A STUDY OF THE VEIN COPPER MINERALIZATION OF THE VIRGILINA DISTRICT, VIRGINIA AND NORTH CAROLINA.

by

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Any project such as this is much less the sole work of the author than it is a collaborative effort of his family, friends, and colleagues, even if they are not aware of it. In view of this, heartfelt thanks are due to nearly everyone the author has dealt with.

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CHAPTER I

INTRODUCTION

The Virgilina district, which extends from Keysville, Virginia to Roxboro, North Carolina (Figure 1), a distance of about 88 km, was a major producer of copper in the late 19th and early 20th centuries. Although mining began in earnest in about 1852, and there is evidence that some prospecting and mining was accomplished between 1700 and 1750, the bulk of production was between 1890 to 1917, mostly from a few large mines. There are, however, more than 30 named mines and prospects that can be located today (Appendices A,B), with many others unnamed or whose locations are no longer known. The copper mineralization occurs either as sulfides in distinct quartz veins or as native copper disseminated through epidotized host rocks within the Precambrian to Cambrian Virgilina formation, a series of mixed metavolcanics and epiclastic sediments (Glover and Sinha, 1973; Kreisa, 1980; Harris, 1982)

Although the geology of the area has been subjected to increasing scrutiny in recent years, (Tobisch and Glover, 1969, 1971; Glover et al., 1971; Glover and Sinha, 1973; Glover, 1974; Black, 1978; Briggs et al., 1978; Kreisa, 1980; Wright and Seiders, 1980; Harris, 1982), there have been no modern studies of the copper mineralization. Watson (1902), and Weed (1911) catalog the known occurrences, Newberry et al., (1948) summarizes the potential, and Laney (1917) provides the only detailed examination of the deposits. More recently, studies of the

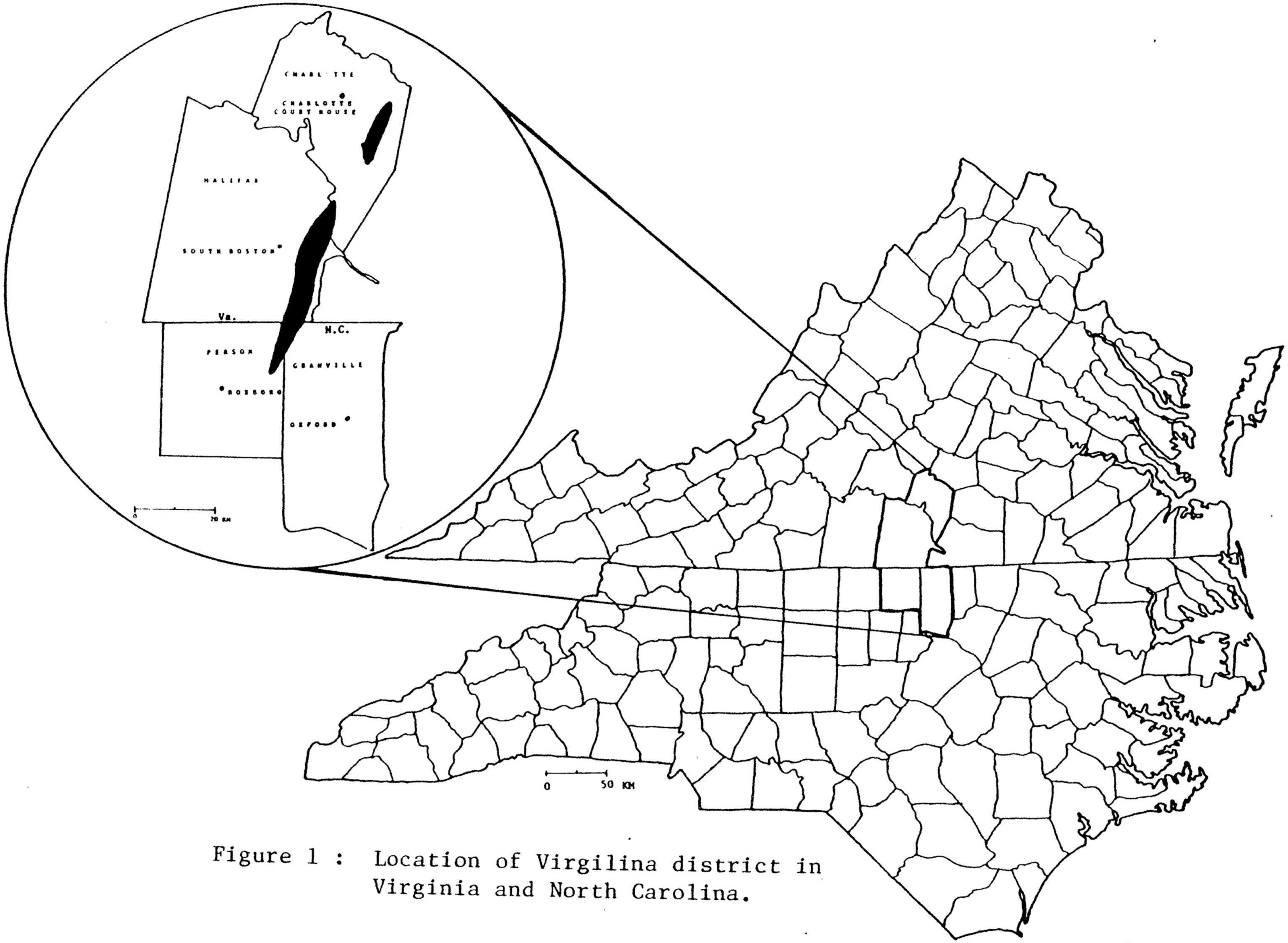


Figure 1 : Location of Virgilina district in Virginia and North Carolina.

host rock trace element chemistry (Stein and Kish, 1978), and the gold mineralization in the district (Linden, 1981), have been completed.

The present study examined the mineralogy and textural relations of the ore minerals in light of modern sulfide phase equilibria and mineralogy in order to consider possible modes of origin in light of modern concepts of ore genesis.

CHAPTER II

REGIONAL GEOLOGY

The Virgilina district (Figure 2) is part of the Carolina slate belt of the southern Appalachians, and is in the Piedmont physiographic province. It consists of an 88 km long strip of Precambrian to Cambrian volcanic, volcaniclastic, and epiclastic rocks folded into a broad synclinorium and metamorphosed to greenschist facies. Scattered throughout the district are numerous plutons and dikes that range compositionally from granite to gabbro. Multiple generations of quartz veins also cross cut the rocks, and are the source of the copper and gold that was mined in the late 19th and early 20th centuries. A detailed discussion of the regional geology is contained in Appendix C.

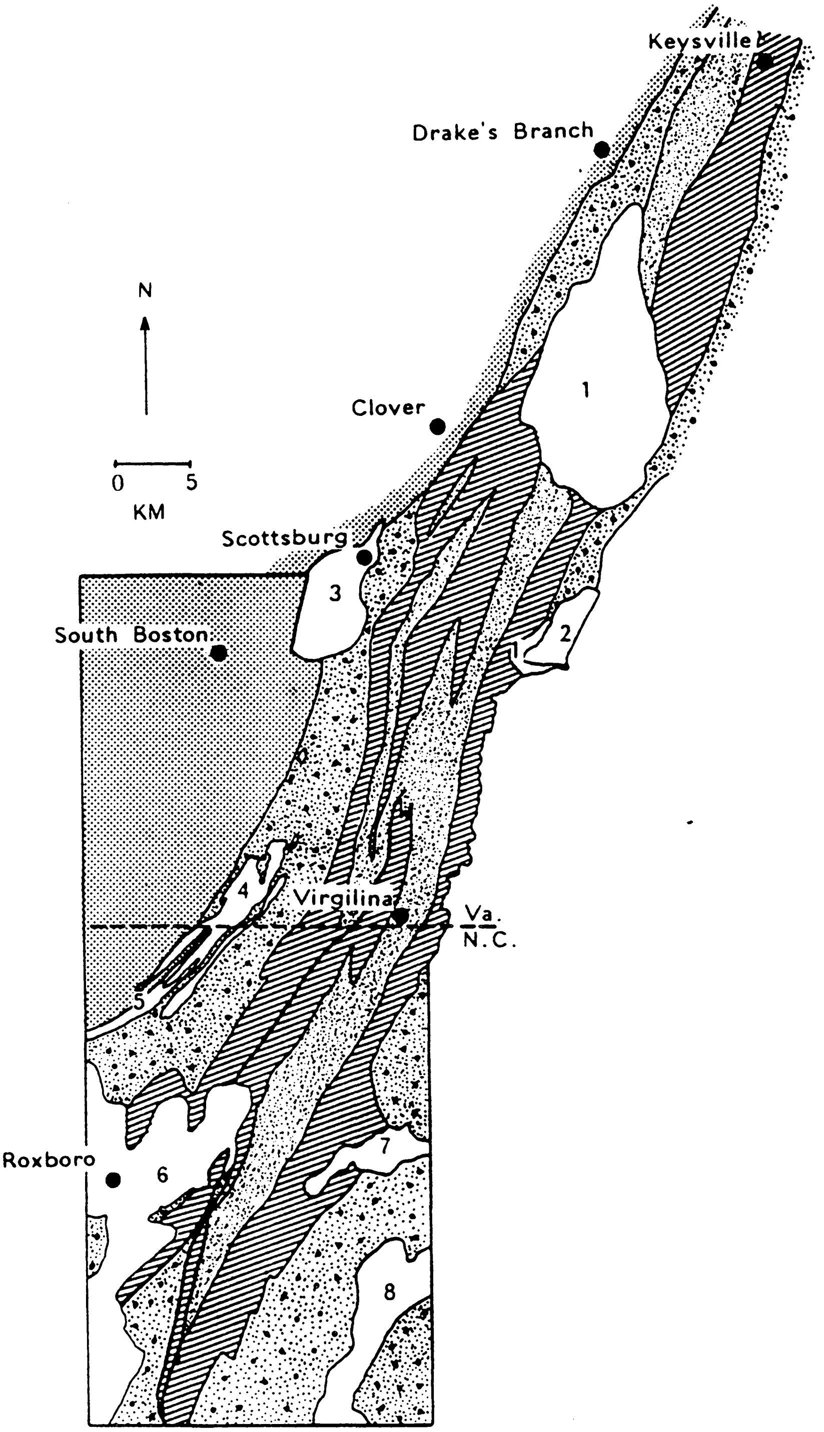
The sedimentary sequence is made up of the Hyco, Aaron, and Virgilina formations, from oldest to youngest. The Hyco consists primarily of andesitic to basaltic pyroclastics, the Aaron of arenites, siltstones, and conglomerates derived from the Hyco, and the Virgilina of interlayered intermediate-to-mafic, rhyolitic-to-dacitic volcanics and volcaniclastics, mudstones, and greywackes (Harris, 1982; Green et al., 1982)

Intrusive rocks in the district include the Redoak and Roxboro metagranites, several scattered gabbroic bodies, including the Abbeyville gabbro, and other unnamed bodies of granodiorite to quartz diorite, granodiorite, and quartz monzonite. Most of these are poorly understood due to the paucity of exposure, (Glover and Sinha, 1973;

Figure 2 : Generalized geologic map of the Virgilina district, adapted from Laney (1917), Legrand (1960), Glover and Sinha (1973), and Kreisa (1980).

░ = Undifferentiated Charlotte belt rocks
▒ = Hyco formation
▨ = Aaron formation
▓ = Virgilina formation

1= Redoak granite
2= Abbeyville gabbro
3= Triassic basin
4= Quartz diorite
5= Gabbro
6= Roxboro metagranite
7= Gabbro
8= Porphyritic intrusives


Keysville
Drake's Branch
N
Clover
1
0 5
KM
Scottsburg
3
2
1
South Boston
4
Virgilina
Va.
N.C.
5
Roxboro
6
7
8

Kriesa, 1980), but are believed to be pre-metamorphic in most cases. Some of the plutons may have supplied volcanics to the Hyco formation (Glover and Sinha, 1973). Dikes in the district, although often compositionally similar to many of the plutons, are considered generally to be younger (Glover and Sinha, 1973; Harris, 1982). Veins up to 5 meters wide are ubiquitous in the district; however, only those found in the Virgilina formation are mineralized to any extent. The veins often show evidence of folding (Figure 3A) or shearing, or include shards of country rock (Figure 3B).

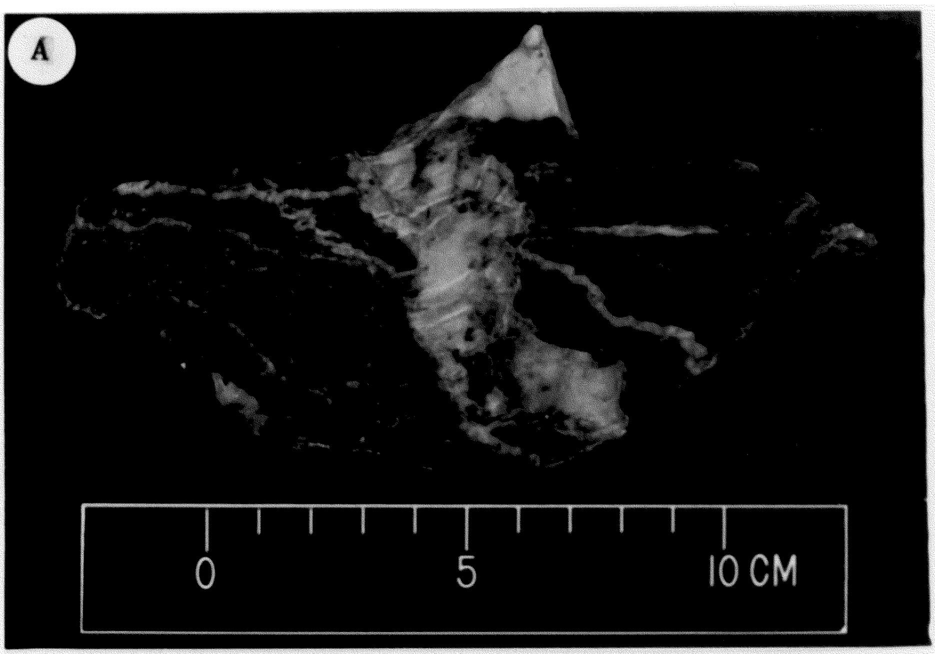
The major structural feature is the Virgilina synclinorium (Brown, 1953). Deformation during late Precambrian or early Cambrian buckle-folded the sequence, but slaty cleavage was not developed until Taconic time (Harris, 1982). There are steeply dipping brittle faults in the district, some of which pre-date the regional metamorphism, some of which post-date it. In general, the district is considered to be an ancient volcanic arc (Kish and Black, 1982), although the precise nature is not clear. A geologic model developed by Harris (1982) from his work southwest of the district is:

1) Eruption of the intermediate to felsic volcanic rocks of the Hyco formation in a mixed subaerial to subaqueous environment.

2) Differential uplift and subsidence due to faulting (?), resulting in erosion of the Hyco, generating the epiclastic sediments of the Aaron formation; this was accompanied by regional subsidence and apparent cessation of volcanism.

3) Renewed bimodal volcanism resulting in deposition of the Virgilina formation.

Figure 3 : A. Deformed quartz vein, sample 38, Durgy mine, North Carolina; B. Wall rock fragments in vein, sample 96, Holloway mine, North Carolina.


A
0
5
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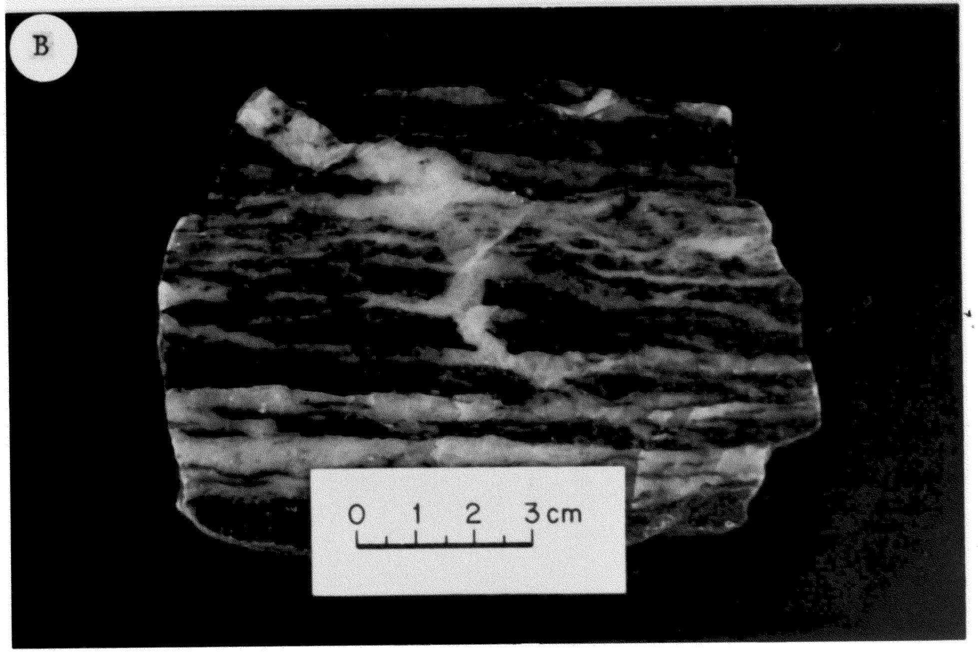
B
0 1 2 3cm

4) Initiation of the 600 Ma Virgilina deformation which folded and faulted the above units.

5) Post Virgilina deformation, intrusion of tonalitic to granodioritic stocks and plugs which may have hydrothermally altered the Hyco and Aaron formations. Concomitant with the plutonic activity was the intrusion of felsic and mafic porphyry dikes and time equivalent eruption and deposition of volcanic rocks of the Uwharrie formation.

6) Sedimentation, accompanied by intermittent volcanism in the Albemarle Group of the central Carolina slate belt.

7) Taconic, circa 480-440(?), Ma deformation and metamorphism of entire slate belt stratigraphy.

8) Mesozoic rifting and intrusion of diabase dikes in the Carolina slate belt.

CHAPTER III

MINING HISTORY

The Virgilina district was one of the earliest major copper-producing districts in the United States. The Barnes mine along the Roanoke river in Virginia was rumored to have been operated between 1700 and 1750, a statement partially substantiated by the discovery of extensive workings at the site in 1880. The first documented mining occurred at the Gillis mine in Person county, North Carolina, in 1852. According to Emmons (1856), who published the first geologic account of the district, "a fine body of glance [chalcocite] ore was exposed". The mine apparently closed soon after this ore was removed. Emmons' paper ends with the comment, "The indications which the rocks furnish, taken in connection with the fact that there are other veins than the one described in the neighborhood, are that this part of Person and Granville counties will prove a mineral district of considerable importance."

Sporadic prospecting occurred in the district until 1886, when the Blue Wing mine was opened in Granville County, North Carolina. Only about 500 tons of ore were removed prior to its closing in 1887. Concurrently, prospecting was undertaken on the Yancey (later named Durgy) property, but the results were unfavorable and the prospect abandoned.

Activity in the district was renewed in 1897 with the opening of the Durgy operations, and with detailed exploration throughout the

Table 1 : Production data from Virgilina mines.

Name	County	Location	Mineralogy	Mining	Production	Grade	Ref.
Abbott and Esther Mae	Halifax	Virgilina, SW	Bn, cc	none	none	none	1,2
Anaconda	Halifax	Virgilina, SE	Cc, mal	1900(?)	210 tons	3-12%	1,2,3,4
Barnes	Charlotte	Buffalo Springs, NW	Bn, cc, mal	1700(?)-1750(?)	?	?	1,2
Baynham	Halifax	Omega, SE	Bn, cc	none	none	none	1,2
Blue Wing	Granville	Virgilina, SE	Bn, cc, mal	1890(?)-1910	50,000 tons	4%	1,3,5
Chappell	Halifax	Buffalo Springs, SW	Bn, cc, mal	1900(?)	?	?	1,2,3,4
Copper King	Person	Triple Springs, NE	Bn, cc, mal	1900(?)	3-5,000 tons(?)	?	1,5
Copper World	Person	Triple Springs, NW	Bn, cc, mal	1882	8-10 tons	10%(?)	1,3,5
Crenshaw	Charlotte	Eureka, SE	Bn, cc	none	none	none	1,2
Cross-Cut	Person	Triple Springs, SW	Bn, cc, mal	1900	?	?	1,5
Daniel's	Charlotte	Eureka, SW	Bn, cc, mal	none	none	none	1,2
Dorothy	Halifax	Virgilina, NE	Bn, cc	1900(?)	150 tons	?	2,3,4
Duke	Person	Triple Springs, SW	Bn, cc, cpy	1895(?)-1905(?)	1200 tons	?	1,5
Durgy	Person	Triple Springs, NW	Bn, cc, mal	1890(?)-1911	70,000 tons	2-15%	1,3,5
Grove	Charlotte	Eureka, SW	Bn, cc, cpy	1900(?)-1916	2,500 tons	?	1,2
High Hill	Halifax	Omega, SE	Bn, cc, mal	1899-1907	10,014 tons	4%	1,2,3,4
Holloway	Granville	Virgilina, SW	Bn, cc, mal	1880-1905	180,000 tons	9%	1,3,5
Jeffers	Person	Triple Springs, SW	Bn, cc, mal	none	none	none	5
Kay	Halifax	Omega, NE	Bn, cc, mal	1900(?)	?	4-30%	1,2
Littlejohn	Halifax	Virgilina, NE	Bn, cc	1900(?)	?	?	1,2
McNeny	Charlotte	Drake's Branch, NE	Bn, cc	1900(?)	?	2-3%(?)	1,2
Old Durgy	Person	Triple Springs, SW	Bn, cc, mal	1900	?	?	1,5
Pandora	Halifax	Virgilina, NE	Bn, cc	none	none	none	1,2
Pannebaker	Granville	Virgilina, SE	Cu(?)	none	none	none	1,5
Pontiac	Halifax	Omega, SE	Bn, cc, cpy	1900(?)	4-6 tons(?)	?	1,2
Seaboard	Halifax	Virgilina, NE	Bn, cc	1899-1907	2,200 tons	3-5%	1,2
Wall	Halifax	Virgilina, NE	Bn, cc	1900(?)	?	?	1,2,3,4

Bn = Bornite, Cc = Chalcocite/Djurleite/Anilite, Mal = Malachite, Cpy = Chalcopyrite

1) Laney, F.B. (1917) Geology and Ore Deposits of the Virgilina District of Virginia and North Carolina Virginia Geological Survey Bulletin 14

2) Sweet, P.C. (1976) Abandoned Copper Mines and Prospects in the Virgilina District, Virginia Virginia Minerals, V. 22

3) Weed, W.H. (1911) Copper Deposits of the Appalachian States USGS Bulletin 455

4) Watson, T.L. (1907) Mineral Resources of Virginia: Lynchburg, Va., Jamestown Exposition Commission

5) Carpenter, P.A. (1976) Metallic Mineral Deposits of the Carolina Slate Belt, North Carolina Bulletin 84, North Carolina Department of Natural and Economic Resources, Division of Resource Planning and Evaluation; Mineral Resources Section

district in 1898. Weed (1911) states that during the period 1898-1904, several hundred thousand dollars were invested in opening various mines.

