A

Preliminary Investigations of a New Sulfide Deposit at Andersonville, Virginia

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Spring, 1969.

UNPUBLISHED SENIOR THESIS

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I Zone 24 (Morris Property)
Soil Geochemistry
Zn > 200 } screen limit
Cu > 50
Pb > 30
Co > 25

II Zone 24 EM 16 NAA
IN PHASE
OUT OF PHASE

Introduction

It is the intent of this paper to present the results of preliminary investigations of various aspects of a new sulfide deposit in Buckingham County, Virginia. It is not the writer's intent to discuss all the problems related to this deposit, to present all of the available data, nor to propose new ideas concerning the genesis of Appalachian sulfide deposits in general. The inavailability of many critical data at the time of this writing do not make these attempts practical or meaningful. It is the writer's intent, then, to farnish the preliminary data and ideas concerning this unusual sulfide body, which hopefully may be pursued at a later date when more data is available.

Location and History of Developement

The sulfide deposit is located on the property of Claude W. Morris, on state road 609, 5 miles southeast of Andersonville, Virginia, and within sight of Willis Mountain, one of the largest economic kyanite deposits in the United States. Located in the Piedmont physiographic provence, the area is relatively flat. Drainage is to the south. The property, itself, is mostly wooded, though some areas have been cleared and are used for grazing.

Outcrops are extremely limited in the area due to the deep and intense weathering typical of the Virginia Piedmont. Thus, structural interpretation must, at present, remain highly speculative. Gossan, however, is common, irregularly scattered over the property. It was this gossan which first attracted mineral exploration to the area.

Prior to the California gold rush in 1849, gold mining operations were numerous in Buckingham County. Operations commonly were gravel washings and gossan works. The later involved concentration of small amounts of gold found in the gossan caps over weathered sulfide bodies. Numerous caved pits and trenches, as well as piles of gossan indicate that such activity was carried out on the Morris property, though there are no historical records of such.

It is of interest to note that several mines were developed in the area, primarily for copper recovery. The New Canton, Bumpus, Ford, and Anaconda Mines, now abandoned, are located close to the Morris property (Luttrell,1966).

Recent exploration and developement work has been dominated by Canadian mining concerns. The Virginia Mining Company (Montréal,Québec) commenced exploration activities in the early 1950's with both aerial and ground geophysical surveys over large areas of Buckingham County. Aerial geophysical anomalies were followed up by ground surveys. The presence of gossan associated with geophysical anomalies constituted grounds for drilling. "Zone 24" , the Morris property, was an area chosen for drilling exploration. 18 holes, with a combined footage of 5049.0 feet, were drilled during 1958-59. Self potential surveys were also carried out (Hagen, 1958, p. 1-6).

Subsequently, Dominion Explorers Ltd. acquired exploration rights to the Morris property. North American Exploration, of Charlottesville, Virginia, under contract, carried out extensive geophysical and geochemical surveys on a new grid over the property. Presently, the company is conducting

drilling operations. The data from these most recent surveys have been made available to the writer, and it is upon these data, as well as those of the Virginia Mining Company, that this report is based. Investigations concerning soil geochemistry, gossan, structural geology, and ore textures and genesis, form the bases for the discussion in this paper.

Soil Geochemistry

A soil geochemical survey was conducted by North American Exploration on the Andersonville Grid. Sample spacing was 100 feet on a grid 2000 by 2600 feet. Samples were obtained through the use of a regular soil auger, at depths averaging 6" below the surface, and in any case, below the organic layer. The samples were then dried and sieved to -250 mesh. The fine fraction was then dissolved in acid and analyzed by usual atomic absorption techniques for Pb, Zn, Cu, Co, and Ni, and the results were plotted on the grid map. From this data, histograms were plotted for each element to determine the so called "backround," "threshold," and "anomalous" metal values (see Hawkes and Webb, 1962, p. 28-31). The accompanying geochemical contour map is the result of first contouring all metal values on 5 to 50 ppm intervals to obtain accurate areal trends in the metal content of the soil. To eliminate confusion, an overlay of each metal contouring was made and one contour line, enclosing anomalous values only was plotted (Plate I). The present map, then, is a contouring of anomalous metal values (no anomalous Ni is present), which also shows projected ore body outcropping, and other pertinent data.

A superficial glance at the contour map will show that no simple geochemical pattern is present. This impression is strengthened by the fact that the anomalous contouring is a simplification of an even more erratic primary contouring. This, however, is to be, in part, expected in an area of active human activity which undoubtedly contaminated the area (eg. the emplacement of metal fences, discarded galvanized buckets, etc.), as well as having caused artificial transportation of anomalies (eg. by plowing, grazing, etc.). Thus, at the outset, any interpretation of the data must be prepared to deal only with the general trends in the geochemical patterns.

Several general features of the metal anomaly pattern may be noted. First, and most significant, anomalous metal content of the soil is confined to an area south of the base-line. The abrupt termination of anomalous values for all metals at or near the base-line is spectacular, especially when contrasted to the highly irregular boundaries to the south. Thus, a sharp northern boundary and an irregular boundary for anomalous values is the major characteristic of the pattern.

The exceptions to the above mentioned broad anomalies are the unusually sharp contours of zinc and cobalt. Anomalous zinc contouring is highly irregular and does not appear to relate to the broad patterns. Cobalt anomalies are striking in that they are highly linear and, for the most part, are unrelated to the patterns caused by the other metals. (Discussion of the cobalt anomalies is defferred until a later section).

Finally, it is of interest to note the gossan distribution. Clearly, the outlines of the distribution are strikingly similar to those of the anomalous metal contours, i.e. it has a rather sharp northern termination and a more irregular southern boundary.

Interpretation of Geochemical Data

The goal of the interpretation of the geochemical data was primarily to determine the location of the sulfide body responsible for the anomalous metal content of the soil. While drilling data ~~was~~ were available before an interpretation was undertaken, thus rendering any conclusions virtually infallible, it is felt that on the basis of the geochemical data, alone, an interpretation leading to the discovery of "ore" is possible. When drilling and geochemical data are considered together, the resulting explanation of data may prove to be a valuable guide in exploration in other areas of the Virginia Piedmont.

The mobility of the various metal ions under "surface conditions" is a fundamental phenomenon which must be considered when interpreting the results of a geochemical survey, for the mobility determines the migration of anomalous metal values, and thus the present anomaly distribution. Among the metals plotted on the map, Pb, Zn, Cu, and Co, the following mobilities are reported by Hawkes and Webb(1962, p. 359-377):

Lead: low
Zinc: high
Cobalt: moderately high
Copper: moderately high

Thus, metals such as lead will tend not to migrate far from

it source, while zinc is readily dispersed by such actions as ground water movement, surface run-off, etc.

Clearly, then, the slope and drainage of an area are extremely important in any consideration of geochemical patterns, as the movement of ground water, surface run-off, and soil creep, all factors in geochemical dispersion, are controlled by them. The Andersonville Grid shows a slope and drainage to the south, practically parallel with the side-lines of the grid.

The elemental mobility and the grid topography, when considered together, immediately indicate that the source of the metal ions is located in the northern portions of the anomaly pattern. The shape of the anomaly contours are in complete agreement with this idea. Anomalous lead is confined to a narrow belt on the northern edge of the anomaly pattern. Being relatively immobile, it is confined to an area near the proposed source. Copper values have a sharp northern limit and "spread out" towards the south, having been transported south, possibly by ground water. Anomalous zinc values, while erratic, are generally confined to an area south of the base-line. Being highly mobile, it is expected that zinc distribution would be profoundly affected by ground and surface water movement. The presence of a stream, generally following the zinc anomaly in the southeast, confirms this fact, and, in addition, indicates a source to the north of the present anomalous distribution.

A question may arise as to whether the present pattern of anomalies is residual or transported. It is felt that the later is responsible. The idea that the soil geochemical anomalies are residual is supported, however, by the

fact that the distribution of non-transported gossans, directly derived from a parent sulfide body, is congruous to the geochemical anomalies. The gossans are necessarily derived from material directly beneath them or are residual representations of a sulfide body once above them, since having been eroded away. Thus, the congruence of the gossan-geochemical contours may represent a residual pattern, i.e. a pattern which has not been changed by subsequent ground water action. A problem arises, however, when the lead anomaly curve is considered. If the anomalous metal contouring is representative of a residual pattern, why is lead confined to a small portion of the patten and not ubiquitous?

