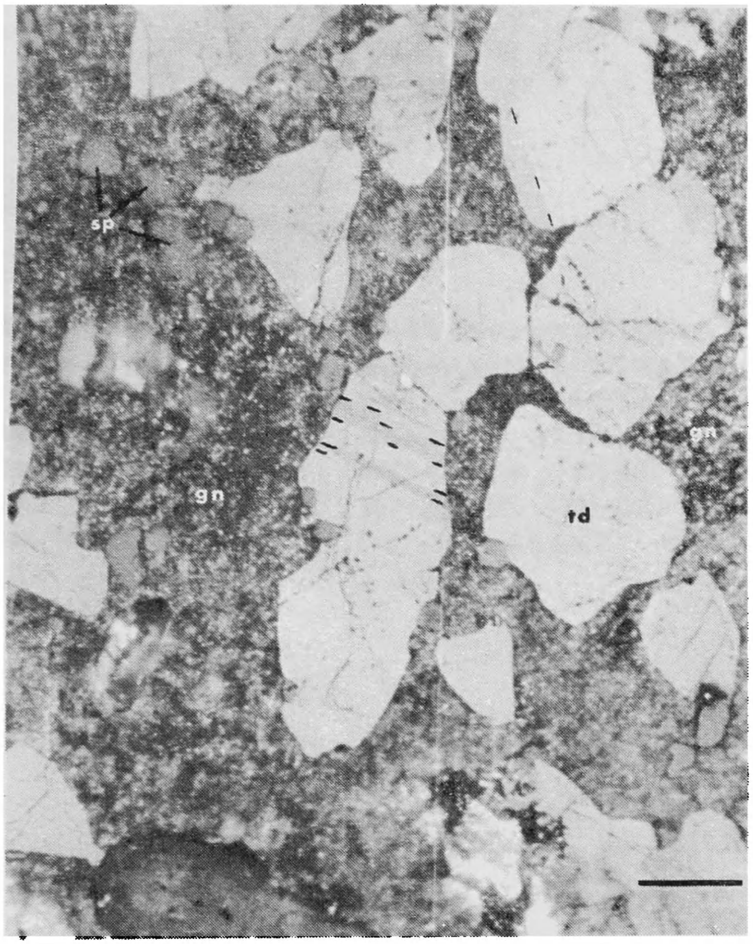


PLATE 8

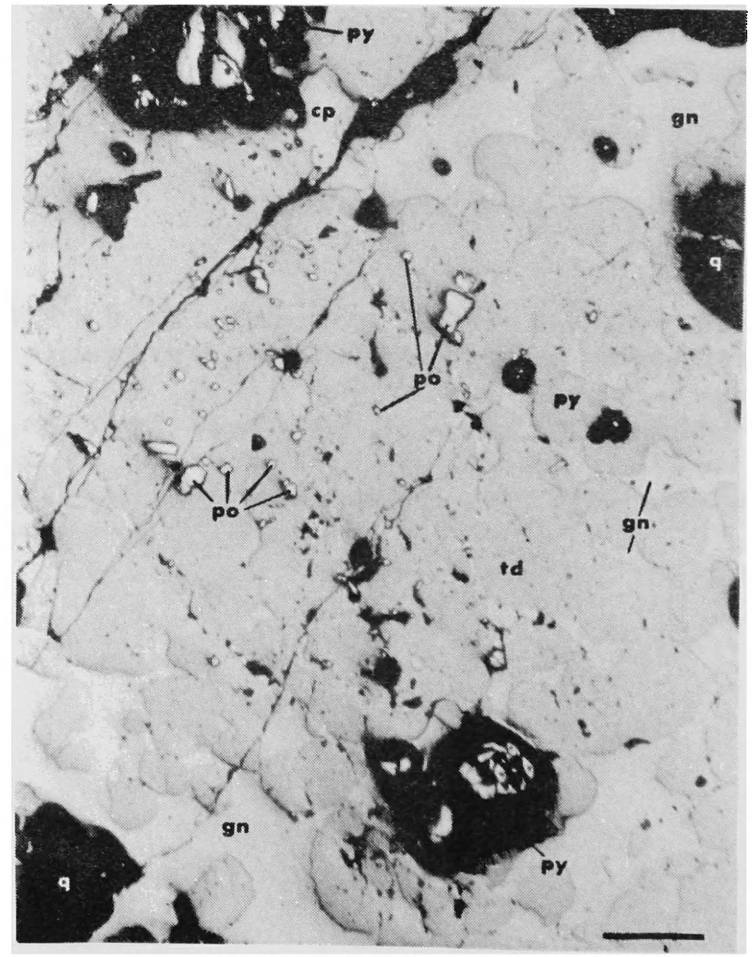


PLATE 9 -- A large idiomorphic pyrite crystal containing oriented inclusions of tetrahedrite. Crystal is enclosed in galena (gn) and associated with minor tetrahedrite (td), siderite (sid), and small, rounded pyrite (py). Sample 3850-94R. Plane polarized light. Bar scale represents 0.1 mm.

PLATE 10 -- Large polycrystalline grain of siderite (sid) extensively replaced by galena (gn). Numerous curved deformation twin lamellae are visible under crossed polarizers. Associated with quartz (q). Sample 3850-94R. Bar scale represents 0.2 mm.

PLATE 9

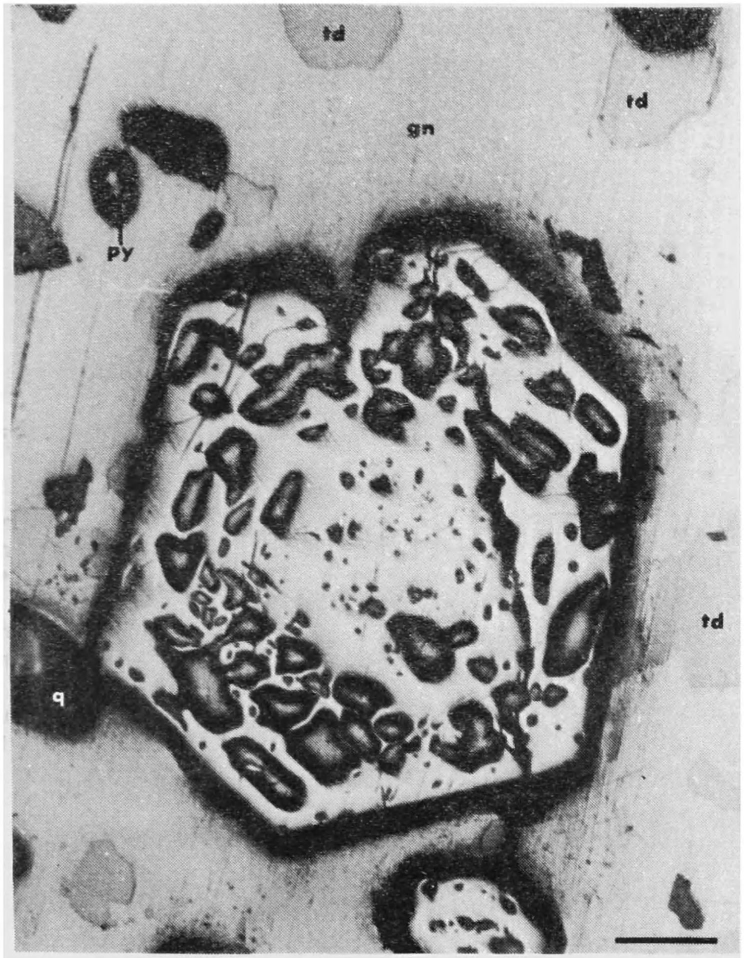


PLATE 10