Most early mining efforts were ill-conceived and resulted in considerable effort in following negligible amounts of malachite stains on quartz veins. As a result, the district today contains dozens of small prospect pits. Several mines were developed seriously at that time: the largest were the Blue Wing, Holloway and Durgy mines in North Carolina, and the High Hill and Seaboard mines in Virginia. Of these, only the Durgy and High Hill mines were equipped with milling facilities. A great deal of ore was shipped from these mines, but few records remain on production. Laney (1917) noted that the data available for his report were woefully incomplete, but estimates of production which can be made from his work can be found in Table 1. The large amount of ore at Holloway made the building of a railroad spur to it a worthwhile expenditure. The spur ran by the Blue Wing mine, and Durgy was near enough to Holloway for its production to be shipped as well. Smelting facilities known to be used by these mines were at Copperhill, Tennessee, and Norfolk, Virginia. By 1906 only the Durgy mine was operating, and by 1908 it had closed. Laney states that several studies by mining engineers indicated that the ores of the district could be profitably concentrated on the site; that they were not was apparently the result of poor management.

Although attempts were made to reopen the mines (Holloway-1905, High Hill-1907, Blue Wing-1909, Durgy-1910), and new processes for concentration tried (a mill designed at Mass. Inst. of Technology at Seaboard, acid leach and electrolytic precipitation facilities at High Hill), all failed, probably due in part to competition from the developing porphyry copper deposits in the southwestern U.S. When Laney completed his study in 1916, none of the mines were in operation.

In late 1916, the Grove prospect was reopened and operated for a brief period of time. This was the only producing mine in the northern portion of the district. It suffered the same problems as the other mines, and when it closed, no further serious attempts were made at mining.

As part of the strategic minerals program during World War II, the Bureau of Mines began a study of some of the major mines of the district: Blue Wing, Durgy, High Hill, and Seaboard (Newberry et al., 1948). Trenching, shaft repair, diamond drilling, and geophysical studies were accomplished to determine the feasibility of reopening the district. The project which confirmed the presence of low grade ore shoots at depth was terminated in 1945.

CHAPTER IV

ORE MINERALOGY

The ores of the Virgilina district can be subdivided into two groups: hypogene ore minerals, and supergene ore minerals. The hypogene minerals consist primarily of bornite, chalcocite/djurleite[1], anilite, and digenite, with lesser amounts of hematite, magnetite, chalcopyrite, gold, and hessite. The supergene minerals include covellite, malachite, cuprite, digenite, and hematite with lesser amounts of chalcopyrite, spionkopite, yarrowite, azurite, and chalcocite/djurleite. Ore minerals not directly associated with the copper mineralization include pyrite, ilmenite, and rutile. Both hypogene and supergene mineralization occur in varying amounts at every locality.

Minerals previously described from the district but not confirmed in this study include native copper and silver, argentite, klaprothite, tenorite, chrysocolla, (Laney, 1917), pyrrhotite, and hemimorphite (Carpenter, 1976). The ore minerals occur disseminated through both the veins and the country rock, but tend to be concentrated in zones in the veins. Grain sizes may vary from < 0.002 mm to as much as 3 cm. Microprobe analyses of ore minerals are contained in Appendix D.

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[1] The chemical, optical, and structural properties of chalcocite and djurleite are sufficiently similar so as to make it virtually impossible to distinguish between the two; hence they are grouped and described together.

Table 2 : Ore mineralogy of the Virgilina district.

Ore minerals observed in this study:

Hypogene

Name	Formula
Bornite	Cu_5FeS_4
Chalcocite	Cu_2S
Djurleite*	$Cu_{31}S_{16}$
Anilite*	Cu_7S_4
Digenite	Cu_9S_5
Chalcopyrite	$CuFeS_2$
Hematite	Fe_2O_3
Magnetite	Fe_3O_4
Hessite*	Ag_2Te
Gold	(Au,Ag)
Ilmenite	$FeTiO_3$
Pyrite	FeS_2

Supergene

Name	Formula
Malachite	$Cu_2(CO_3)(OH)_2$
Covellite	CuS
Cuprite	Cu_2O
Digenite	Cu_9S_5
Hematite	Fe_2O_3
Spionkopite	$Cu_{39}S_{28}$
Yarrowite	Cu_9S_8
Chalcopyrite	$CuFeS_2$
Azurite	$Cu_3(CO_3)_2(OH)_2$

Ore minerals previously reported:

Name	Formula	Reference
Argentite	Ag_2S	Laney (1917)
Chrysocolla	$(Cu,Al)_2H_2Si_2O_5(OH)_4\ nH_2O$	"
Copper	Cu	"
Klaprothite**	$CuBiS_2$	"
Silver	Ag	"
Tenorite	CuO	"
Hemimorphite	$Zn_4Si_2O_7(OH)_2\ H_2O$	Carpenter (1976)
Pyrrhotite	$Fe_{1-x}S$	"

---

*First reported occurrence in Virginia or North Carolina.

**According to Nuffield (1947b), all klaprothite available to him for examination proved to be either wittichenite or emplectite (Uytenbogaart and Burke, 1971).

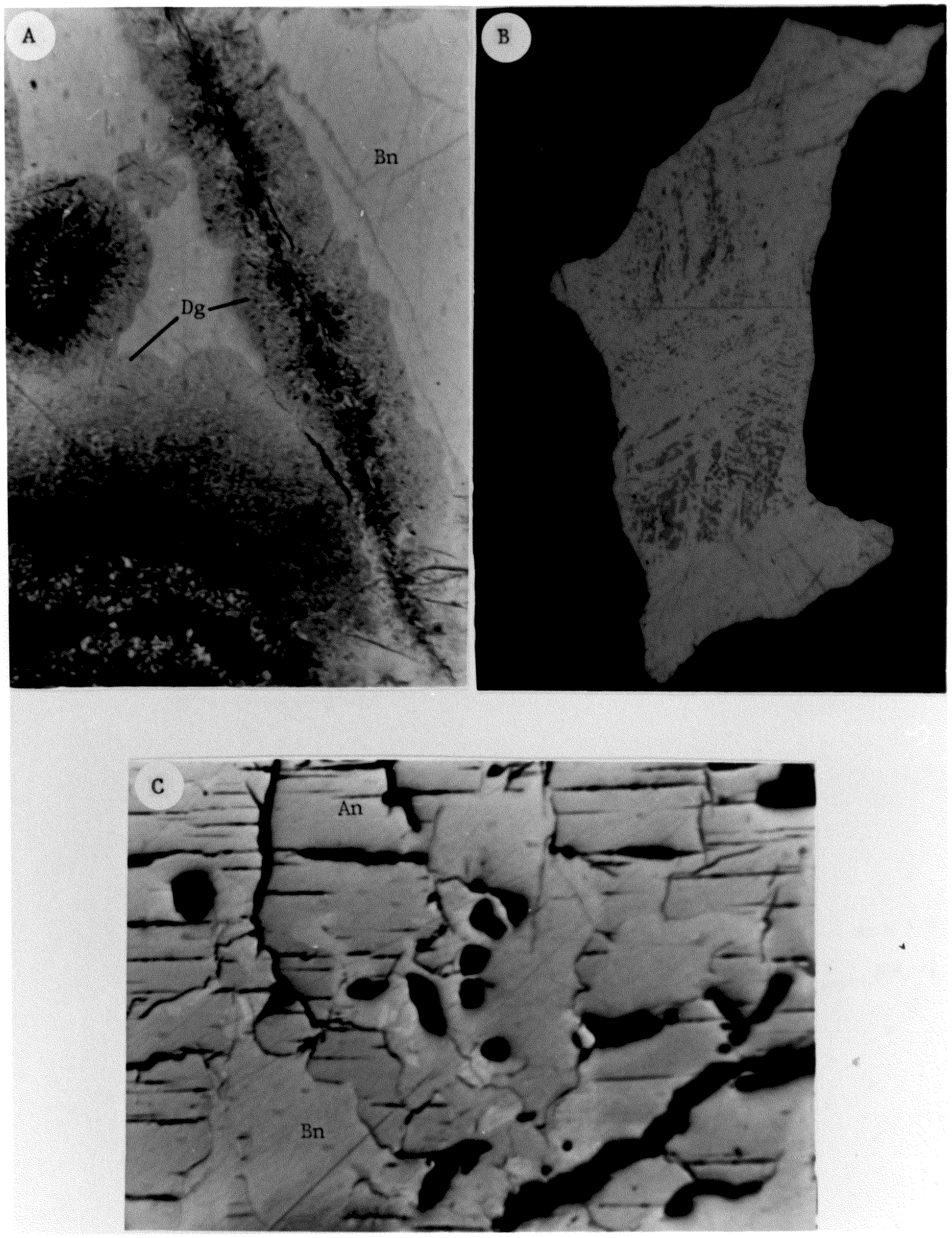
Bornite (Cu_5FeS_4)

Bornite is the most common ore mineral in the Virgilina district, and constitutes approximately 45% of the hypogene ore minerals. However, the percentage occurring at any given locality may range from as low as 1% (Holloway) to as much as 65% (Seaboard). It occurs as disseminated blebs <0.015 mm to masses >3 cm in both the veins and the country rock. Compositions vary distinctly, from virtually stoichiometric to up to 3% copper poor (Appendix D). Few trace constituents were found in microprobe analyses, except at Blue Wing, where up to 0.26 wt % silver was detected, and there is no apparent relationship between composition and location within the district.

The bornite is generally highly fractured and veined. The fractures may be empty or filled with quartz, whereas the veinlets consist of quartz, cuprite, malachite, and hematite, and are often anastomosing or dendritic. No other deformational features are apparent. Boundaries between the veinlets and the bornite are lined with digenite, less often tooth-like crystals of chalcocite or djurleite, and more rarely flames of supergene chalcopyrite. The bornite may also contain randomly distributed blebs of chalcocite, djurleite, and chalcopyrite, and euhedral to subhedral crystals of hematite.

Bornite rarely displays a weak bireflectance, and examination under crossed nicols indicates that masses of bornite consist primarily of large homogeneous areas. Microstructural intergrowths can occasionally be observed, but these are only found in close association

Figure 4 : A. Supergene veinlets in bornite (Bn) displaying reaction rim of digenite (Dg), sample NEJ 00080 High Hill mine, VA. 100x f.o.v. 1.05 mm; B. Kamacite-like intergrowth of bornite (Bn) and chalcocite (Cc), sample NEJ 00198 Mc Neny mine, VA. 200x f.o.v. 0.52 mm; C. Bornite (Bn) replacing anilite (An), sample NEJ 00055 Wall mine, VA. 100x f.o.v. 1.05 mm


A
Bn
Dg
B
C
An
Bn

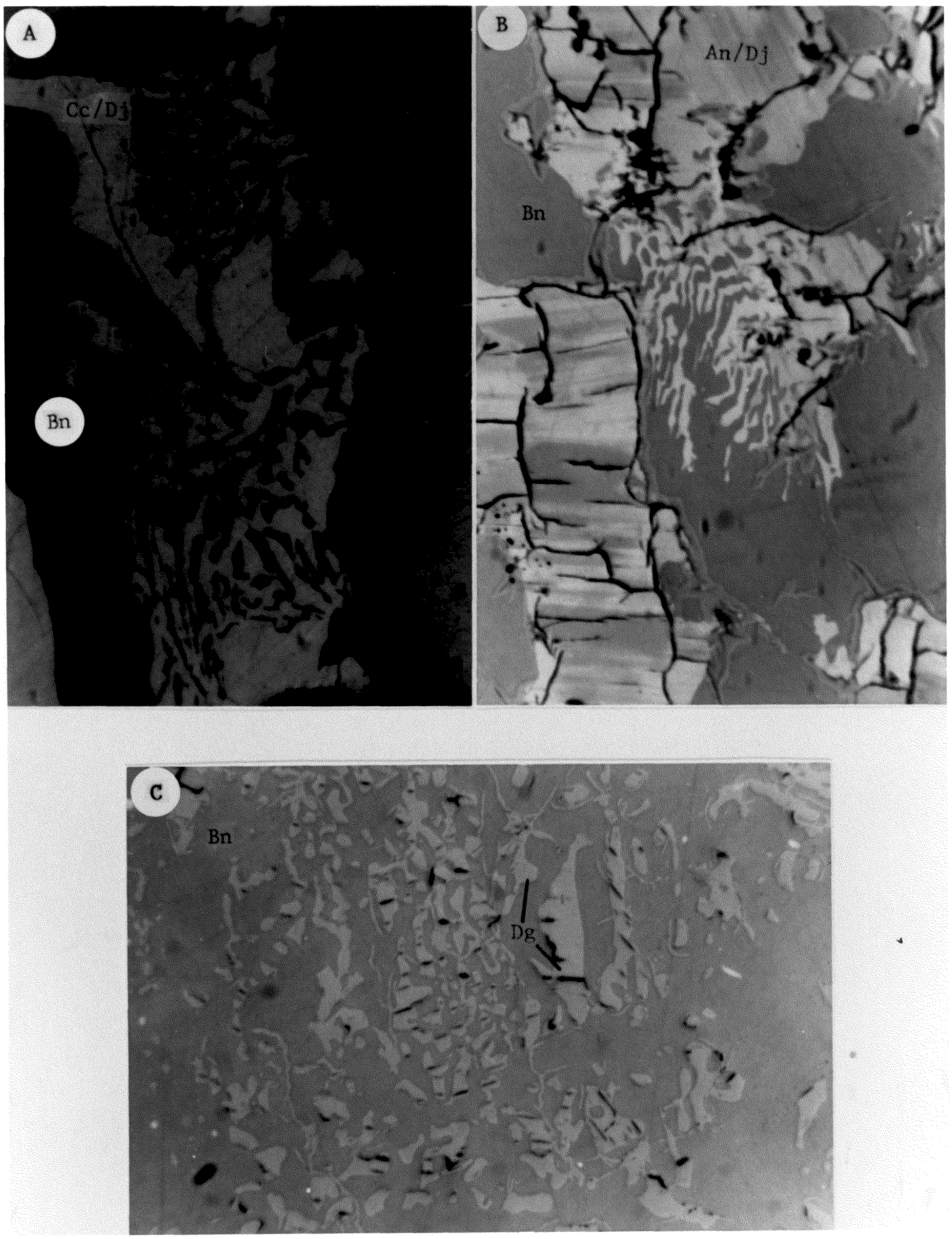
with the "orange bornites" discussed below. Bornite also occurs in myrmekitic intergrowths with chalcocite/djurleite and digenite, in kamacite-like intergrowths with chalcocite, is replaced by chalcocite and djurleite, and replaces anilite. The intergrowths are discussed in detail later in this section.

Peculiarly orange-tinted bornites which display a high relief and tend to tarnish more slowly than normal bornite were found throughout the district in association with covellite, spionkopite, yarrowite, cuprite, and malachite. Petrographic and microprobe study indicates that these "orange bornites" are in fact bornite with microscopic to submicroscopic lamellae of chalcopyrite oriented parallel to the (111) and/or (100) directions in the host bornite. Stein and Kish (1978) reported two optical varieties of bornite from mines in North Carolina. It seems probable that one of their varieties is a submicroscopic intergrowth of bornite and chalcopyrite.

Chalcocite and Djurleite ($Cu_2S/Cu_{31}S_{16}$)

Chalcocite and djurleite represent approximately 30% of the hypogene and 5% of the supergene ores. Distinguishing between the two is virtually impossible by petrographic or microprobe analysis; the only reliable method of identification is by x-ray diffraction. Accordingly, positive determination can only be made for large, inclusion free areas. The x-ray powder analyses undertaken (Appendix

Figure 5 : A. Myrmekitic intergrowth of bornite (Bn) and chalcocite/djurleite (Cc/Dj), sample NEJ 00149 Seaboard mine, VA. 100x f.o.v. 1.05 mm; B. Myrmekitic intergrowth of bornite, djurleite (Dj), and anilite (An), sample NEJ 00160 Chappell mine, VA. 100x f.o.v. 1.05 mm; C. Myrmekitic intergrowth of bornite and digenite (Dg), sample NEJ 00173 Durgy mine, NC. 100x f.o.v. 1.05 mm

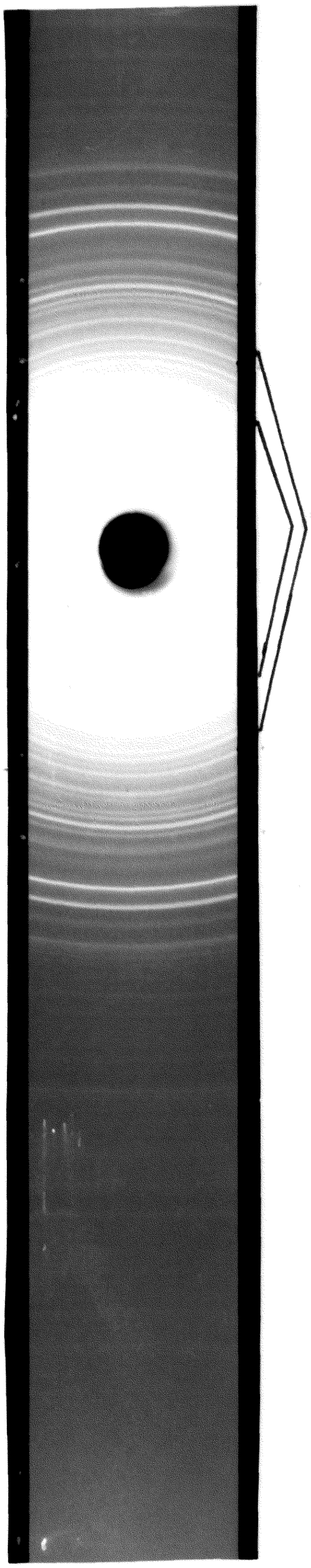

A
Cc/Dj
Bn
B
An/Dj
Bn
C
Bn
Dg

E) indicate that chalcocite is only present when the ores do not contain anilite, either as grains or lamellae. This is in accordance with the phase relations determined by Barton (1973) and Potter (1977). However, the absence of visible anilite does not necessarily imply the presence of chalcocite. Hence, unless the presence or absence of one or the other can be conclusively proven by x-ray methods, it is deemed more prudent to describe the two minerals together.

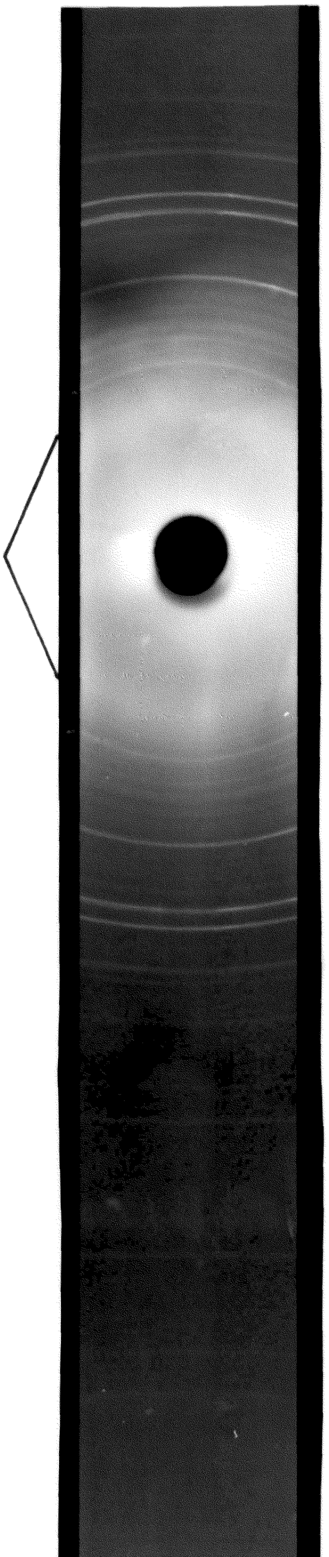
The chalcocite and djurleite occur as disseminated blebs <0.015 mm to masses >3 cm. Both tend to be more restricted to the vein rocks than the bornite. Microprobe analyses indicate that no distinct compositional trends in the district are discernable (Appendix E). Of special interest are the trace amounts of silver detected, ranging from 0.46 wt % Ag to below the limits of detection (0.01 wt %). Comparison of the amounts of silver produced as by-products of the mining operations with the traces of silver detected indicates that a great deal of the production can be accounted for by trace amounts in chalcocite and djurleite or other copper minerals. This implies that the free silver and argentite described by Laney (1917) may have been of supergene origin.

Neither the chalcocite or the djurleite display any deformational features, and both are generally free of the fracturing and veining that are common in the bornite. Some supergene chalcocite and djurleite does occur, usually as tooth-shaped crystals lining the walls of cuprite veinlets in the bornite and anilite, but occasionally with malachite as reprecipitated masses that fill fractures in the ore and gangue.

Figure 6 : Comparison of powder diffraction patterns of chalcocite and djurleite. Dj= djurleite from Chappell mine, VA.; Cc= chalcocite from Seaboard mine, VA.