The so called "lead problem" has lead this writer to believe that the present geochemical pattern is the result of extensive transportation of the metal ions from a discrete source. It is felt that the lead, being immobile, is located close to the source, and that the copper and zinc anomaly patterns are consistent with the idea that transportation southward from a linear source explains the geochemical distributions. Copper, being moderately mobile, shows a broad "wash" to the south, while zinc, being highly mobile, shows a strong association with the soutward drainage pattern.

Therefore, on the basis of surface geochemical data alone, it is thought that the present distribution of anomalous metal values in the soil, reflect transportation southward from a linear source on the northern edge of the anomaly pattern. The increase in size southward of the Pb, Cu, and Zn patterns are consistent with the "transported anomaly" proposal because of the respective increase in mob-

ility of the metal ions. The source of the ions, then, must be closely related to the lead anomaly. Projection of the strike and dip of the ore body to the surface, based on drilling data, shows this to be the case.

The attitude of the source may be further analyzed on the basis of gossan distribution. As explained above, the gossan must appear either directly over the parent material, or be derived from sulfides once over their present location. The sharp northern termination of the gossan distribution, and the irregular southern boundary, considered in conjunction with the geochemical data, then indicates that the sulfide body outcrops at the northern gossan-geochemical anomaly limit, and dips to the north. Hence, no gossan is present over the unweathered portions of the sulfide body, but is present over those areas where the sulfide deposit has been eroded away. ?

Finally, it remains to be mentioned, data relating to the geochemical expression of ore at depth. From drilling information, and the anomaly contours, it appears that anomalous metal content in the soil appears only when the ore is at a depth of less than 75 feet below the surface. Thus, traverses in the direction of dip show a sharp decrease in metal content of the soil, beyond the northern anomalous limits.

In summary, it appears that the low mobility of lead allows the conclusion that anomalous lead values lie immediately near the source of the ions, and that the other metal ions , being more mobile, are more dispersed away from the source. Gossan distribution, correlated to soil geochemistry, may indicate the location and attitude of the sulfide source.

Thus, when geochemical anomalies, gossan distribution, topography, and drainage are considered together, they may be reliably used to locate ore.

Gossans

An investigation of gossans of the Andersonville Grid was undertaken primarily to distinguish a "good" gossan, derived from sulfides other than pyrite, from the pyrite gossans which are common in the Virginia Piedmont. The problem of distinguishing the two types is noted by Hagen (1958, p. 9) in a preliminary survey of the area. This survey was limited to the study of gossan samples themselves, and not their areal distribution on the grid. Much of the gossan on the grid has been piled up in selected areas, probably by early prospectors. Each pile has been shown to contain several varieties which probably did not originate in the same area. Therefore, the distribution of the gossans over the small grid area is not thought to be significant.

Approximately 25 gossan samples were collected on various parts of the grid. Of these, 10 were selected as representative samples of various ill-defined types. The 10 samples were then described in terms of box-work structure, limonite color, and cavity filling. The results appear in the table below. Pieces of these gossans were then crushed and sieved to -250 mesh, totally dissolved in acid, and analyzed by atomic absorption techniques for Zn, Cu, Pb, Ni, Ag, and Cd. These results are also shown on the table.

In classifying the gossans, the samples were immediately divisible by the presence or absence of box-work and/or sponge.

Samples AGR-1,2,4,9, and 10 are classified as amorphous samples. Though some spongy areas are present in most of these samples, they are extremely ill-defined. It will be noted that many characteristics of these amorphous samples are attributed to a pyrite parent by McKinstry (1948, p. 268). As seen from the table, the metal values are characteristically low for these samples.

Among the remaining samples, AGR-3,6,7, and 8, all showed well developed box-work and/or sponge. At the outset, it should be noted that much of this structural developement is due to the oxidation of pyrite. Most notably, those thin-walled, angular cells, commonly of cubic habit, which are lined with black or irredesent limonite, are thought to be of a pyrite origin (Boswell and Blanchard, 1927, p. 430-1). Also, thick-walled cells of irregular or rounded shape, correspond excellently to descriptions of pyrite gossans (McKinstry, 1948, p. 268). From drilling data, it is known with a large degree of certainty, that the major component of the ore is pyrite, and it is not unusual, then, to find that most of the Andersonville gossan shows structure and colors due largely to the weathering of that mineral. The following is a summary of textural and colorimetric characteristics of those portions of the gossan samples which are thought to be derived from a sulfide other than pyrite.

Chalcopyrite: as will be noted in the table, samples AGR-6 and 7 show copper values significantly higher than all other samples analyzed. These two samples show the following characteristics which are unique to them among the other ten samples: 1) patches of bright yellow-orange (Rock color chart No. 10YR6/6-6/5) color. All other yellowish

patches are of a darker hue. 2) The yellowish color is confined to granular limonite which fills subangular, thin-walled box-work, which is usually less than 1mm across. Yellow-orange cross-webbing in the box-work was also observed. These observations correspond to McKinstry's description of chalcopyrite-derived gossan (McKinstry, 1948, p. 270). It should be noted that limonite-filled box-work is not characteristic of gossan derived from pyrite.

Galena: though galena is not common in the drill core, sample AGR-8 shows an unusually high lead content. Further, the gossan texture and color correspond excellently to descriptions of galena-derived gossans from widely scattered localities given by Boswell and Blanchard (1927, p. 431-4). Cubic box-work, arranged in long parallel rows, corresponding to "cleavage" box-work, is well illustrated in sample AGR-8. Relatively thin, siliceous cell walls, encrusted by "sintered limonite" enclosing brick-red, granular limonite, is thought to be characteristic of gossans derived from material containing considerable amounts of galena. Large areas of empty, cubic box-work, derived from pyrite, are present in the sample.

Sphalerite: sample AGR-3 shows the highest Zn content of all the samples analyzed. The gossan sample is dark brown, tough, and highly siliceous, which McKinstry (1948, p.272) and Boswell and Blanchard (1927, p. 430) believe to be diagnostic of a sphalerite-derived gossan. Further, the clean, limonite-free, cells, occasionally intersect at acute angles, strongly suggesting that the gossan was derived from a sphalerite-rich sulfide aggregate (McKinstry, 1948, p. 272).

Sample Number	Station Number	Zn ppm	Cu ppm	Ni ppm	Co ppm	Pb ppm	Ag ppm	Cd ppm	Box work	Box Work Type	Box Work Filling
AGR-1	6E+5S	160	1673	13	12	36	1	1	minor	"sponge"-like	orange-brown limonite
-2	6E+8S	224	845	13	19	75	1	1	not present	—	—
-3	6E+5S	704	1375	12	13	25	2	2	present	thick, brown, siliceous walls, rounded boxwork, sm. acute angles	none
-4	6E+5S	416	1267	13	21	40	1	1	not present	—	—
-5	6E+1S	400	1419	11	12	341	1	1	not prom.	thick siliceous walls, rounded cavities	orange to brick-red granular limonite
-6	2W+3S	640	2596	14	38	279	4	1	prom.	fine, thin-walled, sub-angular	granular, bright yellow-orange limonite
-7	8E+4S	608	2663	13	32	341	3	1	prom.	fine, thin-walled, sub-angular	granular, bright yellow-orange limonite
-8	8E+3S	560	990	14	25	961	11	1	prom.	fine, angular, cubic, sm "cleavage" box work	powdery brick-red, or "sintered" limonite
-9	8E+3S	640	1353	13	15	155	2	1	not present	—	—
-10	8E+3S	176	65	15	18	21	1	1	not present	—	—
Sample Number	Station Number	Zn	Cu	Ni	Co	Pb	Ag	Cd	Box work	Box Work Type	Box Work Filling

In summary, it appears from the limited number of samples studied, that the following characteristics denote growth of a gossan from a parent material other than pyrite: 1) thin-walled, angular box-work, filled with orange-yellow granular limonite denotes a chalcopyrite derivation, 2) cleavage box-work may be characteristic of a galena derived gossan, and 3) highly siliceous, tough, jasper-like gossan with thin to thick walls, intersecting at acute angles, is thought to indicate derivation from sphalerite.

Structural Geology

The structural geology of the Andersonville area is in a rather crude stage of interpretation. The practical non-existence of outcrops on the exploration grid, the limited extent of the drilling program to date, and the lack of a large scale geologic map of the area under consideration, place severe limitations on any structural interpretation. However, regional geology, a geologic map of an adjacent quadrangle, as well as drilling, geophysical, and geochemical surveys of the grid have assisted in working out a reasonable, though far from equivocal interpretation of the geologic structures in the ore-zone area.