Cc



Dj

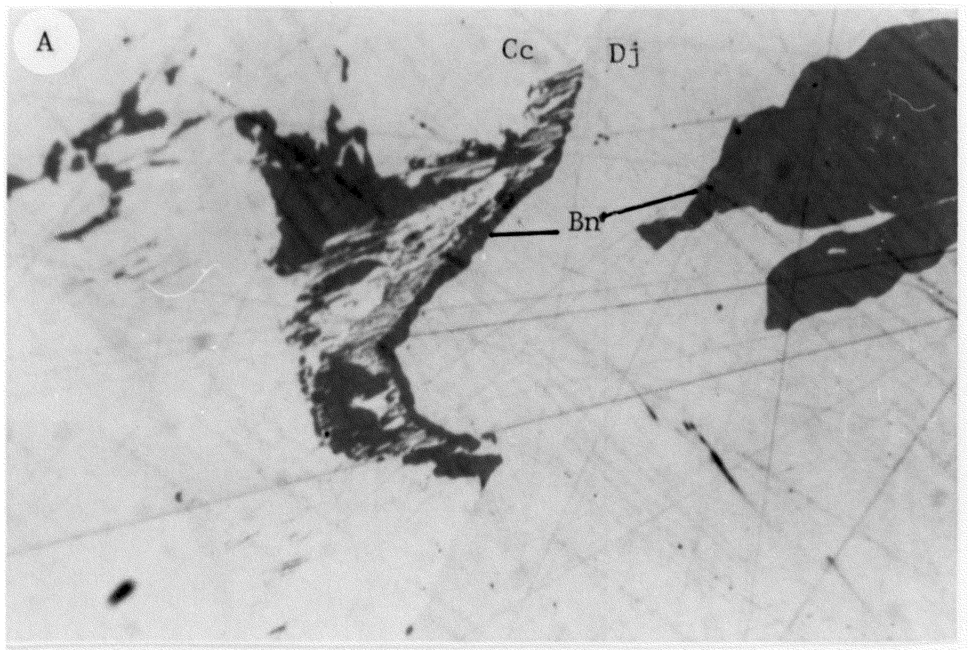
Hypogene chalcocite and djurleite occur in myrmekitic intergrowths with bornite, although the intergrowths are more common with chalcocite. Both chalcocite and djurleite replace bornite, and the djurleite replaces anilite as well as forming lamellar intergrowths with it. The intergrowths are discussed in detail later in this section.

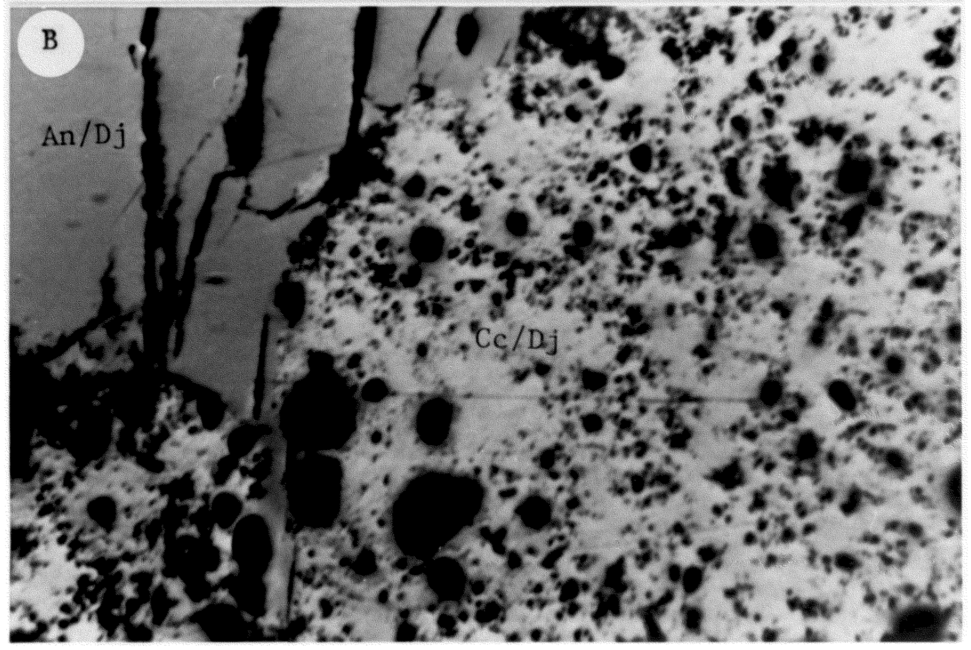
Anilite (Cu_7S_4)

Anilite is common in the district, but not so common as bornite, chalcocite, or djurleite. It comprises approximately 15% of the hypogene mineralization, and occurs, in varying amounts, in most of the mines. The presence of anilite was initially determined by x-ray diffraction, and subsequently confirmed by microprobe analyses. The visible presence of anilite is useful in indicating whether chalcocite or djurleite is present in polished section.

Anilite occurs in isolated grains 0.05-0.1 mm, as 1-20 mm masses of interlocked grains, and is virtually restricted to the vein material. As is the case with the bornite, anilite is highly fractured; although some of the fractures are random, most are cleavages parallel to (001). The fractures and cleavages are usually filled with quartz. Anilite appears homogeneous optically, however, any anisotropic effects are probably masked by a surface layer of an isotropic digenite-like phase created by polishing (Morimoto et al., 1969). It is usually free of inclusions, except for occasional subhedral to euhedral crystals of

Figure 7 : A. Chalcocite (Cc), djurleite (Dj), and bornite (Bn) in myrmekitic intergrowth. Sample NEJ 00062 Tuck shaft of the Pontiac mine, VA. 200x f.o.v. 0.52 mm; B. Supergene chalcocite/djurleite(Cc/Dj), associated with anilite - djurleite lamellae. Sample NEJ 00071 Durgy mine, NC. 100x f.o.v. 1.05 mm.


A
Cc
Dj
Bn


B
An/Dj
Cc/Dj

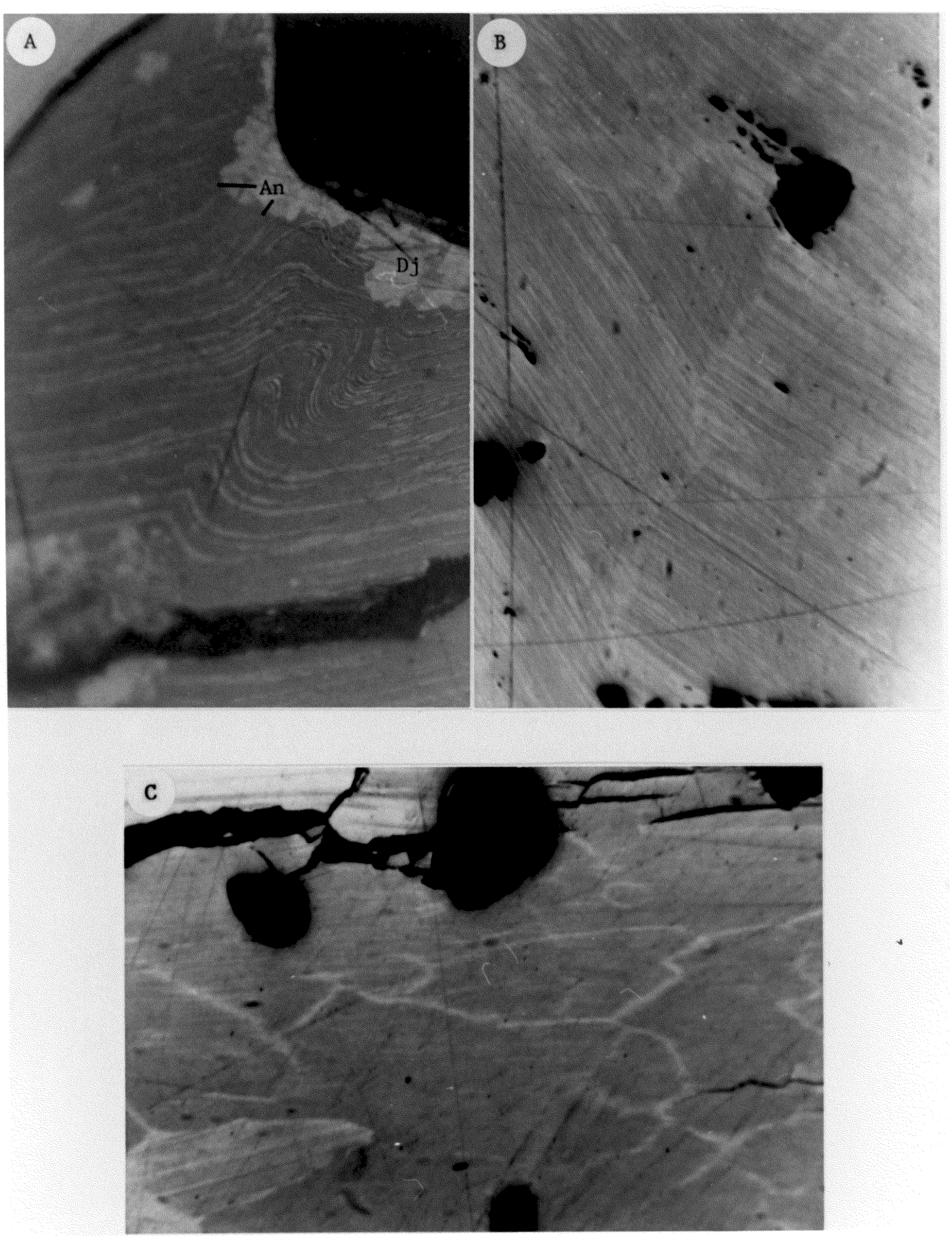
hematite. Microprobe analyses (Appendix E) indicate that anilite may contain trace amounts of iron and up to 0.42 wt % silver.

Anilite occurs in lamellar intergrowths with and is replaced by djurleite, bornite and digenite. These lamellar intergrowths are discussed later in this section.

Digenite (Cu_9S_5)

Digenite, which makes up approximately 10% and 5% of the hypogene and supergene ore minerals respectively, occurs primarily as reaction rims between others ore minerals. In the hypogene ores digenite is found between bornite and anilite, often producing myrmekitic textures. Supergene digenite is found between veinlets of quartz and cuprite and either bornite or chalcopyrite. In both cases, the digenite is massive. Although the formula is usually given as Cu_9S_5, Morimoto and Koto (1970) determined that digenite is unstable below 70 degrees C unless there is approximately 1% Fe in the structure. Microprobe analyses of zones of anilite reacting to digenite indicate that the transition is gradational from Fe-poor (<0.05 wt %) to Fe-rich (>2.0 wt %). In Appendix E , an arbitrary limit of 0.50 wt % Fe is used for distinguishing digenite and anilite.

Figure 8 : Anilite-djurleite lamellar intergrowths (anilite= An, djurleite=Dj): A. Folded lamellae, sample NEJ 00030 Blue Wing mine, NC. 500x oil immersion f.o.v. 0.21 mm; B. Non-parallel lamellae in grains with random orientations, sample NEJ 00155 Cross-Cut NC. 100x f.o.v. 1.05 mm; C. Alteration along grain boundaries, sample NEJ 00156 Cross-Cut mine, NC. 100x f.o.v. 1.05 mm.

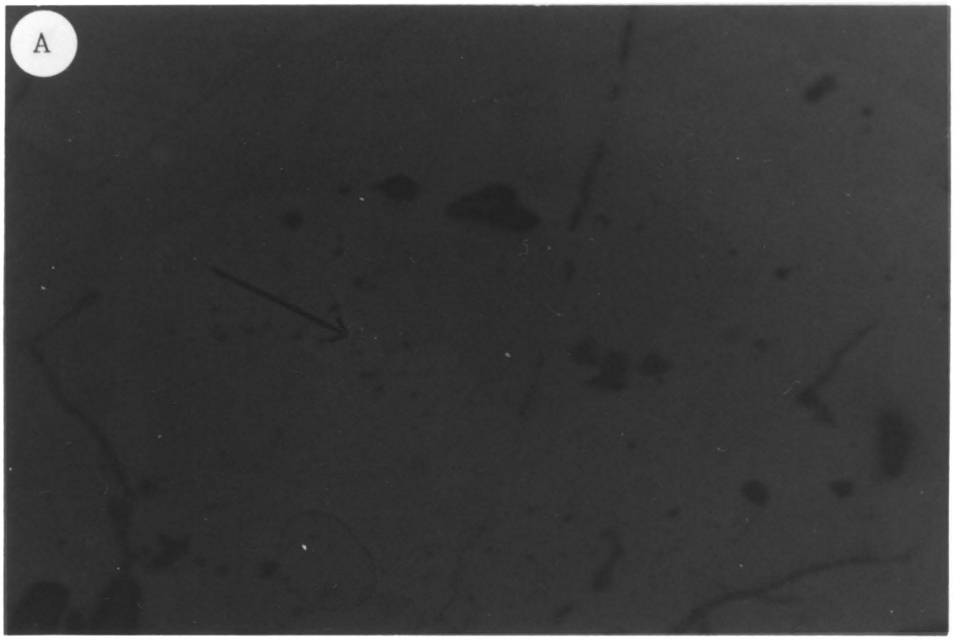

A
An
Dj
B
C

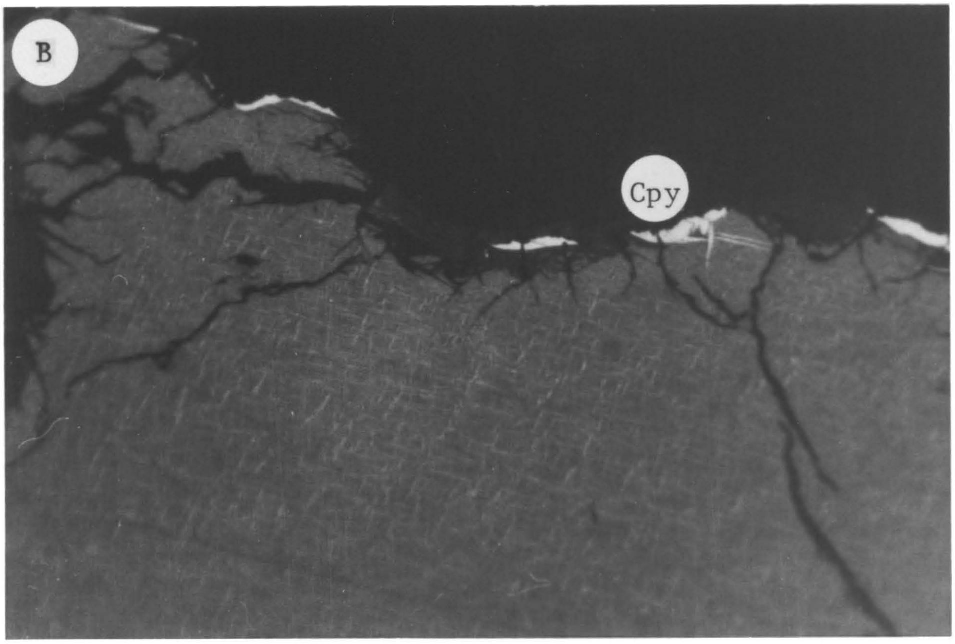
Chalcopyrite ($CuFeS_2$)

Chalcopyrite, which comprises less than 1% of the total mineralization, is the least common of the hypogene ore minerals. Locally, however, it constitutes up to 20% of the ore at the Seaboard mine and at the Glasscock shaft of the Pontiac mine. It occurs as 0.003-0.1 mm blebs and 0.001-0.01 mm lamellae in bornite, 0.5-3 mm masses, and rarely as 0.003 to 0.015 mm supergene flames along fractures in bornite. The presence of chalcopyrite was confirmed by x-ray diffraction of material from localities where it occurs.

The hypogene chalcopyrite is fractured in the same manner as the bornite, with the fractures commonly filled with digenite. Occasionally the fractures follow grain boundaries. No other deformational features are apparent. Examination under crossed nicols indicates that unlike the bornite, chalcopyrite masses consist of interlocked grains in various orientations. Some of the masses contain grains with 120° triple junctions; these features are peculiar to the chalcopyrite, and indicate annealing since the original ore deposition. The supergene chalcopyrite, as noted above, is exceedingly rare, and occurs in bornite fractures along with cuprite and digenite. The compositions of both the hypogene and supergene chalcopyrite are very nearly stoichiometric (Appendix E).

Figure 9 : Chalcopyrite: A. Annealed chalcopyrite displaying 120^{o} triple junctions, sample NEJ 00193 Barnes mine, VA. 100x f.o.v. 1.05 mm, crossed nicols; B. Supergene chalcopyrite associated with bornite/ chalcopyrite intergrowths (Bn/Cpy), sample NEJ 00193 Barnes mine, VA. 500x oil immersion, f.o.v. 0.21 mm.


A


B
Cpy

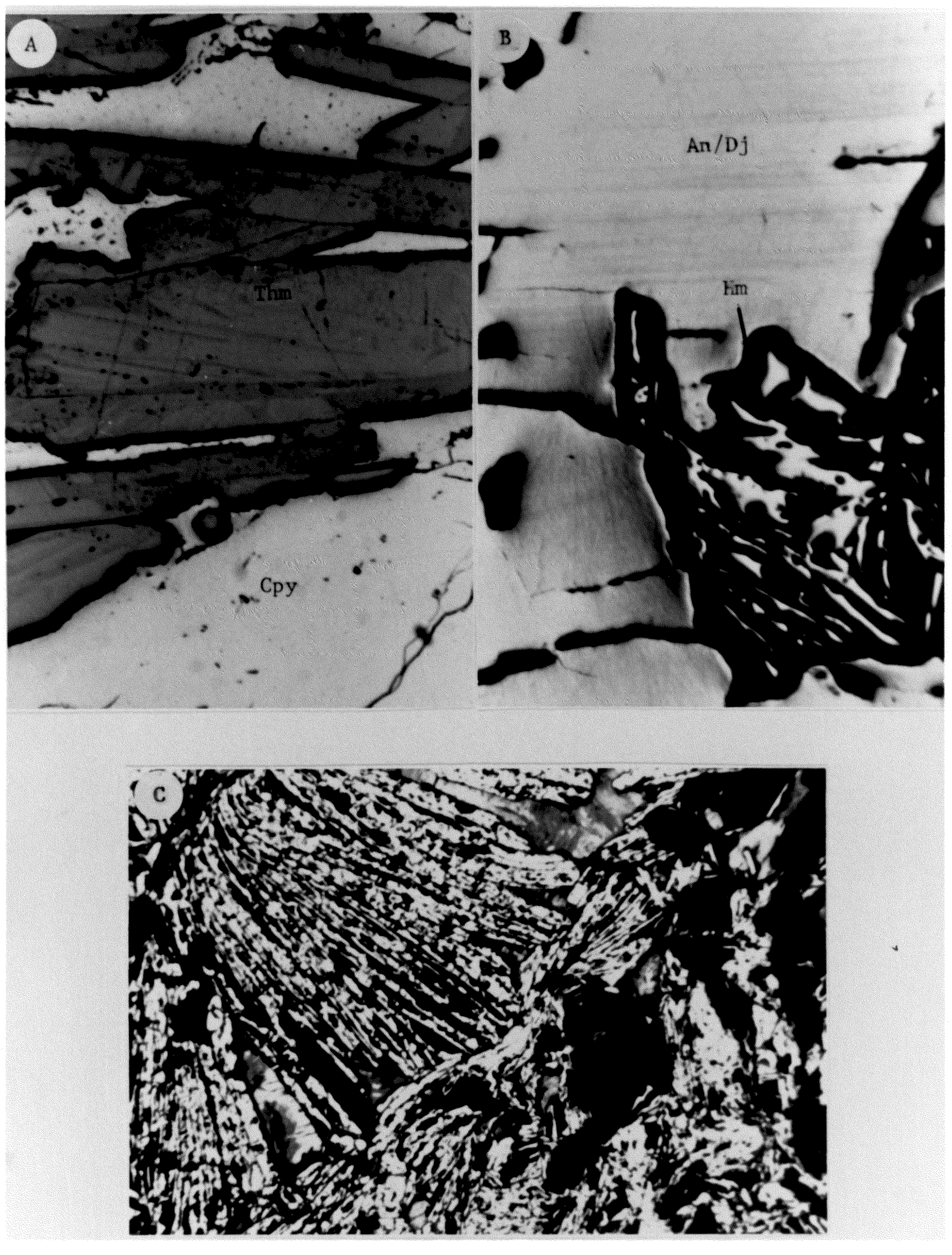
Hematite (Fe_2O_3)

Hematite is ubiquitous in the ores, both as hypogene and supergene mineralization, but occurs in minor (1-2%) amounts only. It occurs as tabular single crystals 0.05-10 mm in length, and as polycrystalline masses or radiating sprays. Often crystals and masses are folded or otherwise deformed.

The hypogene hematite is associated with anilite, chalcocite, djurleite, bornite, and more rarely, chalcopyrite. In addition, martitic hematite is associated with magnetite. The supergene hematite is associated with covellite, malachite, and cuprite. The hypogene hematites can be further divided into two groups: a primary hematite that displays a distinct bireflectance, and a secondary hematite that exhibits no bireflectance.

Microprobe analyses of the bireflectant hematites (Appendix E) indicate that they contain up to 17 wt % $FeTiO_3$, while both the secondary and supergene hematites are closer to stoichiometric Fe_2O_3. Although the titanhematites are often distinctly heterogeneous, there appears to be no discernable zonation within grains. Some of the titanhematites from the Barnes mine have exsolved small (1.5-3 micron) blebs of ilmenite along the edges of grains. Ilmenite and hematite are completely miscible at high temperatures (above 800°C), however at lower temperatures there is a miscibility gap, the precise location of which has not yet been determined (Lindsley, 1973).

Figure 10 : Hematite: A. Primary hypogene hematite (Hm) displaying bireflectance, associated with chalcopyrite (Cpy), sample NEJ 00193 Barnes mine, VA. 100x f.o.v. 1.05 mm; B. Secondary hypogene hematite without bireflectance, associated with anilite-djurleite lamellae (An-Dj), sample NEJ 00133 Holloway mine, NC. 100x f.o.v. 1.05 mm C. Supergene hematite, sample NEJ 00155 Cross-Cut mine, NC. 100x f.o.v. 1.05 mm.


A
Thm
Cpy
B
An/Dj
Hm
C

Magnetite (Fe_3O_4)

Magnetite is uncommon in the Virgilina district, and makes up much less than 1% of the ore minerals. It occurs as subhedral to euhedral crystals 0.02-0.4 mm in size, generally disseminated through the country rock near the vein/rock boundary. The grains are usually fractured, but otherwise show no evidence of deformation. Martitization is very common, and varies from slight to nearly complete replacement. Microprobe analyses indicate that the magnetites contain very few trace constituents (Appendix E).

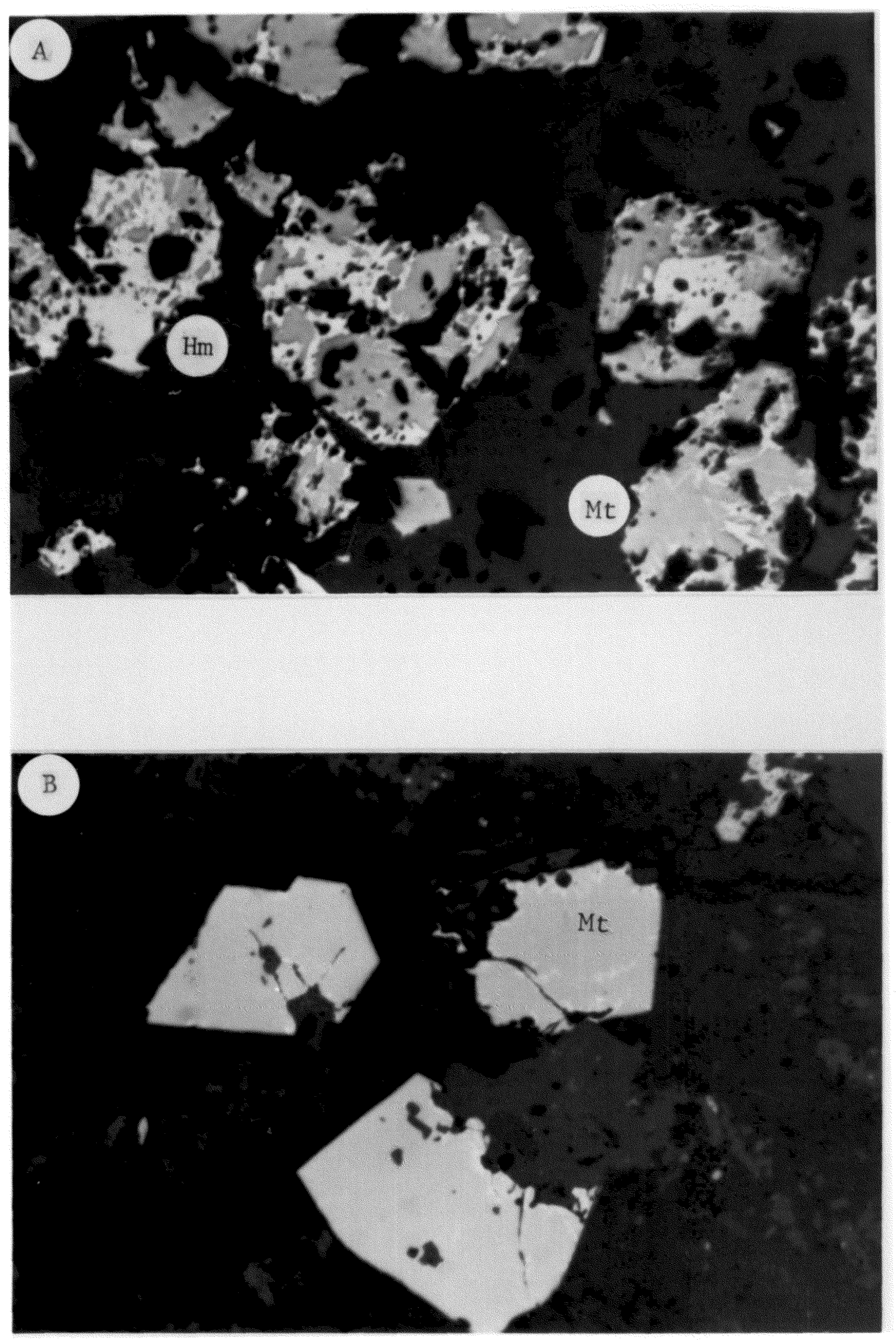
Pyrite (FeS_2)

Pyrite has been found only in samples from the Morong (Mother Lode) mine. As noted previously, this mine was opened in the Aaron formation instead of the Virgilina formation. The grains are subhedral to euhedral, 0.2-2 mm in size, and are disseminated through both the vein and the country rock. The pyrites display no apparent pressure fringes or other evidence of deformation, and most grains contain small inclusions of quartz.

Ilmenite ($FeTiO_3$)

Ilmenite occurs as disseminated blades and blebs 0.03-0.4 mm in size, disseminated through the country rock at the Crenshaw and

Figure 11 : Magnetite: A. Martitized magnetite {magnetite (Mg), hematite (Hm)}, sample NEJ 00068 Anaconda mine, VA. 100x f.o.v. 1.05 mm; B. Alteration free magnetite, sample NEJ 00202 Crenshaw mine, VA. 100x f.o.v. 1.05 mm


A
Hm
Mt
B
Mt

Daniel's mines, and as 1.5-3 micron blebs exsolved from titanhematites at the Barnes mine. Both the blades and blebs show embayments and curved boundaries indicative of resorption. Disseminated through the ilmenite grains are small (3-10 micron) blebs of titanhematite and rutile.

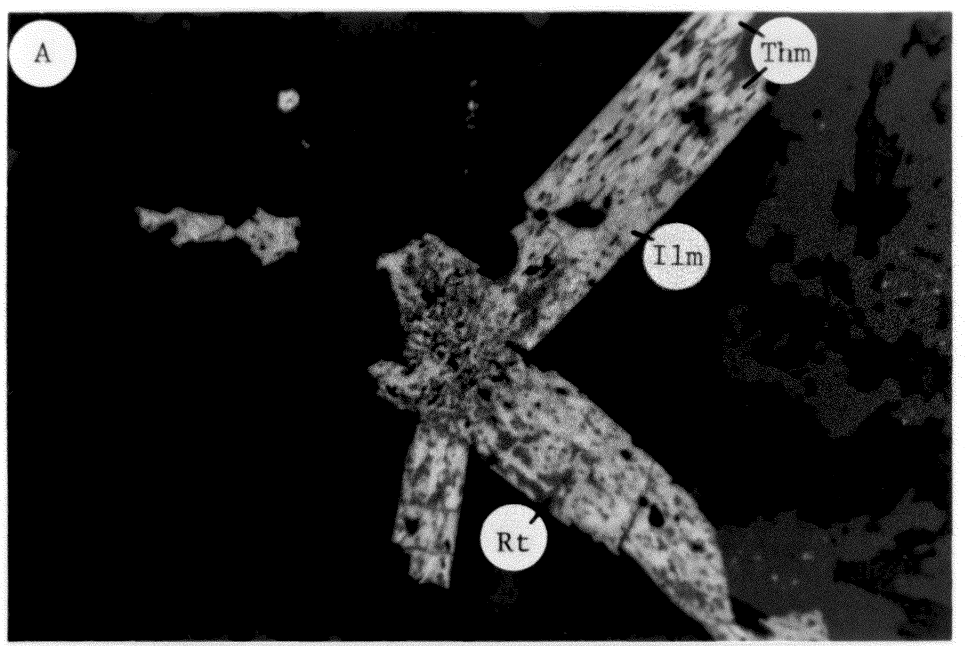
Hessite (Ag_2Te)

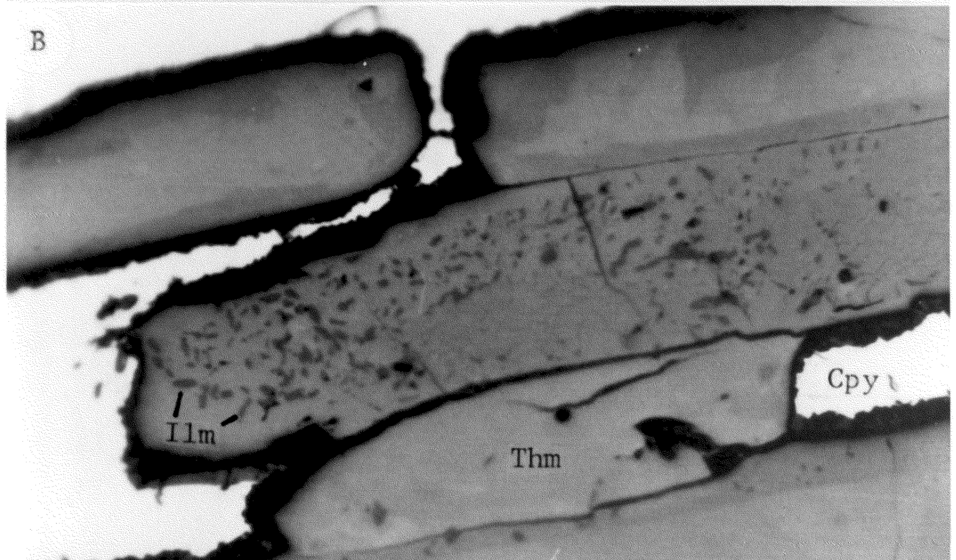
Hessite has been found only in polished sections from the Daniel's mine. It occurs as 0.002-0.066 mm blebs disseminated through the bornite, anilite and digenite, and displays the spotty anisotropism charcteristic of inversion at 155 degrees C from the cubic polymorph (Uytenbogaart and Burke, 1971). Microprobe analyses indicate the presence of up to 7 wt % Cu and 1 wt % Fe.

Gold (Au)

Visible gold grains were detected only in polished sections from the Daniel's mine. The gold is disseminated along the ore/gangue boundary, associated with covellite, cuprite, malachite, and digenite, and ranged in size from 0.002-0.05 mm. Microprobe analyses of the gold indicated it has a fineness of approximately 850. This is comparable with the average fineness of 840 determined by Linden (1981) for material from the abandoned gold mines of the district. Based on the similarities of the veins, both Laney (1917) and Linden

Figure 12 : Ilmenite: A. Blades of ilmenite (Ilm) containing titanhematite (Thm) and rutile (Rt), sample NEJ 00202 Crenshaw mine, VA. 200x f.o.v. 0.52 mm; B. Exsolved ilmenite in titanhematite, sample NEJ 00193 Barnes mine, VA. 500x oil immersion, f.o.v. 0.21 mm


A
Thm
Ilm
Rt


B
Ilm
Cpy
Thm

concluded that the gold and copper mineralization were related. Neither, however, could clearly determine the reason for the differences in mineralization.

The similarity of the gold from the Daniel's mine to that from the gold mines strongly suggests that the gold and copper mineralization is related. The association of gold with hessite may indicate a phase of mineralization that was more concentrated in precious metals.

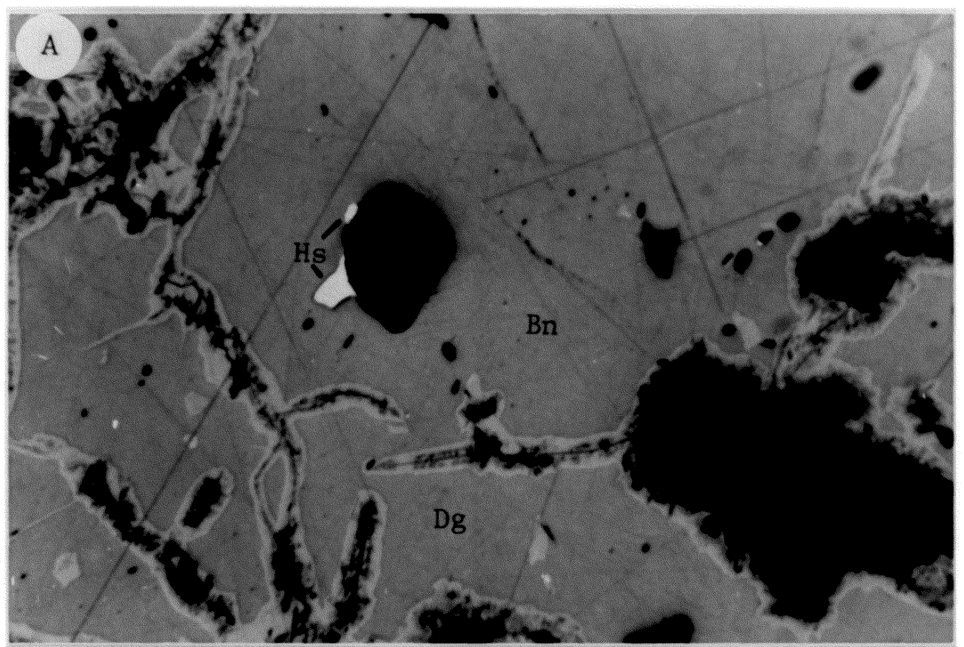
Rutile (TiO_2)

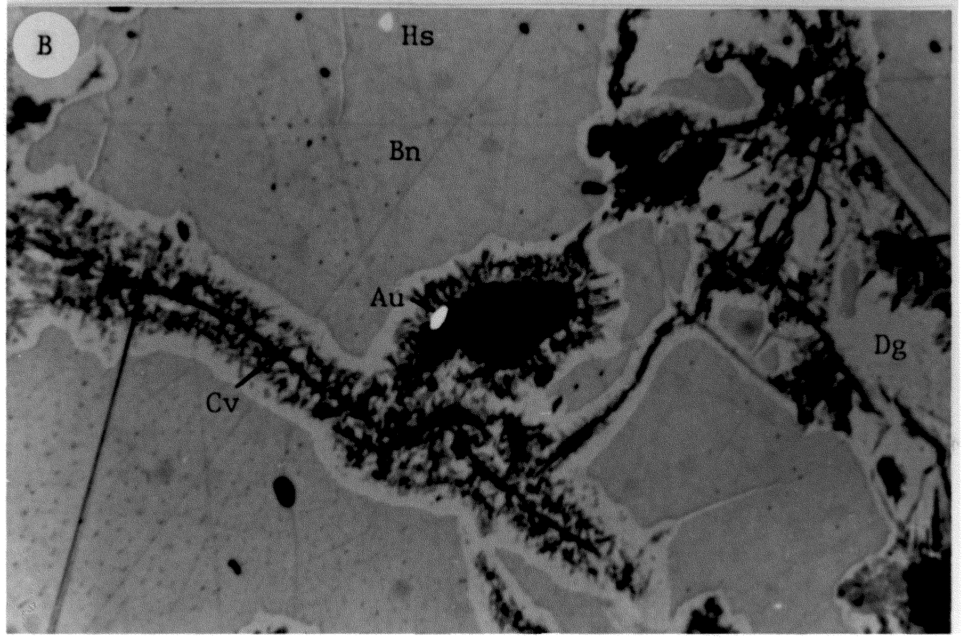
Rutile occurs as finely disseminated blebs in ilmenite associated with titanhematite at the Crenshaw and Daniel's mines.

Malachite ($Cu_2(CO_3)(OH)_2$)

Malachite is the most common supergene mineral of the district, comprising 55% of the total supergene mineralization. It occurs as small druses in cavities, botryoidal crusts and stains on dump rocks and massive or disseminated or as veinlets in the ore. Crystal size may range from <0.02 mm to 1-3 mm. It is always associated with the other common supergene minerals cuprite and covellite. In polished section, malachite generally occurs as radiating sprays of crystals forming a matrix for remnant islands of the hypogene mineralization and other supergene minerals.

Figure 13 : A. Hessite (Hs) blebs in bornite (Bn) and digenite (Dg), sample NEJ 00208 Daniel's mine, VA. 100x f.o.v. 1.05 mm; B. Gold (Au), associated with bornite, digenite, covellite (Cv), and hessite, sample NEJ 00208 Daniel's mine, VA. 200x f.o.v. 0.52 mm.


A
Hs
Bn
Dg


B
Hs
Bn
Au
Cv
Dg

Covellite (CuS)

Covellite makes up approximately 25% of the supergene ores in the Virgilina district. It occurs as corrosion rims on bornite, chalcocite, djurleite, chalcopyrite, and anilite, and as masses replacing the same hypogene minerals, usually in a matrix of malachite. Grain sizes range from less than 0.02 mm up to 0.2 mm. Microprobe analyses indicate that it usually is stoichiometric CuS; however, it may contain up to 0.5 wt % Ag. It is occasionally associated with spionkopite and yarrowite.

Cuprite (Cu_2O)

Cuprite is ubiquitous in the Virgilina district, despite the fact that it comprises only 15% of the supergene ores. It is usually associated with malachite and covellite, occurring in fine-grained masses. Cuprite also occurs in anastomosing and/or dendritic veinlets in bornite and chalcopyrite, with quartz, hematite, digenite, and often chalcocite and djurleite.

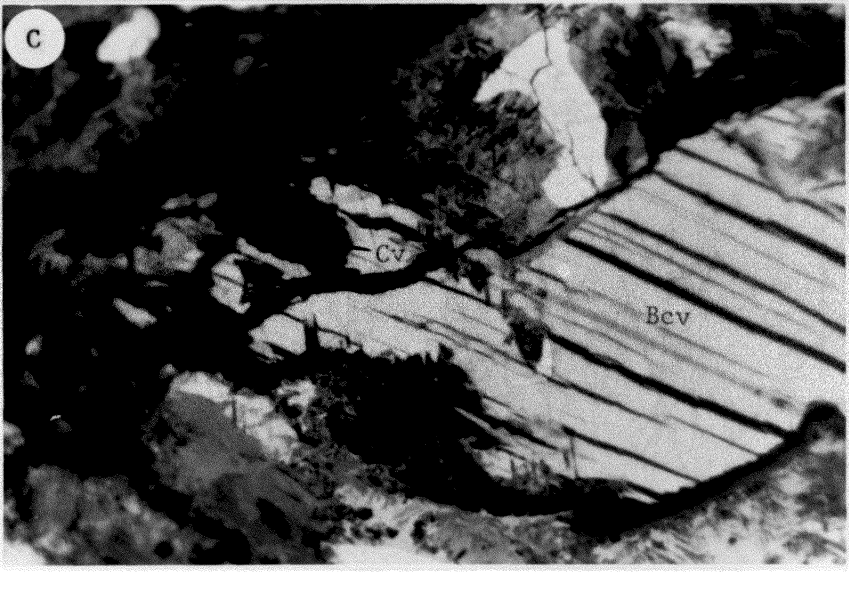
Spionkopite and Yarrowite ($Cu_{39}S_{28}/Cu_9S_8$)

Somewhat uncommon in the supergene ores are spionkopite and yarrowite, the "blue-remaining covellites". They make up less than 1% of the supergene mineralization, although they are distributed throughout the district. Both occur as small (0.008-0.16 mm) grains

Figure 14 : Supergene mineralization: A. Anilite-djurleite (An-Dj) altering to malachite (Mal) and covellite (Cv), sample NEJ 00135 Holloway mine, NC. 100x f.o.v. 1.05 mm; B. Spionkopite and yarrowite (Bcv) psuedomorphous after anilite, associated with supergene chalcocite/djurleite (Cc/Dj), sample NEJ 00081 High Hill mine, VA. 100 x f.o.v. 1.05 mm; C. Spionkopite and yarrowite (Bcv) altering to covellite (Cv), sample NEJ 00122 High Hill mine, VA. 500x f.o.v. 0.21 mm.


A
An/Dj
Cv
Mal


B
Cc/Dj
Bcv


C
Cv
Bcv

associated with covellite, malachite, and cuprite. Spionkopite and yarrowite resemble covellite when viewed in air; however, when viewed in oil-immersion, covellite displays a purplish-red bireflectance, whereas spionkopite and yarrowite remain blue, hence the name "blue-remaining covellites". Microprobe analyses indicate that the blue-remaining covellites examined may consist of either yarrowite, or a mixture of both spionkopite and yarrowite. In addition, up to 0.7 wt % Ag was detected.

Both spionkopite and yarrowite apparently derive from the supergene leaching of copper from anilite (Goble, 1981), and in the Virgilina district always occur as psuedomorphs after anilite. Occasionally, edges of these psuedomorphs are further leached to covellite.

Azurite ($Cu_3(CO_3)_2(OH)_2$)

Azurite is very uncommon in the Virgilina district, occurring only at the Pontiac mine. It is of supergene origin, and generally occurs as microcrystalline sprays or crusts coating rocks on the dumps. Rarely, crystals up to 3 cm can be found (M.L. Miller, personal communication).

CHAPTER V

GANGUE MINERALOGY

The gangue minerals in the Virgilina veins consist of quartz, calcite, epidote, chlorite, potassium feldspar, and plagioclase feldspar, in decreasing order of abundance. The gangue minerals make up the largest portion of the vein mineralogy, as evidenced by the fact that the average run of the mines was only approximately 2-3 wt % copper and 70-75 wt % silica (Laney, 1917).

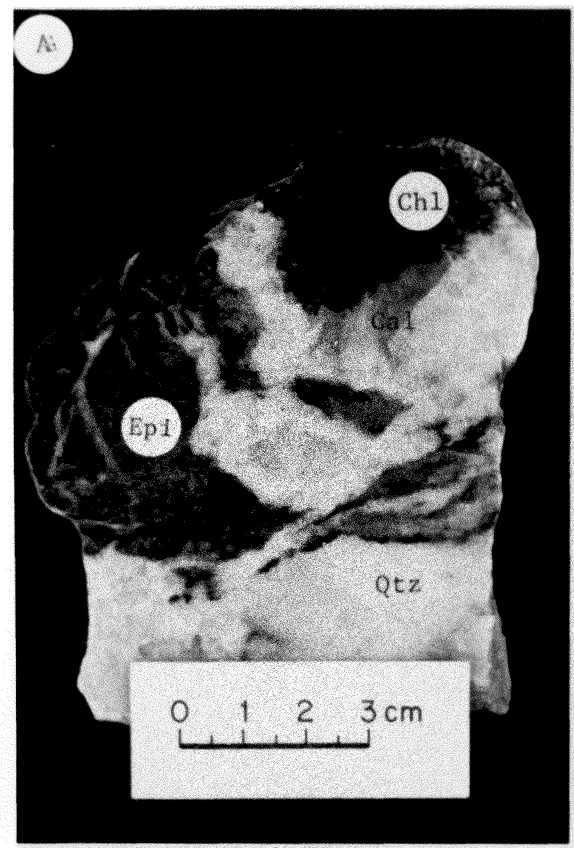
Quartz

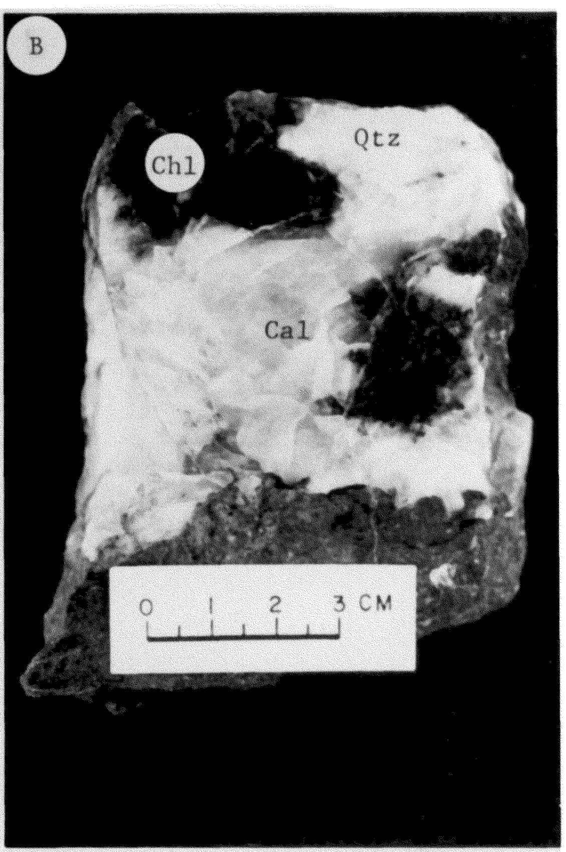
Quartz is the most common gangue mineral, comprising approximately 70% of the veins. It occurs both as singly terminated crystals and as massive vein quartz; overall the crystals make up much less than 1% of the total.