A core model was compiled from the logs of 18 drill cores (Hagen, 1958). The core itself has since been destroyed. The various lithologies encountered in each core were plotted by color code on separate plexiglass panes. Each pane was then areally located by collar coordinates, forming a three-dimensional model. With the aid of the model, the attitude and possible projections of the ore zones were

made considerably more simple. It should be noted in the discussion which follows, however, that the areal distribution of the drills holes is rather small, thus the evidence of relatively large scale structural controls may not appear on such a model.

General Geology

The Andersonville Grid lies in the central portion of the Virginia Piedmont, which is underlain by late Pre-Cambrian and early Paleozoic rocks which show strong and complex deformation. It is clear, from the Geologic Map of Virginia, that the major structural trends in the Buckingham County area, including the dominat James River Synclinorium, are congruous to those of the Appalachians in general, showing a strike to the northeast.

The major rock-types of Buckingham County and the surrounding area, are metasediments and metavolcanics, which comprise the Lynchburg and Catoctin formations, and the Evington Group of Espenshade which includes the Candler, Archer Creek, and Mount Athos formations, which lie over the Virginia Blue Ridge Complex. The Scottsville Basin shows Triassic sedimentary units in normal fault contact with the older metasediments. Long, linear, or more circular stock-like bodies of hornblende gabbro, of unknown age, intrude the metamorphic rocks over large areas. Diabase dikes of Triassic age are common, striking north to northeast.

Geology of the Buckingham Quadrangle

The Andersonville Grid lies approximately 3 miles

south of Enonville which, in turn, is located in the southeast corner of the Buckingham Quadrangle, mapped by Ern (1968). Though Andersonville does not lie down-strike of Buckingham structures, a brief resume of the geology of this area may aid in establishing a structural framework for the area of interest.

The major structure in the quadrangle is the James River Synclinorium, striking northeast, containing the formations of the Evington Group, including schists, quartzites, marbles, phyllites, and greenstone. The various rock units are repeated across strike, reflecting folding and faulting. The northwest area of the quadrangle includes the Lynchburg and Catoctin formations, forming the southeast limb of the Blue Ridge-Catoctin Mountain Anticlinorium. The rocks exposed in the Arvonia Syncline, in the southeast quadrant, are younger than those of the Evington Group and the Catoctin. Masses of amphibolite are intruded along the southeast flank of the synclinorium "as concordant sill-like bodies which have subsequently been folded. Similar extensive masses but of a more basic character are associated with the Lynchburg formation" (Ern, 1968, p. 5). All pre-Triassic rocks in the area have been subjected to regional metamorphism of the quartz-albite-muscovite-chlorite subfacies of the greenschist facies grade (Ern, 1968, p. 1).

The Candler formation, the largest mappable unit in the quadrangle, is composed of schists and phyllites of various compositions. "In the central and southern portions...mafic and ultramafic sills intruded, and were folded with the Candler formation" (Ern, 1968, p.11).

Geology of the Andersonville Grid Area

Study of the model based on drilling data, shows two parallel, tabular sulfide bodies of variable thickness (averaging 15 feet) striking N50-60°E and dipping between 20 and 35° to the northwest. The dip is uniform to a depth of approximately 370 feet, beyond which drilling data is not available. While the ore zone apparently thins slightly with depth, and shows variation in thickness along dip, it can not be described as lensoid, a characteristic of many Piedmont ore bodies. Brecciation and shearing are present in many areas of the core. Hagen (1958, p. 167) notes that the gneissic texture is highly contorted in the ore zone area of some of the cores, foliation showing variations up to 60° from the surrounding country rock. The upper sulfide zone occurs largely in hornblende gneiss, while the second zone is largely contained in a quartz-biotite schist. These two host rocks, along with minor thicknesses of quartzite schist, quartz-sericite schist, and quartz-kyanite schist, which are apparently lensoid, are the only major lithologic types present. While Hagen (1958) does not note the relationship between foliation and the dip of the ore zones, it is apparent from relationships shown in the model, that the zones do not follow foliation, the same ore zone commonly cutting both lithologic types. The structure of the host rock is apparently quite complex, and is not readily determined from the model, though tight folding or faulting is strongly suggested.

The soil geochemical data, discussed more fully in a

preceeding section, is mentioned here only to point out two general features of the anomaly patterns which may have a bearing on a structural interpretation. The most obvious feature is the long, wide anomaly contour surrounding the projected ore-body outcrop. The anomaly abruptly terminates northward, reflecting the dip of the sulfide body in that direction. In striking contrast to the broad Pb-Cu curves, the Co contours are long and narrow. Of particular note is the lineation of the contouring along the southeast corner of the grid, and the vaguely linear nature of the contours across the northeast corner. Of note, also, is that the shape of these anomalies is rather uniform when compared with the broad, irregular cobalt anomaly associated with Cu in the south-central, southwest corner of the grid.

Geophysical investigation of the grid yielded significant associations with data derived from the core model and the geochemical survey. The results of an EM-16 survey, which detects underground conductors, are shown on Plate II.

A realtively weak conductor, trending parallel with and approximately 100 feet south of the base-line is outlined by the "cross-over" of the real and imaginary components in that area. This conductor, fading towards the west, corresponds to the projection of the ore zone outcrop. Since the "assymmetry in the curves is diagnostic of the dip of the conductor, the side maximum being on the <u>down-dip side</u>" (Parasnis, 1966, p.132), it is clear from an examination of the curves, that the ore zone dips to the north and west, the side maximum being to the north. A second conducting zone, parallel and south of the first, probably represents the second sul-

* The possibility that the fence is responsible for the EM anomaly may not be ignored. However, the persistance of the negative data in areas far removed from the fence, the asymmetry of the anomalous curves, and the mirror-image symmetry of the curves on the north and south side of the grid, are thought to be strong evidence that something other than the fence is responsible for the anomalies in those areas. Other barbed wire fences in the area do not show similarly associated anomalies.

fide zone.

The most striking feature of the EM-16 survey is not the ore zone conductor, but a strong conductor, sharply parabolic is shape, enclosing the eastern three-quarters of the grid. At the outset, it should be noted that as far as is known, this spectacular conductor is not associated with any superficial body such as a pipeline, telephone or power line. While a wire fence parallels the conductor, it is on wooden posts and is not though to have affected the survey results (Young, 1969).

Attention is immediately drawn to the parallelism between the long, linear cobalt anomaly and this conductor. Since cobalt is usually associated with the more mafic rocks ("Umaf 200; Maf 45; Fels 5ppm" (Hawkes and Webb, 1962, p.363.)), and since cobalt is not extensively associated with the other metal anomalies in the area, it is concluded that this major cobalt-conductor anomaly is associated, not with a linear sulfide body, but possibly with a body of mafic - ultramafic rock. Since ultramafic rocks in the adjacent Buckingham quadrangle commonly contain significant percentages of opaque minerals, it is felt that such a rock could serve as a strong conductor (Ern, 1969), and could contain anomalous cobalt.

The second striking feature of this EM anomaly is its shape which is highly suggestive of a nose of a plunging fold form. This assumption is supported by the fact that analyses of the side maximum portion of the negative EM curves indicate that the conductor shows symmetrical dips towards the center of the grid, indicating a synformal structure. Thus, it is postulated that the conductor is a mafic or

ultramafic sill, outlining the fold structure. Similar fold structures involving mafic sills were mapped by Ern (1968) in the Buckingham quadrangle, and the existence of such a structure on the Andersonville Grid is felt by Ern (1969) to be possible.

It should be stated quite clearly that the above hypothesis is highly speculative, as no confirming drilling or outcrop data are available. A folded, water soaked fault zone could explain the conductor equally well. However, when the model, geochemical, and geophysical data are considered together, the above proposal appears to be the best presently available. Drilling of the strong conductor clearly is necessary to resolve this problem.

The major structure in the area, then, is thought to be a synform plunging to the southeast. The question of ore localization remains. Two possibilities exist: 1) the ore was localized along conjugate shears developed during the folding of the synform which is overturned approximately 60° to the northwest, and 2) ore localization took place in a post folding fault of minor displacement, striking N60°E and dipping 25° northwest, which, itself, was localized by a zone of weakness along the axial regions of the fold. The later is favored because conjugate shears, necessarily forming before or during folding, would, themselves, show evidence of folding. Since the ore zones are relatively flat, it is felt that they do not occupy areas of conjugate shearing. Post-folding fault control is favored as it would account for the flatness of the ore zones. Further, fault developement along older areas of weakness (the axial regions of the fold where

the ore does appear to be located) is a common and reasonable phenomenon, and could be caused by relatively minor stress which could conceivably differ from the major northwestwardly directed force responsible for the regional structural trends (Brent, 1969).