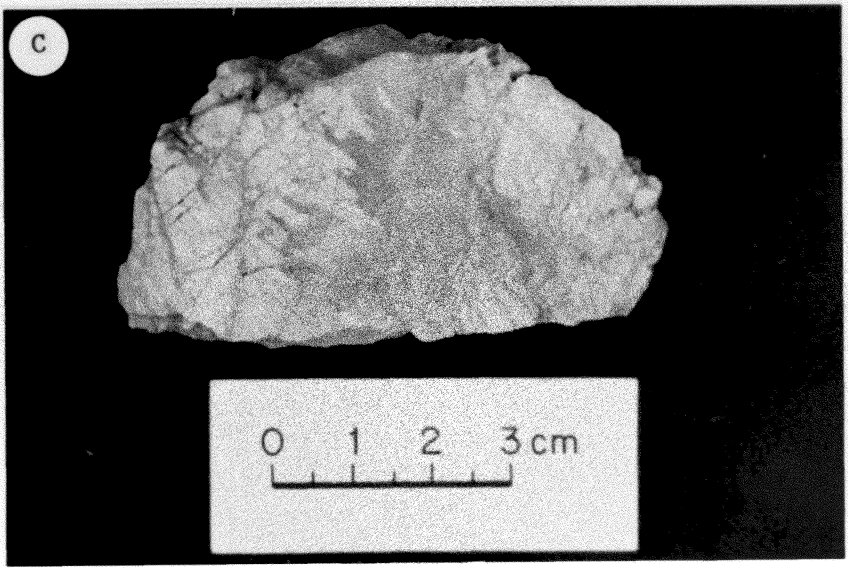
The singly terminated crystals were found in vugs in solid vein quartz, in fracture zones, or on dump material as druses of small (1-3 mm) crystals. They are associated with malachite, limonite, or saprolitic country rock. The vugs were determined to be solution cavities along healed fractures.

The massive quartz is usually of the milky white "bull" quartz variety, although occasional transparent zones can be found. Boundaries between clear and milky quartz are quite sharp, possibly indicating multiple generations of fluids. The ore minerals, however,

Figure 15 : Gangue mineralization: A. Vein quartz, calcite, chlorite, epidote and country rock, sample 248 Littlejohn mine, VA.; B. Vein quartz, calcite, and black chlorite with country rock,sample 114 Wall mine, VA.; C. Vein quartz and microcline, sample 261 Glasscock shaft of Pontiac mine, VA.


A
Chl
Cal
Epi
Qtz
0 1 2 3cm


B
Chl
Qtz
Cal
0 1 2 3 CM


C
0 1 2 3cm

are not preferentially associated with either type of quartz. Both types are highly fractured, and the fractures are usually healed by silica. Fluid inclusions are ubiquitous along these healed fractures. The quartz also often shows recrystallization due to strain, although it is more common in the smaller veins.

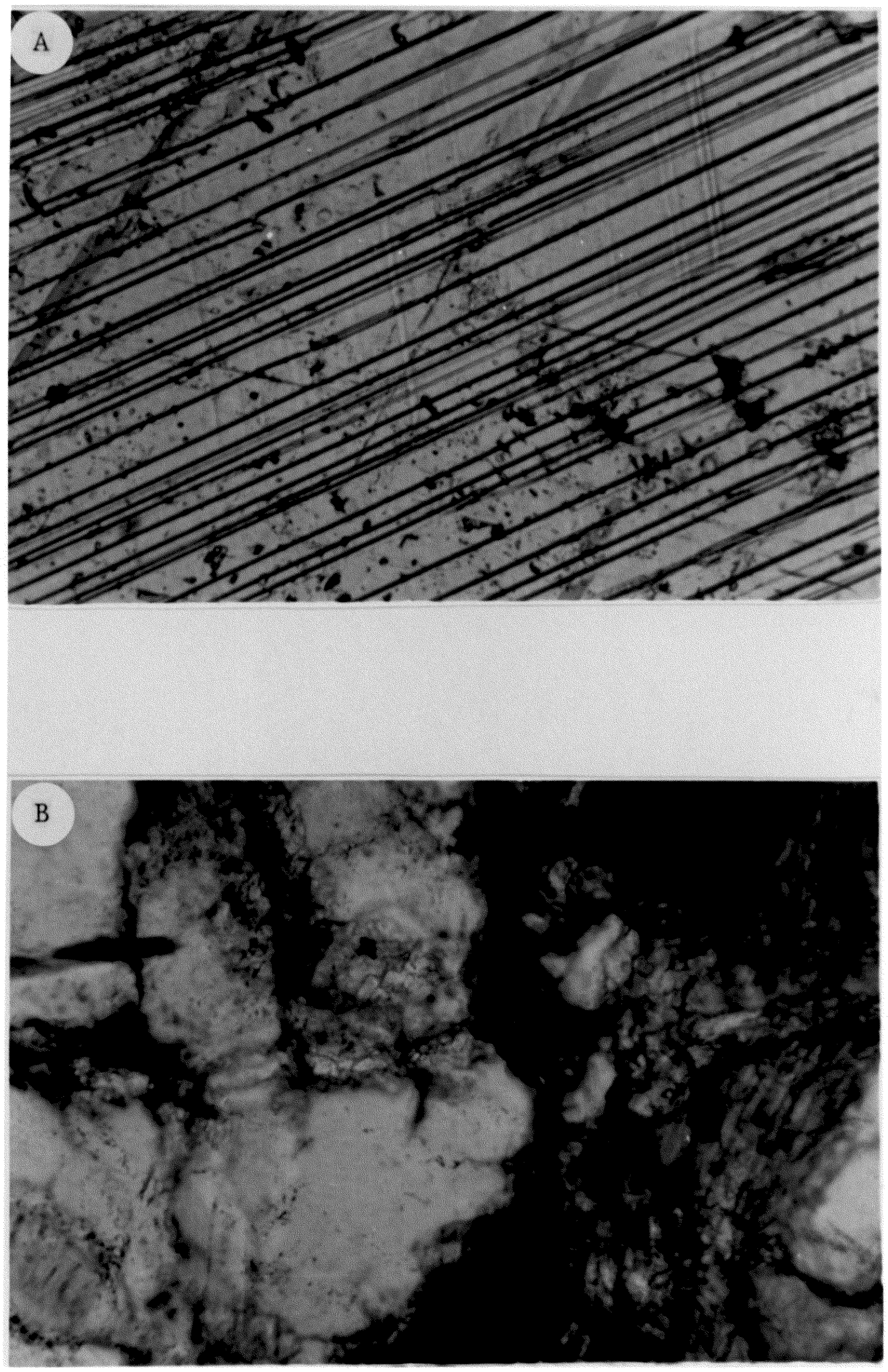
Calcite

Calcite is second in abundance only to quartz, making up nearly 15% of the gangue. Locally however, it can be as much as 50% of the vein. It is massive and ranges in color from clear or white to pinkish or flesh-colored, and is associated with both the clear and milky quartz.

The calcite is fractured much as is the quartz, and the fractures contain fluid inclusions as well, although the inclusions are much less common than in the quartz. Polysynthetic twinning parallel to {012} always occurs, a feature common in calcite that has been deformed.

Calcite from several of the mines, especially the Wall and High Hill mines, fluoresces under ultraviolet light. Analyses of the fluorescent calcites show that they contain appreciable levels of manganese (Table 3). Calcites from other mines range from strongly fluorescent to non-fluorescent, and there is no apparent relationship between degree of fluorescence and mineralization.

Figure 16 : Gangue mineralization in thin section: A. Polysynthetic twinning in calcite, sample NJ 009 Copper King mine, NC. 100x f.o.v. 1.05 mm; B. Polygonized quartz veinlet, sample NJ 025 Anaconda mine, VA. 100x 1.05mm;


A
B

Epidote

Epidote is much less common in the veins than quartz or calcite, and makes up approximately 5% of the total gangue mineralogy. As a vein mineral it occurs as small masses disseminated through the quartz. The most common occurrence of epidote is as a border between the quartz veins and the adjacent, unaltered country rock. Epidote in this location is usually associated with the ore minerals. Ores are either disseminated in blebs and stringers through the epidote or are along a quartz-calcite/epidote interface. In thin section, it is pale greenish-yellow, indicating a composition near pistachite.

Chlorite

Chlorite comprises less than 5% of the gangue mineralogy. It occurs disseminated through the veins either in irregular masses >1 to <50 mm in size , and made up of randomly oriented fibers, or as spheroids 0.1-1 mm in size, consisting of concentric fibers.

The chlorite also occurs in two distinct colors: a medium green, and a dark green-black. The spheroids are nearly always of the green-black variety, and are often intimately associated with the ore minerals. In thin section, the medium green chlorite has a mottled appearance and displays the characteristic anomalous blue interference colors, while the spheres do not. Possibly the green-black variety is a more iron-rich chlorite.

Table 3 : Microprobe analyses of carbonates from the Virgilina district.

Carbonate analyses[*]

Sample	CaO	MgO	MnO	FeO	SrO	Cations
Wall 1237	55.14	0.09	0.32	0.16	0	$Ca_{0.99}\ Mn_{0.01}$
Wall 1237	53.16	0.28	0.45	0.30	0.03	$Ca_{0.98}\ Mg_{0.01}\ Mn_{0.01}$
Wall A	54.88	0.13	0.37	0.15	0.06	$Ca_{0.99}\ Mn_{0.01}$
High Hill 1	55.48	0.01	0.12	0.18	0.03	$Ca_{0.99}$
High Hill 1	55.20	0.03	0.14	0.17	0	$Ca_{1.00}$
High Hill 1	54.57	0.03	0.17	0.23	0	$Ca_{0.99}$
High Hill 1	57.21	0.03	0.11	0.16	0	$Ca_{1.00}$
High Hill 2	55.68	0.35	0.69	0.28	0	$Ca_{0.98}\ Mg_{0.01}\ Mn_{0.01}$
High Hill 2	54.64	0.53	0.78	0.30	0.06	$Ca_{0.97}\ Mg_{0.01}\ Mn_{0.01}$

[*] Data courtesy J.R. Craig

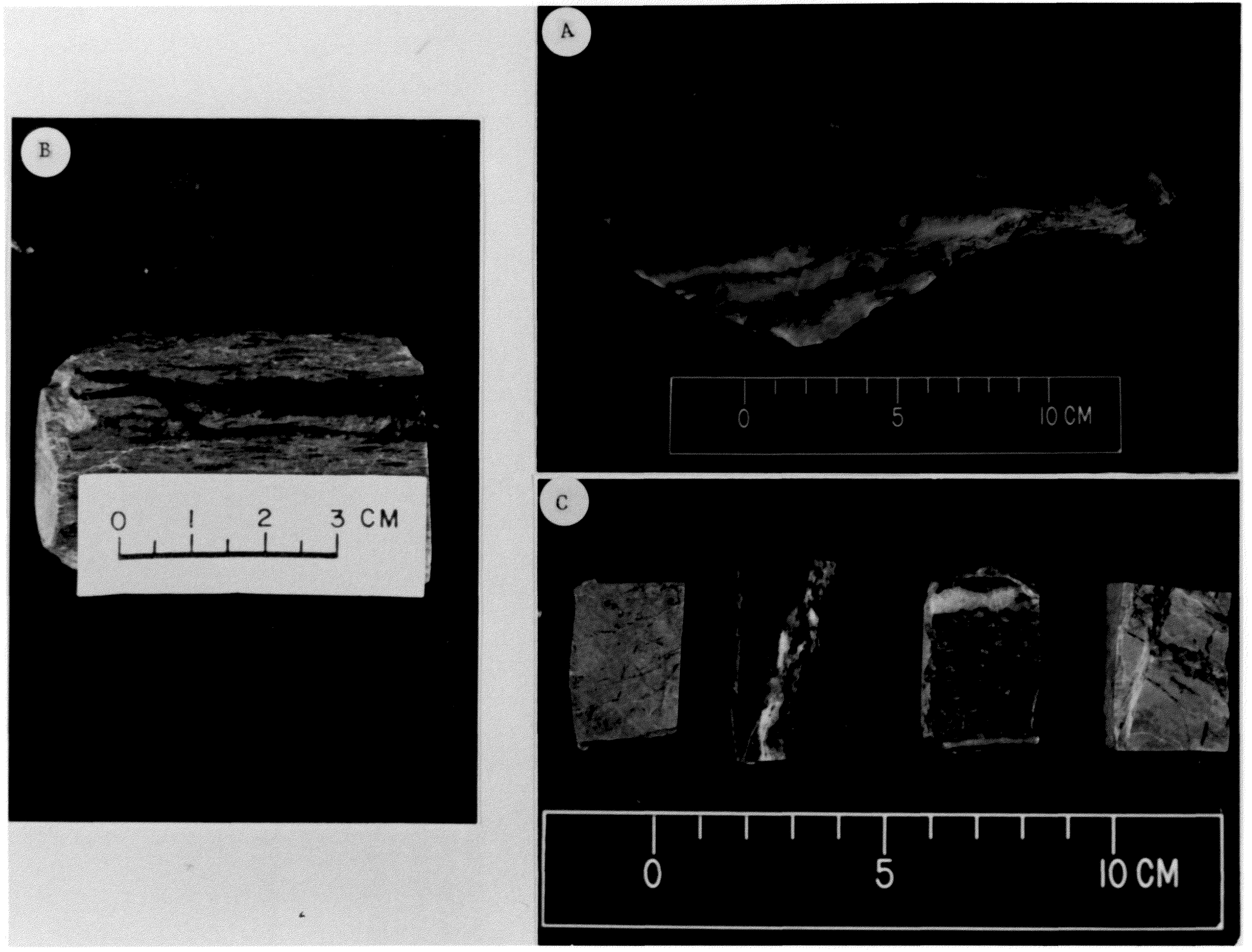
Potassium feldspar

Potassium feldspar is a common but minor constituent of the veins. It occurs as masses 1-25 mm in size or as single crystals 0.05-0.1 mm in size disseminated through the quartz. Feldspar from the Glasscock shaft of the Pontiac mine was found not to display the cross-hatched albite and pericline twinning characteristic of inversion from low sanidine. This indicates that the feldspar formed in the stability field of low microcline, which puts an upper limit of 350°C to 400°C on the temperature of formation.

Plagioclase feldspar

Plagioclase, although common in the country rock, is rather rare in the veins. It occurs as isolated crystals in quartz, usually with an alteration rim of sericite. At the Pandora mine, large (5-10 mm) crystals of plagioclase have been almost wholly altered to epidote and sericite. Laney (1917) determined that plagioclases in the district varied in composition from albite to oligoclase.

Figure 17 : Relations of ore to gangue: A. Mineralization along vein/wall rock boundary, sample 252 Littlejohn mine, VA.; B. Mineralization within wall rock, sample 114 Wall mine, VA.; C. Mineralization along and in wall rock (R to L): 1) Sample NJ 003, Copper King mine, NC.; 2) Sample NJ 050, Littlejohn mine, VA.; 3) Sample NJ 025, Anaconda mine, VA.; 4) Sample NJ 010, Copper King mine, NC.


B
0
1
2
3 CM
A
0
5
10 CM
C
0
5
10 CM

Relations of Gangue to Ore

The ore minerals, as noted previously, occur disseminated through both the veins and the country rock adjacent to the veins. Although often concentrated in zones, the ores display no preferential association with any of the differing gangue minerals, or with clear or milky quartz.

Fragments of country rock, both altered and unaltered are often included in the veins, usually along the vein margins. Ore mineralization is quite commonly associated with these fragments; occasionally it may be disseminated through an individual fragment, but more often it is along the border of a fragment and the vein (Figure 17).

In general, ore mineralization occurs near or at the interface zone of the vein and the country rock. This zone is virtually always altered to epidote or epidote + chlorite. Veins that do not display this alteration halo tend not to be mineralized. This suggests that the metalliferous hydrothermal fluids reacted with the country rock during their traverse. The reaction altered the country rock to epidote and chlorite and caused precipitation of the copper mineralization.

CHAPTER VI

FLUID INCLUSIONS

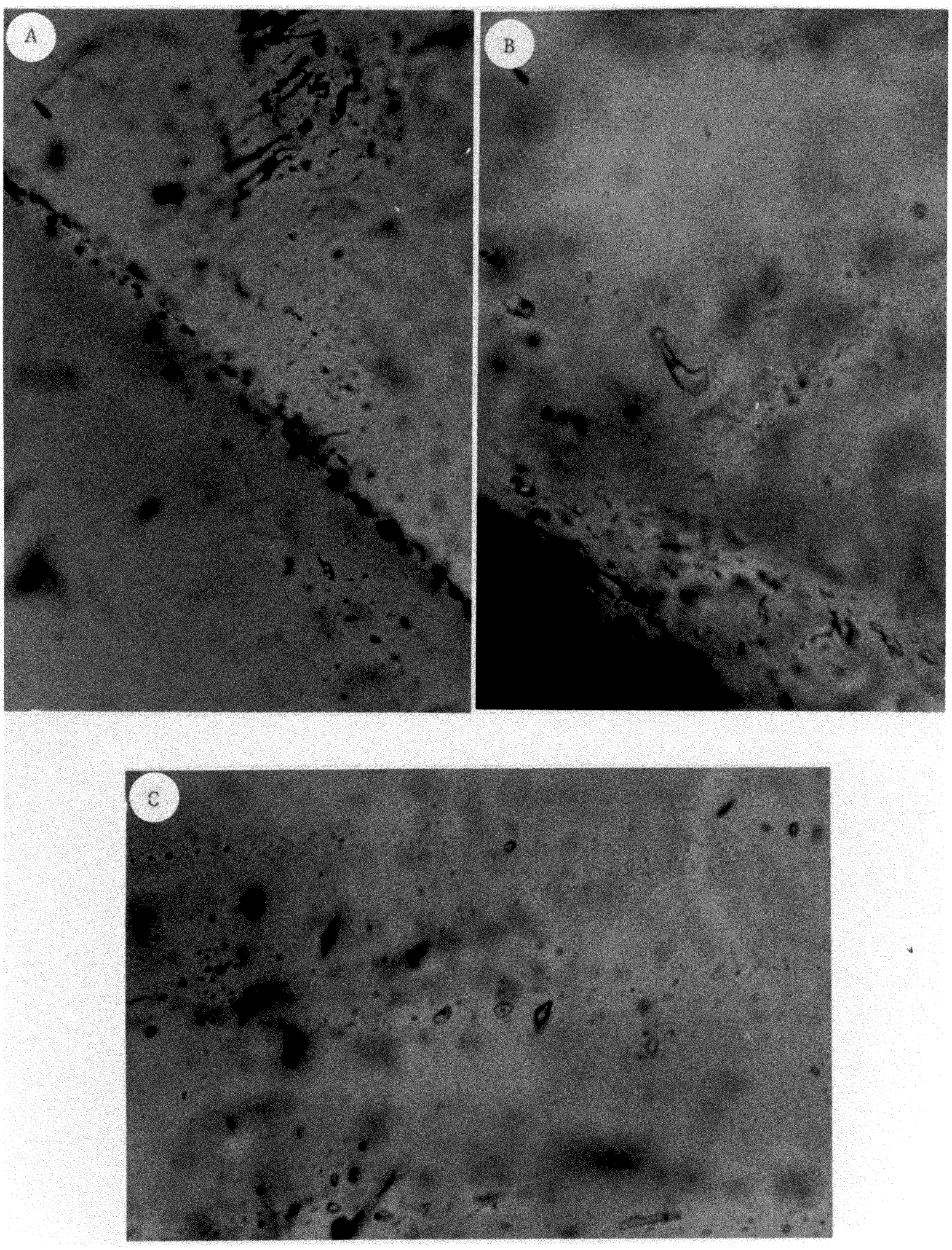
Samples collected from the visited mine sites were examined to determine their suitability for the determination of salinity and homogenization temperatures from fluid inclusions. Most of the vein material in the Virgilina district is milky white "bull" quartz. The milky color is due to submicroscopic inclusions, both fluid and solid. These inclusions are far too small to be of any use. Occasional clear zones in the veins and/or singly terminated quartz crystals generally contain fluid inclusions of useable size, and overall are sufficiently common to prevent the biasing of data.

As previously noted, the singly terminated crystals are associated with fractures, saprolite, and supergene mineralization. This strongly suggests a near-surface origin for these crystals, and they were not processed further.

The clear zones in the vein quartz and calcite were cut into chips and doubly polished by standard techniques (Craig and Vaughn, 1981). Microscopic examination of the the chips was then undertaken to determine their suitability for further work. The clear quartz is highly fractured, and the fractures are usually healed by quartz. The healed fractures in the clear quartz are considerably less transparent than the remainder of the quartz. The clear calcite is similar in association and degree of fracturing to the quartz.