While the dip of the ore zones is not typical of Appilachian faulting, the proposed "major structure" of the area, a southwest plunging synform, is typical. Therefore, it is felt that the structural geology of the Andersonville prospect is not wholly discordant to "typical Appalachian" structure.

Since the ore zones are apparently localized by a combination of axial plane crumpling in a fold, and faults cutting this zone of weakness, it would be desirable to extend geochemical and geophysical surveys along the proposed axial trace in efforts to locate new ore. But this, of course, should await confirmation of the proposed structural control discussed above.

Wall Rock Alteration

A study of the country rock surrounding the sulfide bodies was undertaken primarily to discover the mode of alteration induced by ore deposition. It was hoped that thin sections of both the hanging wall and footwall could be studied, largely to determine the symmetry of any alteration present. However, only the footwall of the upper sulfide zone was suitable for study; megascopically a uniform hornblende gneiss extending several feet from the ore zone. This section is not thought to contain any pri-

mary lithologic differences. Other areas of the country rock presented several changes in lithology, not related to the ore zone, and thus were unsuitable for modal alteration profiles.

Thin sections were cut from the country rock, normal to foliation, at roughly one foot intervals, begining at the gneiss-sulfide contact, and extending 10 feet from the ore zone. No bias was introduced by sample selection. Upon examination, alteration was unnoticable 5 feet from the ore zone, but progressed in intensity toward the sulfide contact. The most spectacular alteration is confined to an area less than one foot from the sulfide body.

above or below ore body

The Country Rock

The country rock studied is a hornblende gneiss with essential quartz and orthoclase. It is a medium-grained, roughly equigranular rock with a rather simple mineralogy. Foliation is well defined.

The major constituent, hornblende, is euhedral to subhedral, showing typical cleavage and a dark green color, with pronounced pleochroism. Commonly, it poikilitically encloses small, rounded grains of quartz and orthoclase. Everywhere the mineral is fresh, showing no mineralogic alteration, and only slight evidences of corrosion.

Orthoclase is similarly unaltered, though a few grains show minor sericitization. Cleavage is characteristically well developed. Grains are exclusively anhedral, and usually are smaller than those of hornblende.

Quartz occurs in anhedral, equigranular aggregates with orthoclase, or as chadocrysts in hornblende. Most grains show strain shadows.

Accessory minerals include plagioclase, microcline, calcite, and pyrite. Plagioclase and microcline are rare; only a few grains per section were observed. Calcite forms rare veins transecting all other minerals. Pyrite, as small anhedral, irregular grains, is unoxidized and irregularly scattered through the sections parallel to foliation.

Alteration

The most striking characteristic of the wall rock adjacent to the ore body, is the virtual absence of typical hydrothermal alteration. Sericitization is noted in many of the sections, but nowhere is it significant. Similarly, chlorite, while observed in many of the sections, is relatively unimportant. Further, the chlorite appears as distinct grains, not as alteration rims on other minerals. Calcite, likewise, is of slight importance, its presence being noted in only one section where it forms microveins in the country rock.

While hydrothermal alteration is conspicuously absent, recrystallization and the formation of new silicates and oxides near the sulfide-gneiss contact is important and spectacular.

Recrystallization is evidenced by an increase in grain size and a disruption of the foliation towards the ore zone. In the thin sections studied, the grain size of orthoclase, plagioclase, and quartz show an increase towards, and reach a maximum at the ore-gneiss contact. Recrystallization,

as studied in thin sections, is further evidenced by a disruption of the gneissic foliation; newly formed biotite and actinolite crystals appearing as wavy shards with only vague suggestions of preferred orientation.

In handspecimen, recrystallization is evidenced by the presence of a coarse - grained material with a pegmatitic texture, adjacent to the ore zone in the hangingwall of both drill cores studied. It is best developed in the second core where four feet of coarse plagioclase, orthoclase, actinolite, and biotite is present. In this area, no evidence of foliation is seen. It is felt that this pegmatite-like material is recrystallized wall rock because most of the minerals aforementioned are common to both, thus indicating that no new elements were introduced into the system as would be the case with a hydrothermal type of alteration.

The formation of new silicates in the contact zone of the wall rock is spectacular. Most important is the developement of actinolite with the corresponding decrease in the amount of hornblende towards the contact zone. The graph showing the modal analyses clearly shows this relationship. In thin sections of wall rock immediately adjacent to the ore zone, actinolite forms between 12 and 18% of the rock, while hornblende forms 1% or less. Distant from the ore zone, hornblende forms 50% while actinolite is not present. In one instance, in the contact zone, actinolite is seen rimming hornblende (?), but in most cases, actinolite forms curving, thin blades scattered through the section showing no relict hornblende structure. The sudden increase of actinolite and the disappearance of hornblende support

the proposal that they are recrystallization-alteration pairs:

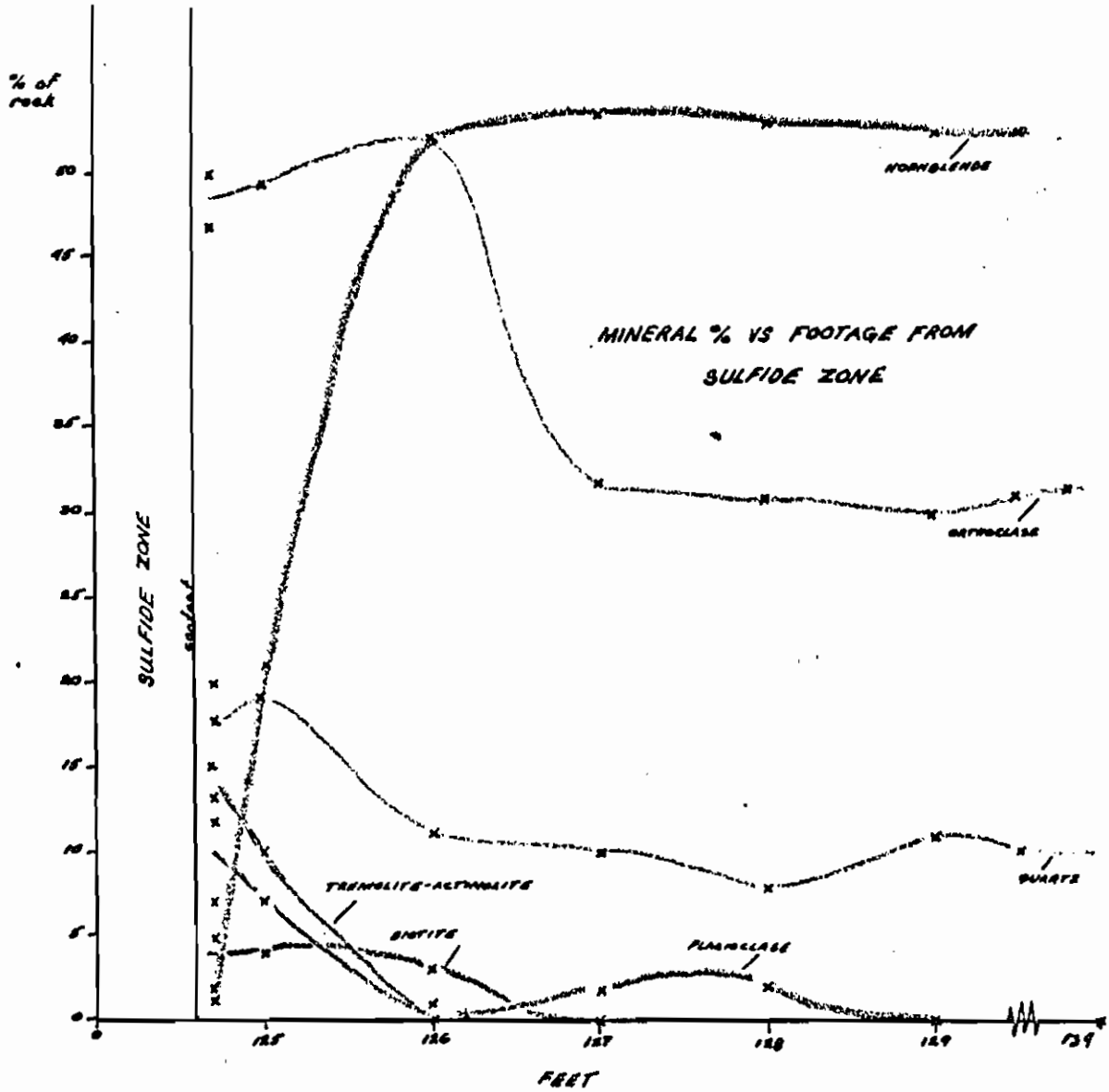
$Ca_2(Mg,Fe,Al)_2(OH)_2((Si,Al)_4O_{11})_2$ (Hornblende-monoclinic) $Ca_2(Fe)_5(OH)_2(Si_4O_{11})_2$ (actinolite-monoclinic)

Such a conversion does not appear to be unreasonable; crystal system and composition remain unchanged with the exception of the possible loss of Al and Mg. The appearance of a light green (pleonaste or gahnite) spinel, associated with actinolite in the contact zone may account for this loss of Mg and Al.