Figure 18 : Fluid inclusions: A. Fluid inclusions along shear plane in quartz, Littlejohn mine VA. 200x f.o.v. 0.52 mm; B. "Necked-down" inclusion in quartz, Durgy mine, NC. 200x f.o.v. 0.52 mm; C. Entrained inclusions in quartz, Copper King mine, NC. 200x f.o.v. 0.52 mm;

C5



Inclusions in the clear quartz and calcite are ubiquitous, ranging up to 65 microns in size, and usually contain vapor bubbles. The major proportion of these inclusions are secondary ones that lie along healed fractures, thereby making them unsuitable as sources of information on the origin of the mineralization. Inclusions that do not lie along apparent fractures show evidence of necking or other deformation, or contain visible fractures in the inclusion walls. Vapor bubbles in adjacent, similarly sized inclusions ranged in size from 0.1% of the inclusion volume up to 20% of the inclusion volume. Occasionally, inclusions can be found that appear primary, but these are often associated with inclusions that are clearly of secondary origin, and are therefore likely to be secondary as well. In no case was an unequivocally primary inclusion located. The abundance of inclusions of that are clearly of secondary origin, combined with the rarity of inclusions that appear primary, suggests that all of the inclusions are secondary.

The fluid inclusion data collected by Ford (1981) on quartz veins in the slate belt of central North Carolina, and Linden (1981) on gold-bearing veins in the Virgilina district show a remarkably wide variation in salinities and homogenization temperatures, a feature often indicative of secondary inclusions. Based on their data, the nature of the veins in the field, and the inclusions observed in this study, fluid inclusion data from the veins in the Virgilina district should be considered suspect.

CHAPTER VII

INTERGROWTHS, TEXTURES, AND PARAGENESIS

Bornite, Chalcocite/Djurleite, and Digenite

Myrmekitic intergrowths of bornite and chalcocite/djurleite or bornite and digenite are the most distinctive microscopic features of the Virgilina ores. The intergrowths, which consist of fine (0.06-0.09 mm) to coarse (0.5-0.7 mm) graphic interpenetrating bornite and chalcocite/djurleite or digenite, were the subject of some of the earliest detailed studies of such features (Laney, 1911; 1917). In all cases observed, the bornite occurs as islands in the chalcocite/djurleite or digenite, and the most common myrmekitic assemblage is bornite + chalcocite.

Laney (1911, 1917), who recognized only bornite and chalcocite, concluded that these intergrowths were the result of simultaneous deposition, a position also held by Ramdohr (1980), who attributes most intergrowths of this type to simultaneous formation. Laney also noted the common presence of chalcocite/djurleite replacing bornite, and attributed this replacement to supergene processes, a conclusion that is grossly at odds with the ore textures. Areas of replacement are optically and chemically homogeneous with hypogene chalcocite/djurleite, and do not resemble either typical leached or enriched supergene ores. The replacement of the bornite by the chalcocite/djurleite is clearly a hypogene feature, albeit a secondary one.

The secondary hypogene replacements are ubiquitous and always associated with the myrmekitic intergrowths. Furthermore, careful scrutiny of the myrmekitic areas indicates that they often occur in embayments in the bornite or that bornite grain boundaries are clearly traceable through the chalcocite/djurleite or digenite. In all cases, the chalcocite/djurleite and digenite are both chemically and optically homogeneous for relatively large areas. Thus, both the myrmekitic and the replacement textures are due to a secondary hypogene process that converted the bornite into chalcocite/djurleite or digenite.

Anilite and Djurleite

The lamellar intergrowths of anilite and djurleite are also a common feature of the ores. They occur primarily at localities such as Cross-cut, Holloway, and Chappell, where the modal percentage of bornite is low (>15%). The intergrowths always occur as lamellae of anilite in djurleite, ranging in size from fairly coarse (0.005-0.02 mm) to submicroscopic. In several cases, submicroscopic lamellae were inferred due to a change in the optical properties of anilite, or an increase in the weight percent copper in anilite detected by the microprobe. The lamellae commonly show folding, or other indications of deformation.

The lamellar intergrowths generally occur adjacent to areas of pure anilite, and in all cases appear to be an intermediate reaction feature from anilite to djurleite. Although the lamellae are usually oriented parallel to sub-parallel in a given field of view, occasionally they have grown in nearby grains that have differing orientations, producing an apparent random orientation of lamellae.

Crystal structure analyses have been performed on both anilite (Koto and Morimoto, 1970), and djurleite (Evans, 1979). Both of the minerals can be considered as based on close-packed arrays of sulfur atoms, with the copper atoms in the interstices. Interestingly however, anilite is based on a cubic close-packed array, while djurleite approximates a hexagonal close-packed array. This leads immediately to the supposition that the intergrowths represent primarily a change in the stacking sequence of the sulfur atoms. This hypothesis was verified by single-crystal precession photographs (Appendix F) which showed that the anilite (011) plane (cubic-close-packed plane) is parallel to the djurleite (100) plane (hexagonal-close-packed plane).

The transition from anilite to djurleite apparently involves both an addition of 0.18 mol % copper and a restacking of the ABCABC.... structure into an ABAB.... structure (Figure 19). The actual mechanism of this transition is not clear.

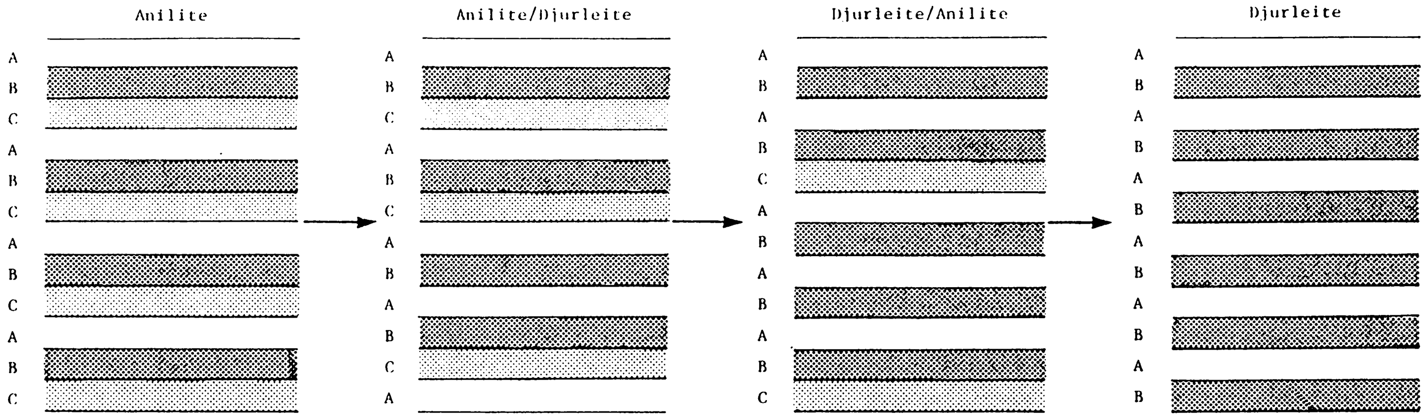


Figure 19 : Schematic view of stacking changes associated with the anilite-to-djurleite transition.

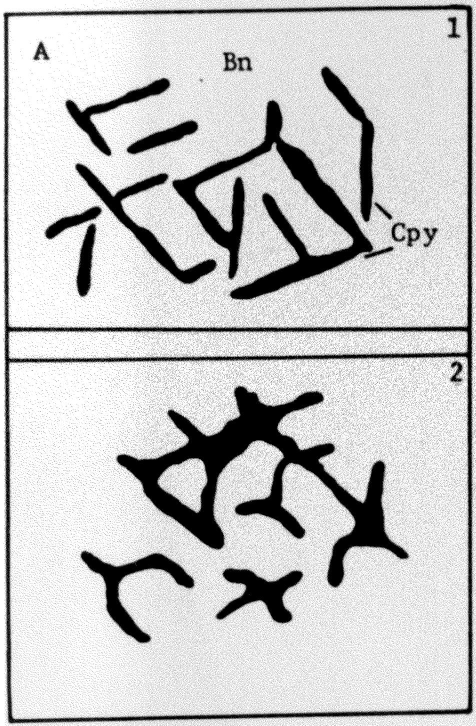
Bornite and Chalcopyrite

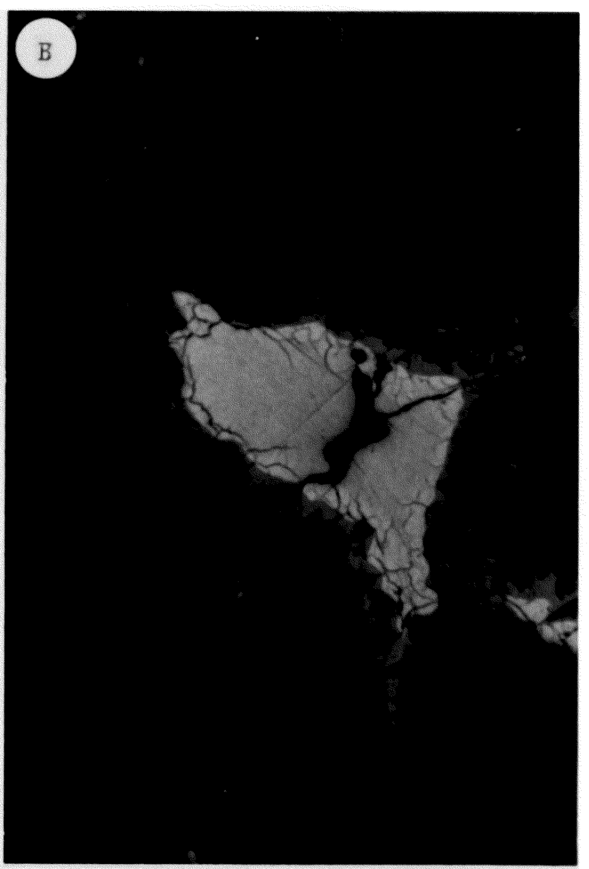
As noted previously, the orange-tinted bornites contain microscopic to submicroscopic lamellae of chalcopyrite oriented parallel to (111) or (100) in the bornite. Such textures have variously been reported as being due to exsolution of the chalcopyrite from the bornite or due to replacement of the bornite by the chalcopyrite (Ramdohr, 1980). The criteria for distinguishing between the two can be seen diagramatically in Figure 20a.

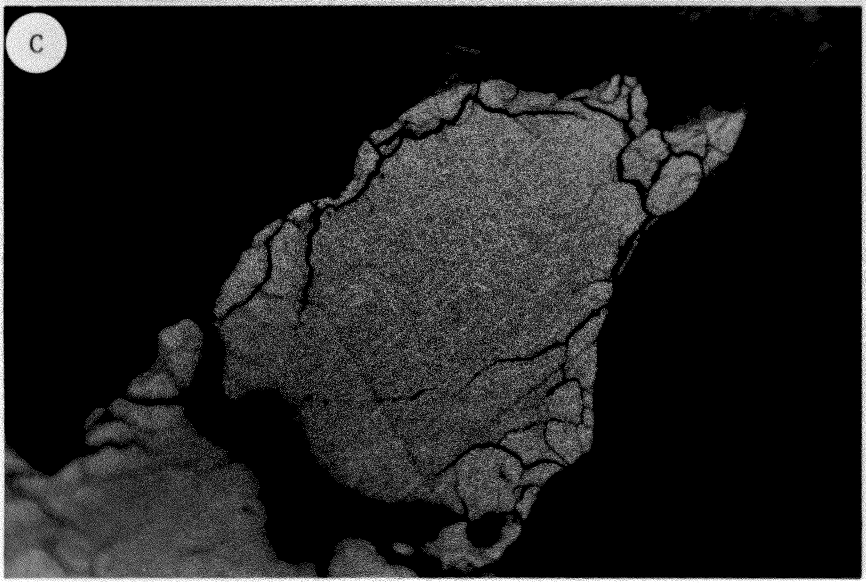
In the case of exsolution, the lamellae tend to taper or pinch out at their intersections; because the exsolved material is derived from the nearby host material, the presence of two lamellae immediately adjacent to one another would deplete the source and cause the intersections to thin. In the case of replacement, the lamellae tend to thicken at intersections, the reasoning being that replacing fluids traveling along given directions in a mineral additively replace the host at a junction.

Most of the intergrowths examined from this district indicate replacement of the bornite by the chalcopyrite. Ramdohr (1980) cautions, however, that these criteria are not wholly unambiguous. In view of this caveat, the determination should only be considered tentative.

Figure 20 : Bornite-chalcopyrite intergrowths: A. Criteria for determining origin- 1) replacement; 2) exsolution (Ramdohr, 1980); B. "orange bornite" microscopic intergrowth of bornite and chalcopyrite, associated with spionkopite and yarrowite (Bcv), and bornite (Bn), sample NEJ 00122 High Hill mine, VA. 100X f.o.v. 1.05 mm; C. same, 500x oil immersion, f.o.v. 0.21 mm.


A
Bn
1
Cpy
2


B


C

Bornite and Chalcocite (kamacite-like)

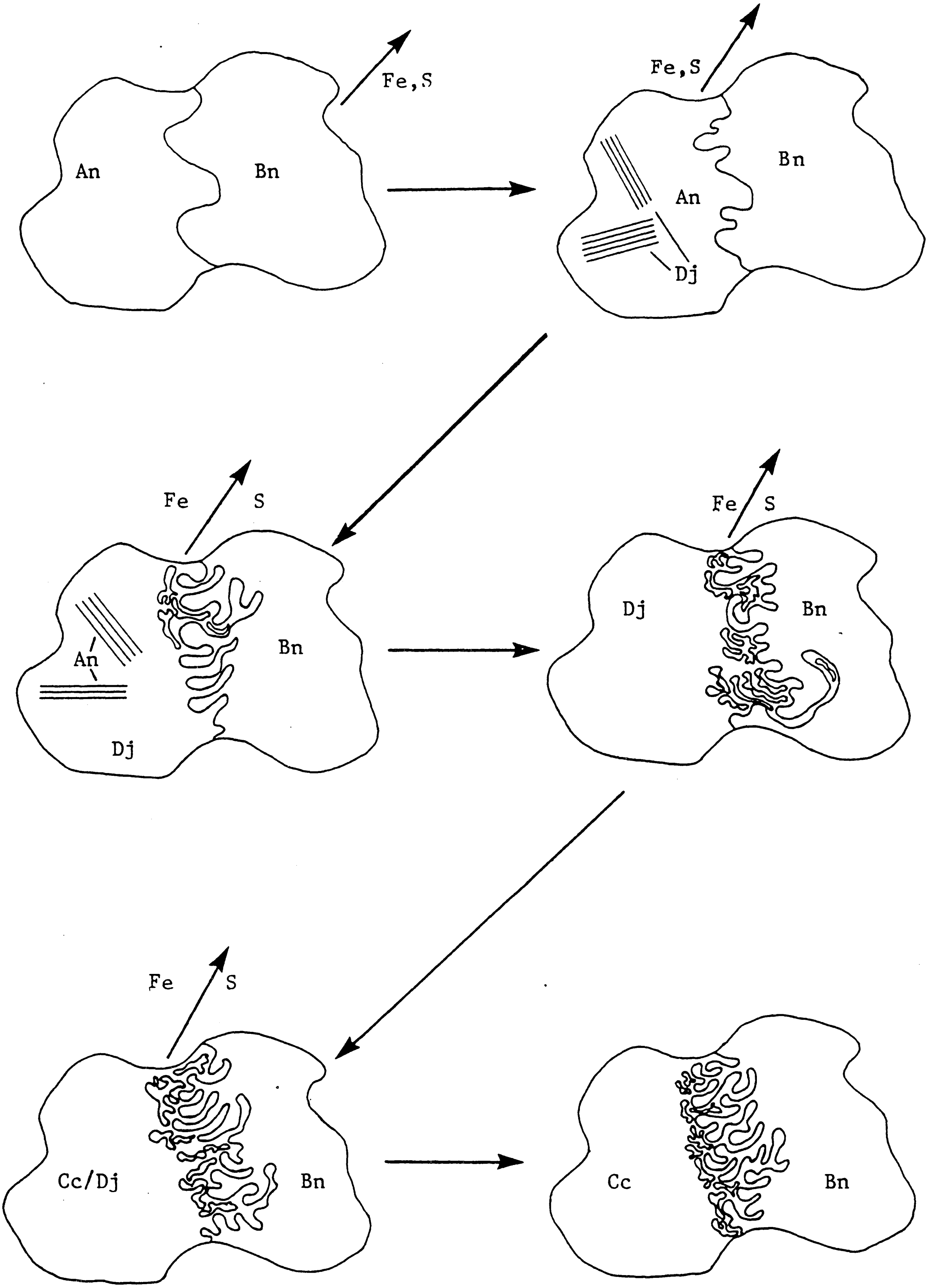
Kamacite-like intergrowths of chalcocite along (111) of bornite are uncommon, but are present in small blebs disseminated throughout the vein quartz. Figure 4B shows such an area from the McNeny mine. Ramdohr (1980, pg. 453) states that, as in the case of the bornite-chalcopyrite lamellae, these intergrowths can be interpreted as either being due to exsolution or due to replacement. The criteria given by Ramdohr is that if the chalcocite-bornite ratio is fairly constant, then the intergrowth is due to exsolution. If the chalcocite-bornite ratio is variable, then the intergrowth is caused by replacement. Observations of these intergrowths tend to indicate that they are of replacement origin, however; in no case is this determination definitive.

TEXTURAL INTERPRETATIONS AND PARAGENESIS

As noted previously, the Virgilina ores can be divided into hypogene and supergene components. The hypogene mineralization can be further classified as being primary or secondary. The major primary ore minerals consist of bornite, anilite, and chalcocite/djurleite, with minor titanhematite and magnetite. The major secondary ores consist of bornite, chalcocite/djurleite, digenite and hematite. In general, the primary ores tend to show reactions to, or with, the secondary ores.

Textural evidence distinctly shows that the assemblage bornite + chalcocite/djurleite has been altered to bornite + chalcocite/djurleite + hematite; the amount of bornite is decreased and the amount of chalcocite/djurleite is increased during this process. The iron in the bornite was apparently oxidized to produce the secondary hypogene hematites. Concommitant with this was a slight loss of sulfur, which thereby increased the copper:sulfur ratio of the minerals, and the composition was altered as shown on the portion of the Cu-Fe-S ternary in Figure 23. The resultant effect was to shift the Cu-S binary phases towards copper (Figure 24). This produces the common replacement and myrmekitic textures. The assemblage bornite + anilite reacts either to bornite + anilite + djurleite + hematite, or to bornite + anilite + digenite; in both cases the amounts of bornite and anilite decreased. Bornites associated with these reactions are distinctly Cu-poor, often by as much as 3 wt %, and the associated secondary hematites are Ti-poor as well.

Figure 21 : Schematic diagrams showing secondary hypogene alteration of sulfide minerals. 1) Transfer of ferric iron to hematite and loss of sulfur from bornite, creating an increase in the copper:sulfur ratio that alters bornite + anilite to bornite + chalcocite. 2) Transfer of ferric iron to hematite or to anilite to produce digenite and loss of sulfur resulting in alteration from bornite + anilite to bornite + digenite. Bn= bornite, An= anilite, Dj= djurleite, Cc= chalcocite, Dig= digenite.


An
Bn
Fe,S
Fe,S
An
Bn
Dj
Fe
S
An
Bn
Dj
Fe
S
Dj
Bn
Fe
S
Cc/Dj
Bn
Cc
Bn

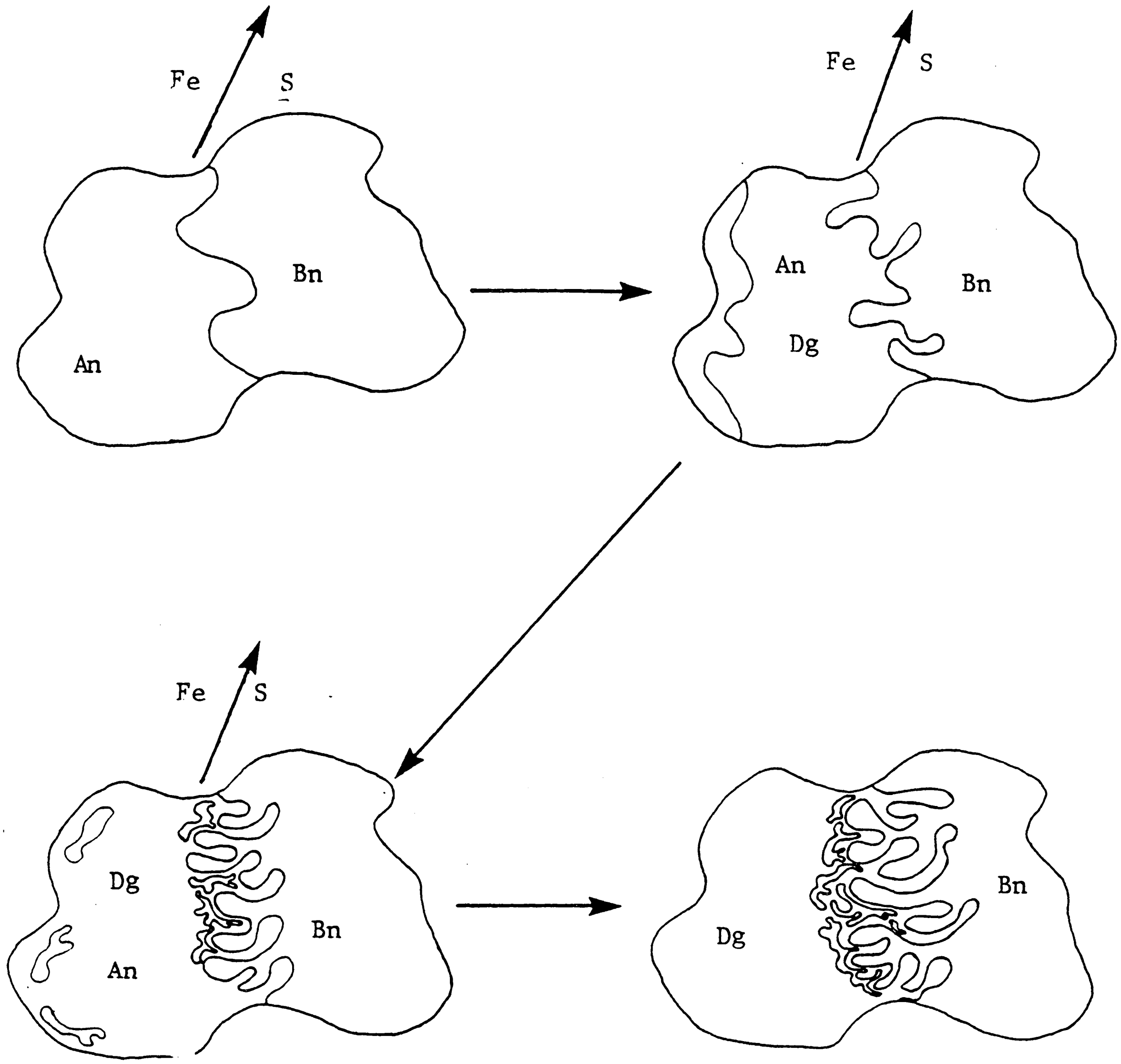

Fe
S
Bn
An
Fe
S
An
Bn
Dg
Fe
S
Dg
Bn
An
Bn
Dg

Figure 22 : Portion of the Cu-Fe-S ternary diagram at 300°C and at 25°C (after Craig and Vaughn, 1981).