Biotite, like actinolite appears suddenly near the contact zone with no analog in the more distant country rock. Commonly it forms thick to thin fibers, frequently curved, which are completely unaltered and strongly pleochroic. Pleochroic haloes due to zircon inclusions are rare or absent. The alteration of hornblende to biotite is not uncommon and has been reported by many writers (see for example Schwartz, 1947, p. 325). One instance of biotite surrounding corroded hornblende (?) was noted, but in general such relationships are uncommon; the biotite does not show relict hornblende texture. However, the graph of the modal analyses supports the idea that hornblende did alter to biotite.

The increase of modal orthoclase and plagioclase towards the ore zone is more difficult to explain. It appears, however, that these minerals were not introduced into the system from an outside source. No evidence for feldspar veining, or feldspar corroding or replacing other silicates was observed. Such evidence is used by Gilluly (1946), Schwartz (1947), and Anderson (1950) to demonstrate orthoclasization in hydro-

thermally altered wall rock. The optical and physical charac-teristics of these feldspars does not appear to differ from those of the feldspars in the unaltered country rock. For these reasons, it is felt that the increase in modal feldspar near the contact zone is the result of recrystallization, probably with the minor introduction of Na and K into the system.



Environment and Type of Alteration

It is concluded that the alteration of the wall rock is not hydrothermally induced for the following reasons: 1) the formation of minerals such as spinel and actinolite indicate temperature and pressure conditions far in excess of those of a hydrothermal environment, 2) the probability that the formation of the "new minerals" in the contact zone took place without the extensive addition of ions from outside the system, with the exception of Na and K in feldspar formation. Hydrothermal alteration usually shows extensive introduction of "foreign" ions into the wall rock which introduce the observed alteration. 3) The lack of the usual types of hydrothermal alteration such as silicification, sericitization, chloritization, and et cetera (Park and McDiarmid, 1964, p. 139-151).

It is proposed that the alteration observed in the drill cores is due to a remobilization of the wall rock, with subsequent ion diffusion and recrystallization, to form the mineral suites and textures now observed, that is re-metamorphism of the hornblende gneiss in the vacinity of the ore zone, without the extensive introduction of new material from outside the system, is the responsible agent. High temperatures are indicated by the formation of spinel, with a melting point of 2135°C (Deer, et. al., 1966, p. 426), and actinolite, while a mildly high directed confining pressure is indicated by a crude retention of foliation in some areas of the contact zone, and the lack of rotation textures in garnet. Complete remobilization of the silicates is indicated by the lack of relict textures (eg. of hornblende), and

of fracture controlled alteration (with the exception of minor introduction of epidote along rare "microtnsion gashes) both of which are typical of hydrothermally altered rocks.

A similar hypothesis is put forth by Kinkel (1967) for the origin of wall rock alteration at Ore Knob, North Carolina. Textural and mineralogical changes adjacent to the Ore Knob deposit are similar to those of the Andersonville wall rock.

Mineralogy, Texture, Paragenesis and Origin of the Sulfide Ores

The following discussion is based on microscopic and handspecimen study of two cores drilled by North American Exploration on the Andersonville Grid, May, 1969. Fifteen polished sections were prepared from material from the two ore zones in DDH-1, while selected handspecimens were studied from DDH-2. Also available for study were the logs of 18 drill cores, logged by Hagen (1958)of the Virginia Mining Company. Clearly, the limited amount of material restricts the applicability of the present study with respect to the entire ore body, but it is felt that the study, in a general way, indicates the origin of this and several other sulfide bodies near-by.

Mineralogy and Textures of the Sulfides
Macroscopic

Two, well defined, ore zones were encountered in the first drill hole. The first zone occurs at 108 feet and extents to 124 feet, the second from 228 feet to 238 feet. Mineralogical and textural differences were noted between

the two, which will be discussed separately.

The most abundant sulfide in zone one is pyrite. It occurs as subhedral to euhedral crystals throughout, with an increase in grain-size downward, the mean size being approximately 0.5cm. Sphalerite, chalcopyrite, and pyrrhotite, in decreasing order of abundance are intergranular. Galena was not observed in handspecimen. All sulfides appear quite fresh and free of corrosion. The sulfides are massive and show no evidence of the foliation of the enclosing country rock. In some areas of the core, pyrite forms greater than 95% of the rock. The lack of intergranular sulfides or gangue in these areas render it extremely friable, being easily broken in the hand rendering loose subhedral grains with shiny faces. No evidences of weathering in these or other areas of the core are present. When broken, all samples from the first zone show shiny pyrite faces and smooth pyrite molds in the other sulfides. Thus, intense interlocking and corrosion do not characterize the sulfide contacts.

Typical assays of the ore from the first zone show .5-2.0% Cu; 1-8% Zn; .005 oz/T Au; and .5-1.0 oz/T Ag. An average grade of .65% Cu, 5.05% Zn, and 40% pyrite for 368,200T was estimated by Hagen (1958, p. 149).

Gangue minerals, identified in handspecimen include biotite, quartz, orthoclase, actinolite, and garnet in decreasing abundances. The biotite occurs as small, unaltered books, showing no preferred orientation. Actinolite occurs as short striated needles, randomly oriented in the ore, impressions of which, on the softer sulfides are common on broken surfaces.

Quartz occurs as rounded grains, as does orthoclase and garnet. Occasionally, rounded breccia fragments are observed in the ore, and are composed of quartz, orthoclase and actinolite. The contacts between breccia and sulfides are generally quite sharp. One large breccia fragment in massive pyrite shows a thin coating of sphalerite and chalcopyrite on one side only, suggesting deposition of these soft sulfides in a pressure shadow (Fig.1).

The second sulfide zone is characterized by the predominance of pyrite, very low percentages of other sulfides, and an increase in the amount of gangue. Elongated pyrite is the most striking characteristic of the second zone, the mineral apparently having been stretched into lozenger shaped grains. Though, at times, massive pyrite, the sulfides in the second zone are usually set in a gangue matrix. Specks of sphalerite and chalcopyrite are observed, but nowhere important, gangue being the most important intergranular material.

Material from the second drill hole became available at a late date and could not be studied carefully. However, a few of the more important characteristics are noted below. Unlike the first core, the ore from the second hole is predominately pyrrhotite, especially in the lower and middle portions of the core, pyrite becoming more important towards the top. Chalcopyrite is more common in this core. Perfectly euhedral pyrite crystals, up to 1cm across, are observed "suspended" in the pyrrhotite matrix, and strongly resemble metacrysts. Irregular blebs of sphalerite and chalcopyrite form the remainder of the sulfides. Galena is not observed. Fresh, shiny books of biotite are commonly scattered

through the pyrrhotite, and show randon orientation. Irregular, rounded grains of quartz and feldspar fom the remaining gangue minerals. In several areas of the core, spectacular flow and pressure shadow features are present. Biotite and chalcopyrite are seen to have been molded around three sides of a quartz-biotite breccia fragment (Fig. 1), or around pyrite cubes, trailing off into "tails on theforth side. Occasionally, notation of the tails is observed.

A crude zoning in the second core may be noted. Massive pyrrhotite predominates in the lower portions, while pyrite and sphalerite are more common in the center. Chalcopyrite is most abundant towards the top of the core, where is occurs as massive, irregular patches, and locally as fracture fillings in the hangingwall.

Microtextures of the Sulfides

The textures discussed below were revealed by microscopic examination of polished sections from the first and second sulfide zones in DDH-1, and are divided into depositional and stress related phenomenon. The former involves the so called "primary" textures such as those due to replacement, while the former are "secondary" textures such as flow, shearing, and injection.

Depositional Textures

The so called "caries" structure is the most common and the least diagnostic texture in the sulfides from both zones. As suggested by Lindgren, such a texture is displayed by minerals showing smooth, scalloped embayments by another mineral,

"as if the metasome had 'bitten into' the host" (Edwards, 1947, p.129). This textural relationship is most common between chalcopyrite and sphalerite. Chalcopyrite forms convex scalloping into sphalerite along long grain boundaries (ref. Ag-120) in many instances. However, with slightly greater frequency, the reverse is true, often within the same field of view. (Fig.2) Similar conflicting relationships have been observed in the sphalerite - pyrrhotite, chalcopyrite-pyrrhotite, galena-sphalerite, galena-pyrrhotite, and chalcopyrite-galena pairs.

Occassionally, the "caries" structure is accompanied by diffussion fronts. Most common examples are found in the sphalerite-chalcopyrite pairs. Here, small blebs of the metasome are observed in the host, paralleling, but separate from the major host-metasome replacement front, and is thought to evidence minor metasomatic replacement preceeding the major, unbroken, replacement front. Excellent examples were noted in section Ag-120 and Ag-116.

Relict textures, such as pseudomorphs, are rare and of questionable validity in all of the sections studied. Squarish outlines of gangue in a gangue matrix may represent pseudomorphs of pyrite, but the total absence of pyrite in the "replacement" mass, renders such an interpretation doubtful. One example of triangular pitting in chalcopyrite showing "caries" boundaries with galena (ref. AG-120) may indicate relict galena cleavage in the chalcopyrite metasome, but sufficient numbers of examples are lacking to clarify this relationship. Summarizing, relict textures are extremely rare, and when present do not present clear evidence of replacement. This is especially striking when the Anderson-

ville specimens are compared with those of the Valzinco Mine where relict textures are common and strikingly clear (Riesmeyer, 1968, p. 8-10).

The poikilitic texture of many of the pyrite grains is characteristic of the Andersonville ore. Small, rounded inclusions of all other sulfides present, as well as many silicates, are observed in the pyrite. Commonly, euhedral silicate is enclosed by pyrite. The uncorroded nature of the pyrite, and the relative rarity of veining excludes the possibility that all of these enclosed sulfide and silicate blebs are veins viewed in the third dimension. The poikilitic nature of the inclusions is further demonstrated by the fact that when these inclusions are etched or scratched out of the pyrite face, a smooth cavity, completely bounded by pyrite is observed. Such a texture could result from the enclosure of earlier sulfides and silicates by the crystallizing pyrite.

The Andersonville pyrite is also unusual in that it is relatively free from replacement by other sulfides. In polished section it shows smooth sharp boundaries with all other minerals. The smoothness of these contacts is further indicated by the impressions of pyrite cubes on both other sulfides and gangue on broken surfaces in handspecimen, which are smooth and shiny. This is unusual in that pyrite, usually an early formed mineral in sulfide deposits, is commonly extensively replaced by the other sulfides and gangue, leaving only irregular blebs of the mineral. Excellent illustration is found in the Valzinco ores, where rim, "atoll", interior, and "caries" replacement of pyrite is common (Riesmeyer, 1968, p.8-9). Because of this lack of replacement, it is concluded that the pyrite in the Andersonville deposit was formed either

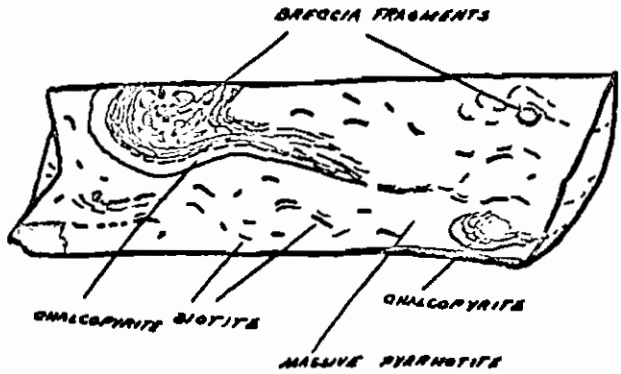
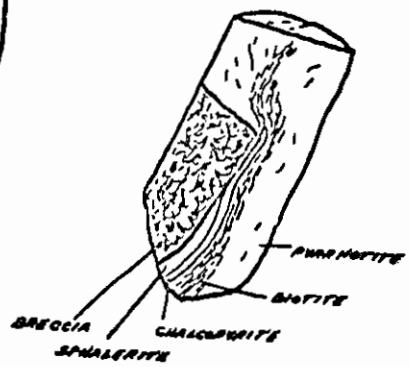
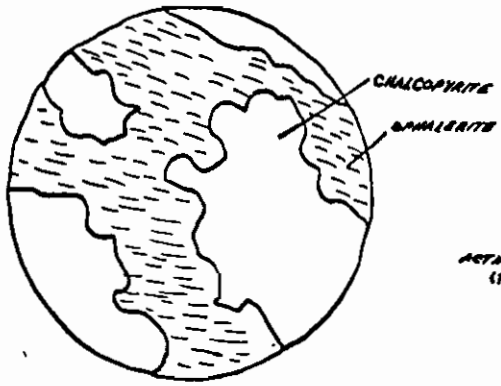


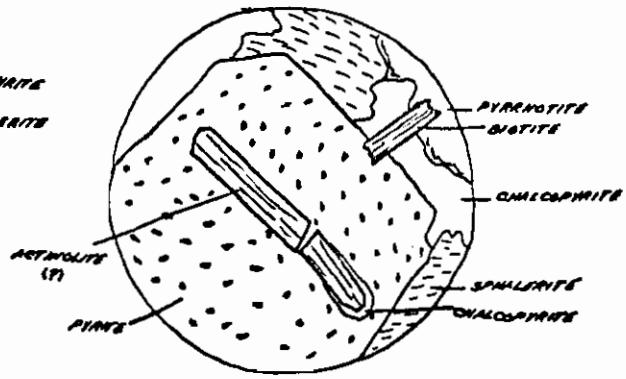
FIG. 1 CORE FRAGMENTS x 1/2





AGR-120 x 120

FIG. 2



AGR-124 x 60 (COMPOSITE)

FIG. 3

with or after the other sulfides, for if it had formed earlier, replacement surely would have taken place (Edwards, 1947, p. 115).

Silicate gangue-sulfide boundaries also commonly display "clean-line" contacts. Euhedral biotite "books" and actinolite crystals serve as the best examples when they are found embedded in massive sulfide. Both silicates show mutual boundaries with all sulfide species, with no corrosion evident in either sulfide or silicate, though sulfide rarely veins silicate. AG-124 reveals a spectacular example, showing an actinolite crystal with well developed prism faces and terminations, uncorroded by pyrite which completely surrounds it, and in one place veins it (Fig. 3).

Of importance is the fact that euhedral gangue silicates commonly cut across boundaries between different sulfides. Examples of either biotite or actinolite cutting sphalerite-chalcopyrite, pyrite-pyrrhotite, sphalerite-pyrite, and chalcopyrite-pyrite borders has been observed. Excellent examples of several of these relationships are shown in section AG-124. Little or no corrosion is observed to be associated with these relationships.

The straight-line borders and lack of corrosion between silicates and sulfides indicate that they were both deposited under the same temperature-pressure conditions, and thus, most probably, at the same time. This fact acquires great importance in the following discussion of paragenesis. Such examples and conclusions are discussed by Kinkel (1967) in relation to the Ore Knob sulfide textures.

Several, clearly defined, examples of simultaneous deposition are shown by exsolution textures in the ore. Most common is the exsolution of chalcopyrite from sphalerite. Usually the chalcopyrite forms tiny blebs or rod-

shaped inclusions scattered randomly through some of the sphalerite grains, and correspond well with the description of the "emulsion texture" of Edwards (1947, p. 80). An especially striking example is shown in section AG-116 where sphalerite is choked with small inclusions of chalcopyrite. Small rod-shaped bodies of chalcopyrite show crystallographic control in section AG-124 where the chalcopyrite is oriented along the {111} and {100} of sphalerite.