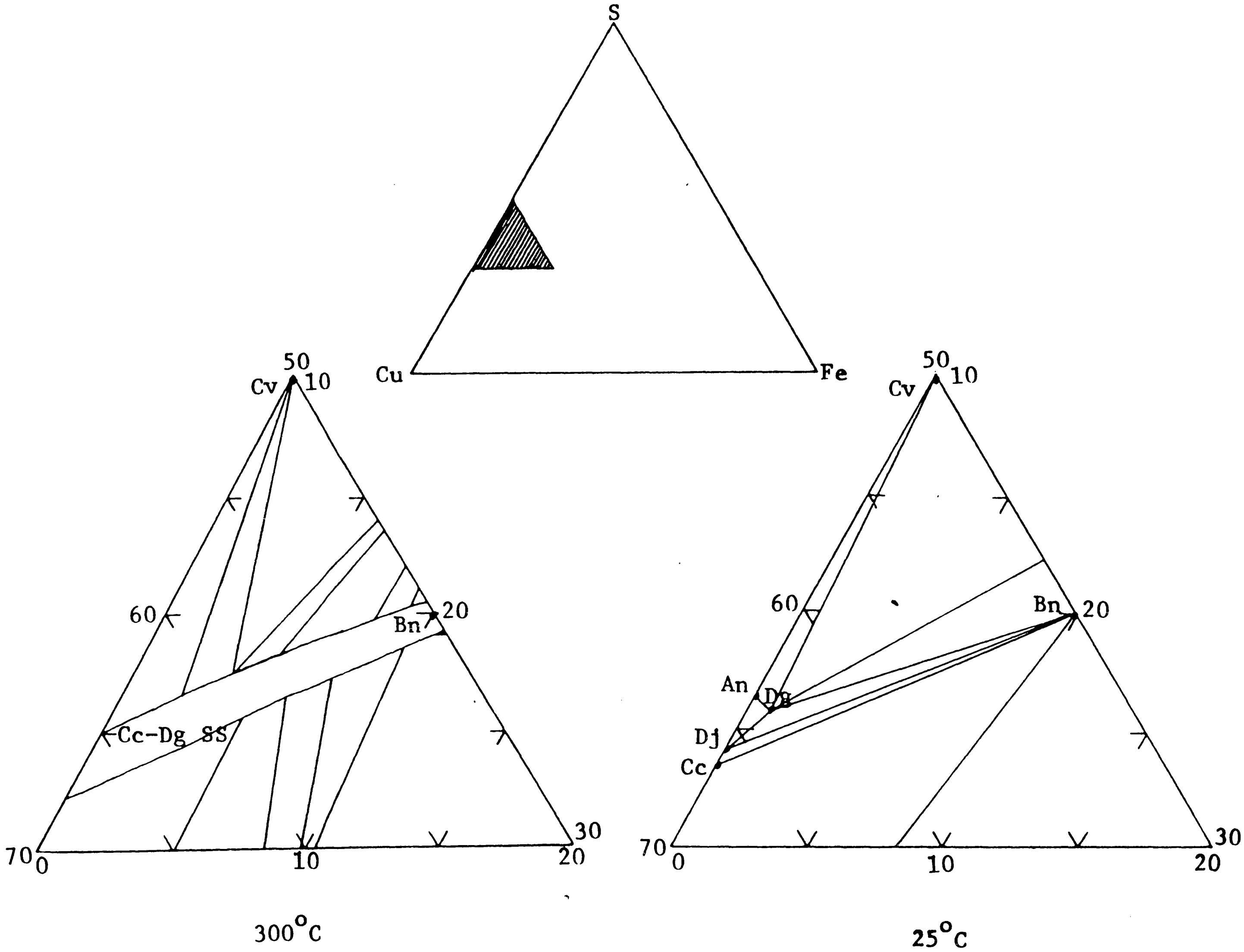
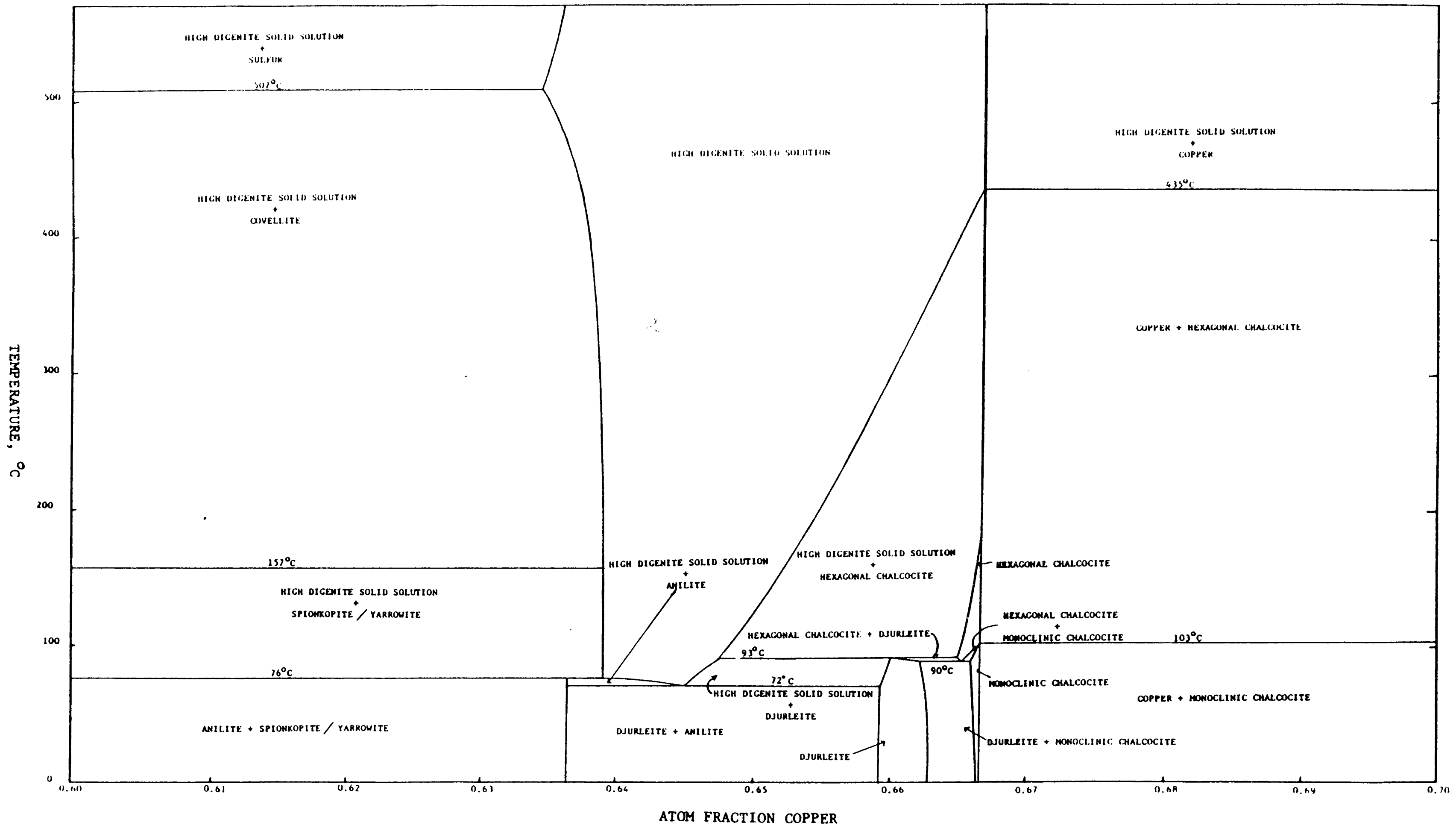

S
Cu
Fe
50
Cv
10
60
20
Bn
Cc-Dg SS
70
0
10
20
30
300°C
50
Cv
10
60
Bn
20
An
Dg
Dj
Cc
70
0
10
20
30
25°C

Figure 23 : Phase relations on the Cu-S binary from 0.60 to 0.70 atom percent copper, after Barton (1973) and Potter (1977).


HIGH DIGENITE SOLID SOLUTION
+
SULFUR
507°C
HIGH DIGENITE SOLID SOLUTION
HIGH DIGENITE SOLID SOLUTION
+
COPPER
435°C
HIGH DIGENITE SOLID SOLUTION
+
COVELLITE
COPPER + HEXAGONAL CHALCOCITE
157°C
HIGH DIGENITE SOLID SOLUTION
+
ANILITE
HIGH DIGENITE SOLID SOLUTION
+
HEXAGONAL CHALCOCITE
HEXAGONAL CHALCOCITE
HIGH DIGENITE SOLID SOLUTION
+
SPIONKOPITE / YARROWITE
HEXAGONAL CHALCOCITE
+
MONOCLINIC CHALCOCITE
HEXAGONAL CHALCOCITE + DJURLEITE
103°C
93°C
90°C
76°C
72° C
MONOCLINIC CHALCOCITE
HIGH DIGENITE SOLID SOLUTION
+
DJURLEITE
COPPER + MONOCLINIC CHALCOCITE
ANILITE + SPIONKOPITE / YARROWITE
DJURLEITE + ANILITE
DJURLEITE + MONOCLINIC CHALCOCITE
DJURLEITE
500
400
300
200
100
0
0.60
0.61
0.62
0.63
0.64
0.65
0.66
0.67
0.68
0.69
0.70
TEMPERATURE, °C
ATOM FRACTION COPPER

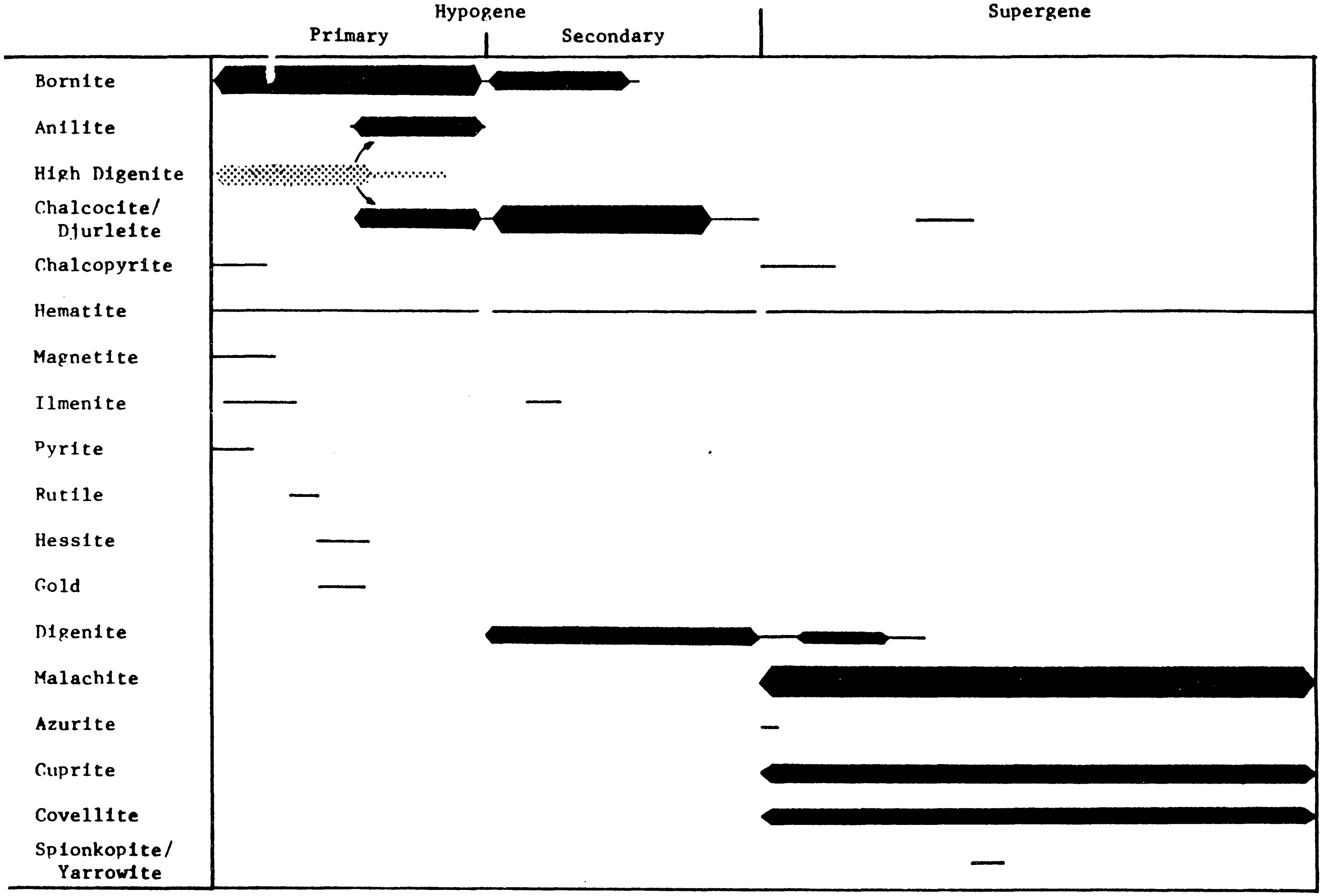


Figure 24 : Paragenetic diagram of the Virgilina district ores.

The bornite and chalcopyrite assemblages tend to show little or no reaction, although the chalcopyrite does give indications of having been annealed. Rarely is this assemblage associated with hematite, and then only titanhematite. The fine intergrowths of chalcopyrite and bornite, considering their appearance and associations, are probably of supergene origin.

These data are interpreted to indicate that the primary ores underwent some sort of reaction subsequent to their formation. This reaction, at a temperature high enough to anneal the primary chalcopyrites, created hematites or digenites at the expense of bornite, and increased the Cu:S ratio of the remaining minerals. This increase resulted in a shift in the bulk compositions of the Cu-sulfides from anilite and djurleite chalcocite, often leaving a Cu-depleted bornite. The final and most common assemblage in the Virgilina ores is therefore bornite + chalcocite. A paragenetic diagram derived from these interpretations is given in Figure 25.

CHAPTER VIII

ORIGIN AND METAMORPHISM OF VEINS

Two models have been proposed for the formation of the copper mineralization of the Virgilina district. In his original work, Laney (1917), attributed the veins and ores to a magmatic hydrothermal source, whereas Stein and Kish (1978) offer evidence in favor of an in situ metamorphic origin for the deposit.

The arguments Laney cites for a magmatic hydrothermal origin are as follows:

1) The veins tend to follow pre-existing faults and/or fractures, often cross-cutting the schistosity.

2) Quartz and potassium feldspar are rare minerals in the surrounding rocks, but common in the veins; with a composition generally approximating andesite, the country rocks are too silica-undersaturated to produce silica-rich veins during metamorphism.

3) The greenstone in which the mineralization occurs was determined to be (to the then-present limits of detection) far too poor in copper to produce copper mineralization.

To obtain the silica, a magmatic source of granitic composition was required. Laney hypothesized that the deposition of the ores was caused by a combination of a decrease in the pressure and temperature during fluid ascent, fluid mixing, and by reaction with the wall rocks.

The evidence Stein and Kish use to argue for a metamorphic origin are:

1) Veins are often present along foliation and are subparallel to major structures.

2) Strained ore and gangue minerals in veins are limited in extent.

3) Metasomatic epidosite bodies are often associated with the veins.

4) The country rock adjacent to the veins is depleted in copper, enriched in lead, and have constant cobalt relative to the other greenstone.

They consider that removal of copper and silica from the greenstone during metamorphism to form the veins and ores produced the epidosite bodies.

Difficulties are encountered with either model. Laney's three arguments can be discounted, in view of the current body of geologic knowledge. Stein and Kish understate the degree of deformation of both ore and gangue minerals, but overstate the amount of epidote surrounding the mineralized veins. The veins contain fragments of the metamorphosed country rock, often with the schistosity of the fragments at an angle to the regional schistosity. Veins also follow fractures that cross-cut the schistosity at acute angles; fractures developing during a regional metamorphic event would tend to be perpendicular to the schistosity.

Whole rock geochemical analyses (F. LeSure, personal communication) indicate that the copper mineralization occurs in rocks with high nickel and chromium contents, or fairly mafic rocks, and the gold mineralization in rocks with lower nickel and chromium contents, or more felsic rocks. Fluids traversing fractures in the Virgilina formation probably reacted sufficiently with the rocks to deposit large quantities of ore, whereas fluids entering the Hyco and Aaron did not. This may imply a silicic source for the fluids, because these hydrothermal fluids would react vigorously with mafic wall rocks. The district contains plutons ranging in composition from granite to gabbro, and several are apparently granodiorite to quartz diorite, the typical compositions of plutons associated with porphyry copper deposits. However, a direct plutonic source is not evident, and the orientation and parallel natures of the veins does not suggest a link to any known intrusive body.

Alternatively, a deeper, metamorphic source could supply the mineralizing fluids. The release of the directed stress of regional metamorphism could produce hydrofracturing in the country rocks. This could provide conduits of the observed orientation for the associated fluids, and potential sites for the deposition of the copper.

The presence of disoriented schistose wall rock fragments within the veins indicates that they formed after the peak of metamorphism, but the presence of numerous deformation features indicates that they formed before the end of deformation. In summary, although the veins clearly have a source outside the country rock in which they are now present, the original source of the mineralizing fluids cannot be definitively determined at this time.

CHAPTER IX

SUMMARY OF FINDINGS

An investigation of the ore and gangue mineralology of the copper vein deposits of the Virgilina district has identified several ore minerals not previously reported from the area. In addition, examination of the paragenesis and the complex intergrowths of the ore minerals has shed light on the history of the veins. The hypogene ore mineralogy of the veins, in decreasing order of abundance, consists of bornite, chalcocite/djurleite, anilite, digenite, hematite, chalcopyrite, pyrite, magnetite, ilmenite, rutile, hessite, and gold. The supergene ore mineralogy, in decreasing order of abundance, is malachite, covellite, cuprite, digenite, hematite, chalcopyrite, chalcocite/djurleite, and spionkopite and yarrowite.

The present study is the first to identify anilite, djurleite, hessite, spionkopite, and yarrowite in this district. In light of the active precious metal exploration in the Appalachians, the discovery of hessite and associated gold may be economically significant. The newly reported copper sulfide phases have potential value not only for their copper contents, but also for the trace amounts of silver which they contain.

The lamellar intergrowths of anilite and djurleite, the presence of coexisting chalcocite and djurleite, and the gradual transition from anilite to digenite have heretofore not been reported in the literature on natural copper sulfides. Morimoto et al., (1969) mention the presence of epitaxial intergrowths on anilite and djurleite, but the present study presents the first observation of these lamellar intergrowths as an intermediate stage of reaction between anilite and djurleite. These intergrowths may represent intermediaries in much the same sense that non-classical biopyriboles such as jimthompsonite and chesterite (Veblen and Burnham, 1979a,b), are intermediaries between amphiboles and micas.

Djurleite has been recognized as a mineral distinct from chalcocite since 1962 (Morimoto, 1962; Roseboom, 1962). However, its extreme similarity to chalcocite has precluded identification of it except by careful powder diffractometry. In fact, the desciption of djurleite in one of the most widely used references on ore microscopy (Uytenbogaart and Burke, 1971) is given as "very similar to chalcocite". The discovery of the two minerals coexisting allows for the collection of absolute and comparative reflectance data, which can be used for simpler identification of the two than is now possible.

Since the discovery of anilite in 1969 (Morimoto et al.), there has been considerable uncertainty over the relations of anilite and digenite, as well as the low temperature Cu-Fe-S ternary phase relations (Craig and Scott, 1974). Morimoto and Koto (1970) and Morimoto and Gobuyo (1971) found that digenites were only stable at low temperatures if they contained approximately 1 wt % Fe in the structure. Microprobe analyses of anilite that is altering to digenite in the Virgilina district indicate a gradual increase in iron content along the Cu_7S_4 - Cu_9S_5 pseudobinary, possibly representing a solid solution. This gradual increase agrees with the phase relations determined by Kullerud (1960), but seems to contradict the experimental findings of Morimoto and Gyobu (1971).

The copper-bearing veins of the Virgilina district formed after the peak of regional metamorphism but prior to the termination of deformation. The fluids and the metals were likely derived, at least in part, from the metamorphosed mafic rocks of the area.

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APPENDIX A

MINE AND PROSPECT LOCATION, DESCRIPTION, AND HISTORY

This appendix contains: 1) The locations of and directions to the 28 mines and prospects located in this study; 2) Brief descriptions of the sites, including any shafts, pits, trenches, and/or dumps noted, along with hand sample descriptions of the ore and country rock; and 3) available information on the histories of the sites. The sources of this information are: Carpenter (1976), Laney (1917), Luttrell (1966), Sweet (1976), Watson (1902, 1907), and Weed (1911).

Abbott and Esther Mae prospects

The Abbott and Esther Mae prospects are in southeast Halifax county, Virginia, in the southwest quarter of the Virgilina 7.5' quadrangle. To get to the Esther Mae prospect, travel 91 meters east on VSR 602 from the intersection of VSR 602 and 737, then 41 meters south of the road. The Abbott prospect is about 137 meters S 30 E of the Esther Mae.