A lamellar exsolution texture involving sphalerite (host) and pyrrhotite (?) guest is observed in section AG-238 where it is common. Thin lamellae of pyrrhotite (?) show definite crystallographic control in the sphalerite host. The identification of pyrrhotite is uncertain and is in need of X-Ray confirmation.

Several other exsolution-like textures are observed in the polished sections, including magnetite (host) -chalcopyrite (guest), pyrrhotite (host) - chalcopyrite (guest), and galena (host) - chalcopyrite (guest). The texture of these relationships strongly resembles an "emulsion texture", but these exsolution pairs have not previously been reported (Edwards, 1947, p. 93) and may represent replacement on a minute scale.

Finally, the presence of graphic intergrowths among the silicate gangue minerals is present in one section (AG-121). The composition of the two silicates is uncertain, however, the graphic texture is clearly evident in polished section. The several grains of graphically intergrown material shows mutual boundaries with the surrounding sulfides, the "caries" textures demonstrating a nearly simultaneous deposition of the two types of minerals.

Textures Resulting from Stress

Numerous examples of textures indicating stress within the ore body are noted in all polished sections, including flow, rotation, shearing, injection, and pressure shadow textures.

The most striking stress related texture observed is the elongation of the pyrite grains in the second sulfide zone previously referred to. It remains to note that under the microscope, shearing in the pyrite is not observed, nor is cleavage pronounced. The lack of rupture indicates that the pyrite was probably deformed into the lozenger-shaped grains under a high temperature and pressure environment which would favor plastic flow.

Unlike the pyrite in the second zone, that of the first shows excellent cleavage and shear developement. (Ref. AG-116) Typically, the cleavage or shear is characterized by closely spaced parallel fractures, usually cutting the entire grain, which are interconnected by conjugate shear or cleavage formed at acute angles to the former. Softer sulfides or gangue usually fill these openings. The more brittle silicates show evidence of fracturing, but the softer sulfides and silicates do not.

Injection of soft sulfides into fissures is commonly observed. The aforementioned chalcopyrite filling fractures in pyrite if the most common example. Veining, of the hydrothermal type, probably does not explain this phenomenon as 1) there is no evidence of banding or crustification in the "veins," and 2) no alteration of the pyrite by the "veining" material is evident. Evidence for pressurized

injection is 1) chalcopyrite, the most common "veining" material, is also the softest sulfide in the ore body, and thus the most likely to flow, and 2) the presence o-f "draw-down" at the vein orifice, indicating plastic flow (ref. AG-116) Newhouse and Flaherty (1930, p.600) note that at certain high pressures, pyrite fractures while chalcopyrite flows. It is felt that the textures here discussed may exemplify their experimental work.

Another, more doubtful, example of forceable injection of a plastic (?) phase is the presence of pyrrhotite wedges in biotite (ref. AG-124). Close examination shows that the "leaves" of the biotite "books" probably have been wedged apart by pyrrhotite. The presence of undistorted biotite in the same area of the section indicates the original undeformed crystal nature of the biotite. Sharp bordered, uncorroded wedge-shaped replacement of biotite by pyrrhotite from a crystallizing liquid media is unlikely.

Textures indicating flow are not uncommon in the polished sections. The most pronounced example involves flow texture in biotite around hard minerals such as quartz and pyrite (ref. AG-229). Biotite is often shown "plated" on the hard mineral, facing the direction of force, while forming "tails" on the other side, pointing away from the direction of force, or form "eddie-like" swirls in the pressure shadows. Chalcopyrite forms similar patterns (ref. AG-124). Fig. 3 shows chalcopyrite "plated" onto the end of an actinolite crystal, with "tails" pointing down the sides of the prism faces. In a given section showing flow, the direction in which the "tails" point is the same in all examples, thus indicating stress from a specific

direction.

It may be noted that extensive flowage of the softer intergranular sulfides and silicates, upward along a pressure gradient, leaving behind only hard pyrite crystals, might account for the "friable" pyritic portions of the core previously mentioned.

The deposition of softer minerals in pressure shadows behind harder minerals during flow results in the "shadow deposition" texture observed in many of the sections. Here, galena forms wedge-shaped masses behind quartz grains, the apex pointing away from the direction of force.(AG-234). The formation of biotite and chalcopyrite behind a quartz-biotite breccia fragment, with subsequent rotation to form a sinusoidal structure is shown in Fig. 1 (DDH-2).

Finally, the observation that biotite, in places, is extremely krinkled and even isoclinally folded (ref. AG-228 and 124), clearly indicates stress conditions in the ore body at one time.

In summary, it is felt that these textures described above, resulted from the movement of a plastic or viscous fluid media under the effects of a directed stress. The indications of the resulting flow are in those areas where the flow was interrupted by hard minerals generating the patterns described above.

Paragenesis

In many cases, the paragenesis of an ore deposit is easily visulized. Cross cutting relationships, pseudomorphs, non-conflicting "caries" structure, and crustification

readily yield a consistant and clear history of sequential deposition. As discussed previously, "caries" structure is the most common "replacement" structure in the polished sections, almost to the exclusion of all others. As previously noted, evidence of reversal of the "caries rule" is commonly observed. Further complications in establishing a paragenetic realtionship are encountered when it is realized that though the "caries" texture is "...suggestive of replacement, it is not a reliable indication, nor does it reveal with any certainty the sequence of deposition" (Edwards, 1947, p.129). This, together with the fact that many of the grain boundaries observed show no evidence of replacement (eg. silicate-sulfide borders), make the establishment of a paragenetic sequence difficult.

If the assumption that pyrite poikilitically encloses blebs of the other sulfides is correct, then pyrite should be the last sulfide to have crystallized. If, on the other hand, the rule that euhedral minerals, enclosed in a less symmetrical matrix, are the first to crystallize, then pyrite should be placed towards the begining of the sequence. This poses a major problem in that pyrite, the most important sulfide in the ore body, may not be placed unequivocally in a sequence. An even more serious problem is encountered when the gangue minerals are considered. In the sections studied, sharply euhedral silicate crystals are observed to cut mutual boundaries of every possible sulfide pair. If the evidence for the simultaneous deposition of sulfide and silicate, as outlined previously, is accepted, then the conclusion must be drawn that all of the sulfides present

were deposited either at the same time or in very rapid sequence. This interpretation is in agreement with Bastin's (1950, p. 61) method of determining paragenetic sequence.

Finally, study of the "caries" textures in the polished sections, show that there is considerable over-lap in the depositional sequence of all sulfides with the exception of pyrite. The amount of over-lap, based on the frequency of "caries" reversals might be slightly amended upon modal analysis, but presently shows that sphalerite "replaces" chalcopyrite more often than the reverse. Thus, like pyrite, sphalerite is not in the"correct" hydrothermal sequence, as it should be earlier than chalcopyrite.

It is concluded that the paragenetic sequence of the sulfide-gangue mineralization is extremely unclear. Further, textural analysis indicates that pyrite and sphalerite are not in the normal sequence of pyrite-pyrrhotite-sphalerite-chalcopyrite-galena (earliest to latest deposited) as suggested by McKinstry (1948,p.150).If the poikilitic texture interpretation is used, pryite is grossly out of depositional sequence, being the last to crystallize. Finally, the simultaneous deposition of the various sulfides, as indicated by gangue-sulfide relationships, suggests a non-hydrothermal deposition where sequential crystallization is the rule.

Ore Genesis

When dealing with the Andersonville ore genesis problem, the following factors must be borne in mind: 1) the abnormal or unclear paragenetic relationships between sulfides commonly of a hydrothermal origin, 2) the presence of mutual boundaries between sulfides and silicates, 3)

the porphyroblastic texture of the pyrite, 4) the presence of unoriented gangue silicates, identical to the silicates in the wall rock, in the massive sulfides, which do not show evidences of corrosion or replacement by the sulfides, 5) the numerous evidences of stress, such as flow structures in the sulfides, 6) the lack of typically hydrothermal textures such as veining, crustification, pseudomorphism, and low temperature wall rock alteration, and 7) the narrow band of high temperature metamorphic alteration in the wall rock adjacent to the sulfides. The writer attributes these characteristics to a metamorphic remobilization of an early, hydrothermally deposited sulfide suite.

It is postulated the original ore was hydrothermally deposited. The assumption is easily made in that it is probable that all evidence for such an origin has been subsequently destroyed by remobilization. However, the vein nature of the deposit, and the sulfide assemblage, characteristic of a high to moderate temperature hydrothermal deposit (Park and McDiarmid, 1964, p.289-302), indicate that the ore does have hydrothermal origins.

The action of a rising thermal gradient with subsequent tectonic stress may explain the present texture of the ore. The question immediately arises, do the present textures result from rheomorphism, involving remelting, or metasomatism? Evidence, through again largely lacking, indicates the later. The peculiar reversals in sulfide paragenesis, as well as the presence of euhedral silicates in the sulfides, both violating the "laws" of sequential deposition from a liquid, indicate that metasomatic remobilization was the responsible agent. A plastic phase probably was present, also.

First, consider those relationships and textures for which a metamorphic origin is commonly accepted; 1) poikilitic structure, and 2) metacrysts. As previously noted, the euhedral, uncorroded, pyrite is distinctive in the Andersonville ore, and commonly contains chadocrysts of all other sulfides. As noted by Williams, et.al. (1965, p. 168), "...porphyroblasts tend to have idioblastic outlines (and) tend to be riddled with inclusions of other minerals which have presisted from pre-metamorphic stages of the rock's history." Further evidence that the pyrite cubes in the Andersonville ore are porphyroblasts is indicated by experimental results of Roberts (1965), which show that upon heating a mixture of sulfides and clay minerals under pressure, euhedral sulfide porphyroblasts formed as well as other metamorphic textures. Ramdohr (1950 in Kinkel, 1967, p.51) notes that porphyroblasts showing mutual inclusions of different sulfides are evidence of a metamorphic origin. Finally, Kinkel (1967, p. 22-23) notes the presence of pyrite, euhedral against pyrrhotite, and poikilitically enclosing sulfides and silicates at Ore Knob, concluding that the pyrite crystals are porphyroblasts. Pyrite from Ore Knob and Andersonville show strikingly clear similarities. It is concluded that pyrite was the last sulfide to form in the remobilized ore at Andersonville, under metamorphic conditions.

The second striking feature of the Andersonville ore is the inclusion of euhedral silicate in the massive sulfide, or euhedral silicate cutting sulfide boundaries. Evidence for a metasomatic origin of these silicates include 1) the

absence of corrosion of either silicate or sulfide which surely would have taken place under hydrothermal conditions, and 2) the unoriented nature of the silicates, indicating that they are not remnants of the enclosing, well-foliated wall rock. It would appear that the sulfides and silicates crystallized or recrystallized under the same temperature - pressure conditions, and at the same time. The silicates in the sulfides, identical to those in the wall rock , possibly crystallized there after diffusion from the parent wall rock. This is contrary to the principles of hydrothermal deposition which usually shows sequential deposition (Kinkel, 1967, p. 51). The above textural relationships indicate that both silicate and sulfide formed in an environment which allowed free diffusion, without the intervention of a fluid media which would have promoted sequential deposition. Such conditions are typically metamorphic.

If the theory of metamorphic remobilization is accepted, the unclear paragenetic sequence present in the ores is easily explained. The original sequential depositional textures of the sulfides would have been destroyed by diffusion in the solid state. Conflicting "caries" structures would be expected in such a system where all sulfides were simultaneously exposed to a thermal-chemical, or pressure gradient. The obliteration of such textures as veining, crustification, and pseudomorphism, would, with time, be completely destroyed by remobilization.

The "exsolution textures," previously noted, may be the result of diffusion upon remobilization, rather than unmixing of two phases. While reports of a metamorphic origin of "exsolution" textures are unknown to the writer,

such an origin does not seem unreasonable, and may account for the unreported guest-host relationships referred to earlier. As an analog, it has been reported that graphic or myrmekitic structure in silicates may form as a reaction to metamorphism (Marmo, et.al.,1953, p. 713). Such textures, in silicates, are observed in the Andersonville ore sections, the silicate grains showing mutual boundaries with sulfides, thus indicating simultaneous growth.

Remobilization which affected the ore zone also affected the immediately adjacent wall rock. As previously noted, unoriented gangue minerals and minerals of the wall rock are the same with the exception that biotite is more common in the gangue. An increase in grain-size of the minerals of the contact zone over those of the country rock is also present. Exactly the same situation is noted by Kinkel (1967, p. 50-51) in the Ore Knob deposit. In addition, coarse pegmatite-like deposits of plagioclase-orthoclase-actinolite, observed in the hangingwall adjacent to the ore zone in both the Andersonville cores, possibly having an analog in the "pegmatite" of Ore Knob, indicates recrystallization and reorientation of the original wall rock components. Kinkel (1967, p. 51) concludes that both the wall rock and ore zone were reorganized with a "coarsening of grain-size and randomly oriented growth, indicat(ing) mobility of the elements as conditions of equilibrium changed."

The limiting of such reorganization of the wall rock, under metamorphic conditions, to a narrow band, less than one foot wide, is not easily explained. However, a rising thermal gradient, moving preferentially along a highly

conductive sulfide zone may explain the reorganization of the ore and immediately adjacent wall rock and the unaltered nature of the country rock distant from the ore body.

During, or after remobilization of the Andersonville deposit, the ore was deformed largely through plastic flow. Flow, rotation, pressure shadow deposition, and injection textures have been described previously. It remains to cite experimental examples of sulfide flow under pressure. Experiments by Newhouse and Flaherty (1930) and Buerger (1928), show that the softer sulfides, i.e. galena, chalcopyrite, and finally pyrrhotite, flow under pressures which fracture pyrite.(Buerger, 1928, p. 1), demonstrated that the softer sulfides flow within seconds under a pressure of 3000 bars, with the attendant fracturing of pyrite. This readily explains several features observed in the Andersonville ore: 1) chalcopyrite, the softest of the common sulfides in the ore, is the most common mineral found injected into pyrite fractures; sphalerite, being less mobile, is the second most common injected material, and pyrrhotite, the least mobile, was not found to "vein" pyrite., and 2) chalcopyrite is more abundant in the upper portions of DDH-2, forming fracture-fillings, possibly because it, among the other sulfides, could flow more readily upward into an area of lower pressure. Finally, there exists the intriguing possibility that galena, being the last sulfide to crystallize in a hydrothermal deposit, and thus the most easily mobilized, as well as being the softest sulfide present in the Andersonville deposit, may have been either "squeezed" or diffused up a pressure-temperature gradient, leaving behind only scattered blebs, representing a previously greater abundance.

Summary and Conclusions

A preliminary investigation of a new sulfide deposit near Andersonville, Virginia, was carried out in the Spring of 1969. Analysis of soil geochemical surveys indicate that the anomalous metal values on the exploration grid are transported from a linear source which lies up slope from the anomaly contours. Abrupt termination of anomalous values north of the base-line indicate a sulfide body dipping in that direction. The congruity of gossan distribution with the geochemical anomalies is in agreement with this interpretation.

The presence of box-work, the type of box-work, and the type of cavity-filling limonite are used to distinguish several types of gossan present on the grid. Physical-chemical properties of several gossan samples indicate derivation from chalcopyrite, sphalerite, and galena aggregates containing abundant pyrite.

The structural control of the ore body is unknown. However, evidence points to the possibility that the ore was localized in a shear zone or fault zone, itself localized along the crumpled axial regions of a plunging synform. Geophysical and geochemical evidence are used to interpret the structural geology of an area of deep chemical weathering where outcrops are uncommon.

Thin section study of the wall rock adjacent to the sulfide zone does not reveal any of the usual types of hydrothermal alteration. An increase in grain-size of the country rock towards the ore zone, loss of regular foliation in the contact zone, and the apparent lack of the

introduction of new chemical constituents into the rock near the sulfide zones, indicate that recrystallization is responsible for the mineralogical and textural changes immediately adjacent to the sulfide body.

Analysis of polished sections of the sulfides indicate that evidences of primary depositional textures have been destroyed by subsequent metamorphism. Typically hydrothermal sulfide textures such as veining, pseudomorphism, crustification, and those indicative of sequential replacement, are largely lacking. Porphyoblastic pyrite, poikilitic and exsolution textures, flowage and pressure shadow deposition are among the evidences indicating a remobilization of an originally hydrothermally deposited ore. Unaltered, randomly oriented silicate species, in the sulfides, are identical to those in the wall rock, indicate that sulfides and silicates recrystallized in a similar temperature-pressure environment. Such an environment is not typical of hydrothermal deposition. It is proposed, then, that the Andersonville sulfide deposit, originally hydrothermally deposited, was subsequently metamorphosed, resulting in the extensive reorganization of sulfides and silicates, bringing about the present textural relationship observed in the core samples.

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