Sweet (1976) described the Abbott site as a shallow 3 by 2 meter pit with a small rim dump of greenstone schist and quartz with malachite staining, and the Esther Mae as a small water filled shaft with a rim dump of greenstone schist and occasionally sugary and vuggy quartz with some malachite staining; no outcrops were seen at either site. In 1982 the conditions were virtually unchanged.

Laney (1917) considered the Esther Mae as being on the main Seaboard vein, but did not mention the Abbott in his text. However, the Abbott, but not the Esther Mae appears on his map. The Esther Mae is described as having ore "similar in all respects" to that at Seaboard. Luttrell (1966) listed the Abbott as having bornite in quartz.

Anaconda mine

The Anaconda mine is in southeast Halifax county, Virginia, in the southeast quarter of the Virgilina 7.5' quadrangle. To get to the mine, travel 80 meters south on VSR 734 from the intersection of VSR 734 and 735. The mine is 40 meters off the left (east) side of the road in a fenced-in pasture.

According to Sweet (1976), the site consisted of a dump 6 meters in diameter and 1 meter high containing light green schist with malachite staining and quartz fragments with some hematite stains. Some dump material was used locally for road building. About 25 meters west of the dump was a low spot in the pasture, possibly corresponding to a shaft. No outcrops were seen. Little change had occurred by 1982.

Laney (1917) provides little information, the mine having been closed for several years prior to his research. Weed (1911) described the ore as "a mixture of glance and gray copper in quartz", and stated that the epidotized greenstone contained a 5-10 cm wide vein with a mineralized zone 2-7 cm wide.

Barnes mine

The Barnes mine is in southwest Charlotte county, Virginia, in the northwest quarter of the Buffalo Springs 7.5' quadrangle. To get to the mine, travel 1.1 km southwest on a gravel road that intersects VSR 632. The mine is 483 meters off the right (north) side of the road.

According to Sweet(1976) there was a 5 meter deep caved shaft, a 4 meter diameter water filled pit, several cuts in the hillside to the northeast, and a large dump of greenstone schist and white quartz with bornite, chalcocite, and malachite on the site in 1976. In 1983, the conditions were unchanged.

Laney (1917) stated that during nearby prospecting work in 1880 or 1881, a shaft was discovered that was 17 meters deep with a 9 meter long drift at the bottom leading to a chamber 26 meters long, 5 meters high, and 5 meters deep; the floor was 11 meters below the drift. At either end of the chamber was a pit, one 11 meters deep, the other 7 meters deep. Rumors at that time indicated it was opened and worked between 1700 and 1750.

The country rock is greenstone schist, the schistosity of which strikes N 30 E and dips 70-80 SE. The vein of quartz, epidote, and calcite follows the schistosity, varies from a few centimeters to 1-1.5 meters in width, and contains ore of bornite and chalcocite, with small amounts of gold and silver.

Baynham mine

The Baynham mine is in southeast Halifax county, Virginia, in the southeast quarter of the Omega 7.5' quadrangle. To get to the mine, travel 0.64 km east-southeast on VSR 601 from the intersection of VSR 601 and 714. The mine is 885 meters off the left(north) side of the road.

Sweet (1976) listed the site as having two caved pits about 12 feet deep, and a small dump of greenstone schist, epidote, and white quartz with bornite and chalcocite in 1976. The site was unchanged in 1983, however, no sulfide mineralization was seen.

Laney (1917) described it similarly: a caved shaft, surrounded by a small dump of schistose greenstone and minor vein material of quartz, epidote, chlorite, and bornite and chalcocite. The mine had been abandoned long prior to his work, and no data on its operation was obtained.

Blue Wing mine

The Blue Wing mine is in northwestern Granville county, North Carolina, in the southeast quarter of the Virgilina 7.5' quadrangle. To get to the mine, travel 1.2 km west-northwest on NCSR 1332 from the intersection of NCSR 1332 and 1331 to the Blue Wing Baptist Church. From the east entrance of the parking lot, 15 meters from NCSR 1332, is an abandoned dirt road that trends N 25-30 degrees E. Follow this road for 524 meters to a clearing; at opposite edges are the No. 1 and 2 shafts.

According to Carpenter (1976) in 1966 there were three or four shafts in a line trending N 12 E, the southernmost caved to within 4 meters of the surface, the others apparently open, with a dump to the west covering 0.2-0.4 hectare. He described the country rock as a chlorite-quartz-mica schist that was originally rhyolitic/andesitic lava or tuff, with schistosity striking N 30 E and dipping 60-70 SE. There were stringers of quartz, calcite, and chlorite noted, as well as the main quartz vein. The dump contained gangue of quartz, calcite, feldspar, chlorite, sericite, and limonite after pyrite, and ore of bornite and chalcocite with minor malachite and cuprite. On the west side of the dump was a pile of massive sulfide ore containing quartz disseminated through massive pyrite, pyrrhotite, and possibly chalcopyrite. Considering the dissimilarity of this material to that of the dump and of the district, it seems likely that it was not obtained from the mine.

In 1982, using the map provided in the Bureau of Mines report (Newberry, et al, 1948), four shafts pit were located, all roughly on a line trending N 12 E and extending for about 460 meters. This corresponds with the shafts/pits described by Laney (1917). The No. 1 shaft is at the north edge of the clearing, and consists of a 11 meter wide, irregularly shaped, water-filled pit with a small dump to the east. The No. 2 shaft is a 9 meter wide pit with some wood framing still visible inside. Nearby are a small, water filled pit, some concrete foundations, and railroad rails. The large dump surrounding the pits has been bulldozed to the edge of the clearing. The No. 3 shaft is an

8 meter wide pit with a small rim dump of barren quartz and country rock, and the Spring shaft is a 3 x 5 meter wide water filled pit with a small overgrown rim dump.

Laney (1917) does not mention when copper was first located at Blue Wing. The mine apparently operated on a somewhat infrequent basis from 1895 to 1910 when it finally closed. The No. 1 shaft was only a prospect shaft sunk about 15 meters and then abandoned. The No. 2 shaft was the main shaft, 110 meters deep with levels at 28, 45, 64, and 81 meters, and total drifting of about 520 meters. Only exploratory work was done below 81 meters. The No. 3 shaft was sunk to about 38 meters, connecting to No. 2 at the 28 meter level, and the Spring shaft was also only a prospect, it being about 31 meters deep.

The vein Laney considered to be a fissure vein, varying from 0.5-2 meters in width and averaging about 1.25. It tends to follow the schistosity locally, but overall trends slightly more to the north. There were two distinct ore shoots in the mine proper, one at the No. 2 shaft, and another about 46 meters north near a diabase dike, both pitching about 65 degrees S. Indications were then that they would both persist below the workings. Two other shoots are mentioned: one at the Spring shaft and another about 400 meters south of the Spring shaft. The Spring shaft shoot was similar to the main two, but the other had more hematite than copper.

The country rock is greenstone schist, porphyritic in places and amygdaloidal in others, representng andesitic lavas and/or tuffs. It varies in color from dark green to purplish grey, the schistosity striking N 20-30 E and dipping 70-80 SE. A diabase dike about 5 meters wide intrudes the property, and cuts the vein about 46 meters north of the main shaft. It strikes N 35 W, dips 65 SW and postdates both the vein and the ore.

The gangue mineralization consists of quartz, calcite, chlorite, epidote, and hematite; also common in the veins are fragments of the country rock. The ore minerals are bornite, chalcocite, malachite, and argentite(?) and are usually disseminated, often occurring in the wall rock or at the vein-wall rock contact. Laney indicated that there was little or no supergene enrichment.

Work done by the Bureau of Mines in 1942 (Newberry, et al, 1948) consisted of 112 meters of bulldozer trenching, a 194 meter deep diamond drill hole, and a resistivity survey. Trenching south of the mine located the vein. To the north, flooding prevented further work. The vein width is not mentioned. The drill hole intersected a 1.2 meter wide vein in the hanging wall, but did not intersect the main vein. Indications from the geophysical survey were only of the two veins, and no others were found in the footwall for 2.4 km.

Chappell mine

The Chappell mine is located in southeast Halifax county, Virginia, on the extreme west edge of the southwest quarter of the Buffalo Springs 7.5' quadrangle. To get to the mine, travel 0.64 km down VSR 853 from the intersection of 853 and U.S. 59 to a private drive on the left (west) side of the road. Travel 0.56 km to the end of the private drive. The mine site is on a straight line from the end of the road, about 90 meters west across a small clearing and just into the forest.

According to Sweet (1976), in 1976 there were two shafts present: one about 6 meters in diameter and about 6 meters deep, and a second further to the south about 3 meters deep and water filled. There were also several small pits , a trench, and several dumps. In 1982, there was little change. The wall of shaft No. 1 is weathered greenstone schist with schistosity striking north and dipping 65 SE. A 1.5 meter thick quartz vein in the wall strikes N 5 W and is vertical. Both shafts have dumps of greenstone schist and quartz with visible malachite, bornite, and chalcocite, some of which has been used for local road material.

Laney (1917) listed shaft No. 1 as being 17 meters deep with about 8 meters of drifting, and No. 2 as 26 meters deep with 30 meters of drifting. He also stated that the vein was narrow but well mineralized.

Copper King mine

The Copper King mine is in northeastern Person county, North Carolina, in the northeast quarter of the Triple Springs 7.5' quadrangle. To get to the mine, travel 122 meters along a dirt road that trends N 10 W from the intersection of NCSR 1557 and 1542, then 114 meters N 45 E to the mine, which is in a very small clearing on the bank of a small intermittent stream.

According to Carpenter (1976), the site consisted of a single caved shaft full of dump material in 1966. He desribed the country rock as a chlorite sericite phyllite with common stringers of epidote, calcite and quartz, as well as slickensides with copper oxide prominent on the surfaces. There was no change by 1982.

Laney (1917) stated that the prospect was a single shaft about 30 meters deep with a small drift sunk in highly epidotized greenstone with quartz in irregular masses, lenses, and stringers. There is apparently no distinct vein, and the ore minerals bornite, chalcocite, klaprothite(?), malachite, azurite, cuprite, and chalcotrichite are intimately associated with the gangue of epidote, quartz, calcite, chlorite, plagioclase, and hematite. Laney also reported well terminated albite crystals nearly 25 mm long and more than 6 mm thick embedded in massive sulfides.

Copper World mine

The Copper World mine is in northeastern Person county, North Carolina, in the northwest quarter of the Triple Springs 7.5' quadrangle. To get to the mine, travel 1.9 km north on NCSR 1542 from the intersection of NCSR 1542 and 1556 to where a powerline crosses the road. Follow the power line for 1423 meters southeast. The mine is 38 meters north of the cut for the line.

According to Carpenter (1976), the property contained two water filled shafts in a chlorite phyllite that had malachite staining in fractures. Quartz and calcite stringers cross cut the country rock and the mineralization consists of chalcocite, malachite, and cuprite in quartz. Only a small amount of dump material remained on the site. By 1983 the site was unchanged.

Laney (1917) stated that the mine apparently was on the strike of the Gillis vein, implying that the two were on the same vein. The vein does not crop out, but is similar to others of the district, containing quartz, epidote, calcite, and chlorite as gangue and bornite, chalcocite, malachite, tenorite, and cuprite as ore. The only information on operation of the mine is from Weed (1911, pg. 463), who said that the mine was opened in 1882 and a 18 meter deep shaft was sunk with drifts at 9 and 18 meters.

Crenshaw mine

The Crenshaw mine is in eastern Charlotte county, Virginia, in the southeast corner of the Eureka 7.5' quadrangle. To get to the mine, travel 2.6 km north-northeast on a fire road from its intersection with VSR 623. The mine is 800 meters off the right (east) side of the road.

Sweet (1976) listed the site as containing a 8 meter diameter pit with an exposure of greenstone schist striking N 55 E, and dipping 80 SE, a 2 meter diameter water filled shaft, a small trench, and a large dump. In 1983 the site was unchanged.

Laney (1917) described several prospect pits on a narrow, well-defined vein that follows the strike of the greenstone schist, and that copper staining as well as sulfides were seen.

Cross-Cut mine

The Cross-Cut mine is in northeastern Person county, North Carolina, in the southwestern quarter of the Triple Springs 7.5' quadrangle. To get to the mine, travel 0.64 mile on NCSR 1555 from the intersection of NCSR 1555 and 1542. On the right (north) side of the road there is an overgrown, sunken road trending N 5 E. Follow the road for 533 meters to the second intermittent stream, then up the stream approximately S 55 E for 46 meters to outcroppings of rock in the stream bed.

Carpenter (1976) stated that the shaft in the bed of the stream was filled to within 4 meters of the surface in 1966 and that numerous small pits were to the southwest. In 1982-83 there were three small openings including the shaft located in the stream bed, along with large amounts of dump material both in the stream and on either side.

According to Laney (1917), this was only a prospect. The main shaft was sunk to a depth of 21-24 meters on a meter wide vein trending N 40 W. The country rock is a sheared andesitic tuff with schistosity trending N 30 E. The gangue minerals are quartz, chlorite, sericite, and calcite, and the ore minerals are listed as being bornite, chalcocite, pyrrhotite, azurite, malachite and cuprite. Laney also noted the presence of veins to the southwest and northwest showing copper staining.

Daniel's mine

The Daniel's mine is in eastern Charlotte county, Virginia, in the southeast quarter of the Eureka 7.5' quadrangle. To get to the mine, travel 4.5 km north on a fire road from its intersection with VSR 623. The mine is 240 meters off the left (west) side of the road.

Sweet (1976) stated that in April 1972, a 3 meter wide water filled shaft containing large white quartz boulders and a large dump of greenstone schist and quartz with malachite and chalcocite mineralization was present; in February 1976, the shaft was further caved and partly filled with tree stumps and limbs.

Laney (1917) listed the site as having two prospect pits or shallow shafts opened on a narrow (1-2 meter) well-defined vein with gangue and ore similar to that of the rest of the district. There was no change by 1983.

Dorothy mine

The Dorothy mine is located in southeast Halifax county, Virginia, in the northeast quarter of the Virgilina 7.5' quadrangle. To get to the mine, travel 1.3 km south on VSR 738 from the intersection of VSR 738 and 602. The mine is 200 meters off the left (east) side of the road.

According to Sweet (1976), in 1976 there was a 1.5 meter square water filled shaft, a water filled pit, two shallow pits, and several small dumps of greenstone, greenstone schist, and quartz on the site in

1976. No mineralization was seen. In 1982, there were a series of small pits and trenches trending uphill S 10 W from the lowest near a small intermittent stream. All were filled to within a meter of the surface. Any dumps present were obscured by plant cover, and there was no sign of mineralization.

The mine is not mentioned in Laney (1917). However Weed (1911) listed it as having two shafts with bornite and chalcocite occurring in a quartz vein. Sweet also mentions an exposure of greenstone schist south of the mine and approximately 174 meters east of VSR 738 in an old road bed. The schist strikes N 8 E with a vertical dip and contains a 0.6 meter wide barren quartz vein. Nine meters west of this is a 20 cm wide vein that strikes N-S and cuts across the schistosity.

Duke mine

The Duke mine is in northeastern Person county, North Carolina, in the southwestern quarter of the Triple Springs 7.5' quadrangle. To get to the mine, travel south on NCSR 1573 for 0.56 km from the intersection of NCSR 1573 and NCSR 1536 to a logging road on the right (west) side of the road. Travel 123 meters N 80 E, then 36 meters N 10 E to the first pit, and 27 meters N 30 E to the second.

According to Carpenter (1976), the shafts were caved with little dump material visible in 1966. In 1982, there were two water-filled pits, 3-5 meters in diameter with virtually no dump material nearby, only some sheared greenstone and quartz showing slight malachite staining. No sulfides were seen in hand specimens. According to local residents, the dump material was used to pave NCSR 1536.

Laney (1917) states that the property contains several veins, all of which show traces of copper. There were two shafts sunk beyond the pit stage: the Hicks shaft, which was sunk to 85 meters with a drift at 30 meters extending 61 meters NE and 15 SW, and a second at 81 meters extending 18 meters NE, and the No. 3 shaft which was 68 meters deep and had a single drift 30 meters down extending 36 meters NE and 18 SW.

Shearing in the greenstone schist trends N 10 E and dips vertically. Most of the veins on the property follow the schistosity, but some cross-cut it. The gangue minerals consist of quartz, epidote, calcite, sericite, and hematite, and the ore minerals of bornite, chalcocite, malachite, azurite, cuprite, minor chalcopyrite, gold and silver. Some chalcocite occurs in shear planes and fractures in the veins and rock.

Durgy mine

The Durgy mine is in northeastern Person county, North Carolina, in the northwest quarter of the Triple Springs 7.5' quadrangle. To get to the mine, travel 0.21 km south on NCSR 1542 from the intersection of NCSR 1542 and 1559, then travel 91 meters N 70 W to the old No. 2 shaft.

According to Carpenter (1976) the workings in 1966 consisted of three caved, choked, and flooded shafts, approximately 15 meters in diameter and 7.5 meters deep, and a large dump. He described the country rock as a bleached andesitic or rhyolitic crystal tuff containing fragments of apparently altered feldspar. Also noted on the dumps were lavender-purple, green-grey, and tan argillites. The main shaft (No. 2) had a 1.5 meter wide sheared, jointed and occasionally vuggy quartz vein that trended N 5 W and dipped vertically. The country rock around the vein appeared bleached. The shearing is parallel to the strike of the rock, while the joints are approximately normal. Both are filled with malachite, as are some of the vugs. The ore minerals are chalcocite, bornite, and covellite, with supergene malachite and cuprite, and the gangue consists of chlorite, quartz, sericite, and limonite, with minor biotite, pyrite, and epidote.

In 1982, using the map from the Bureau of Mines investigation, (Newberry, et al, 1948), four shafts were located, all on a line trending north and extending for about 655 meters. About 45 meters west of the No. 2 shaft is the old mill site. In addition to the shafts, there are several pits and trenches spread about the site. Some of the openings are filled with trash.

Laney (1917) states that the property was originally called the Yancey mine, and that it was active in 1892. The Yancey shafts, located on a vein west of the main vein were about 400 meters southwest of the present No. 1 shaft, and were sunk to depths of 46 and 27 meters. Apparently, considerable ore was removed and concentrated at a plant about 900 meters west of this. It eventually closed and was not reopened until about 1900, when major development began. A shaft was sunk to 30 meters on the Durgy vein, 460 meters northeast, (this probably is the "Old Durgy" as described by Carpenter (1976, pg. 56)), four shafts were opened on the main vein, and a 100 ton concentrating plant was built. Although there were several ore shoots located, only the one at the main shaft was developed. The mine again closed in 1908, but was opened in 1910 and operated until 1911 when it was closed permanently. At the time of closing, the No. 1 shaft was 49 meters deep, and the No.2 was 125 meters deep. Over 1200 meters of drifting was done, making the Durgy mine the largest of the district in terms of underground development. Levels in the No. 1 shaft were at 27 and 149 meters, and in the No. 2 shaft they were at 27, 49, 79, 104, and 124 meters.

The mine was opened in what Laney termed the tuffaceous phase of the Virgilina greenstone, with areas that are distinctly volcaniclastic, and others distinctly porphyritic. In general, the country rock has a brecciated appearance, varying in color from green to dark purple, with clasts from <2.5 cm to >30 cm in diameter, but Laney gives no indication of the nature of the clasts. The schistosity strikes N 30 E and dips from 70-80 SE; however there are massive areas with no evidence of schistosity. Laney considered the fine-grained matrix to have been volcanic ash. As at Blue Wing, a diabase dike cuts through the greenstone, but it does not intersect the vein. The width of the dike was not determined, as it had no surficial expression and formed the footwall for part of the mine. It is younger that both the vein and the ore, and had no apparent influence on them.

On the property, Laney found four distinct veins and believed that others were present. The four are: the main vein, which was mined; the Durgy vein, lying parallel to the main vein and about 610 meters east of it; the Cross-cut vein, roughly 1.6 km southwest of the mine; and a smaller vein several hundred meters west of the mine. All are fissure veins containing quartz, epidote, calcite, chlorite, and fragments of country rock. The main vein was traced by outcrop and quartz float for over a km and varies in width from 2-5 meters. The gangue minerals include those listed above plus hematite. The ore mineralization, in order of abundance, is bornite, chalcocite, malachite, azurite, cuprite, argentite, chalcopyrite, klaprothite(?) and gold. This and Blue Wing were the only mines in which Laney found identifiable argentite. It was assumed in the other mines based on the smelter returns. The ore is both disseminated through the veins, and segregated into rich zones. The overall grade was from 2-3% Cu and 0.8-1.0 ounces Ag per ton. Although supergene mineralization is mentioned, no indication is given of the extent of leaching or enrichment.

Work by the Bureau of Mines in 1942 (Newberry, et al, 1948) consisted of 348 meters of bulldozer trenching, shaft rehabilitation, nine diamond drill holes totaling 1741 meters, and resistivity and self-potential surveys. No data is given about the trenching; the shaft rehabilitation of No. 2 was extended for 11 meters then abandoned, as the mine design and wall conditions made safe repair unfeasable. Eight of the drill holes intercepted either the vein or the deep workings. The geophysical surveys indicated persistence of the copper at depth, but correlated poorly with the core data.

Grove mine

The Grove mine is in northeastern Charlotte county, Virginia, in the southeast quarter of the Eureka 7.5' quadrangle. To get to the mine, travel 0.48 km east on VSR 772 from the intersection of VSR 772 and VSH 59. The mine is 400 meters off the left (south) side of the road.

According to Sweet (1976), there were several water filled pits at the level of a tributary to Bentley's branch and a large dump that partially blocked the flow of the tributary in April 1972. The dump contained greenstone schist and white and clear quartz with malachite and chalcocite mineralization. In February 1976, the dump had been partially graded, but remaining was a 6 meter diameter, 6 meter deep caved shaft in which the schistosity of the wall rock had a generally N-S strike. Surrounding the shaft was a small rim dump of greenstone and greenstone schist with some malachite staining. There was little change by 1983.

Laney (1917) originally listed the mine as only a few prospect pits on a narrow, well-defined quartz vein, but the mine was reopened since his fieldwork and he added a footnote stating that 3 shafts of 18, 26, and 49 meters in depth had been sunk on the vein. The 26 meter shaft had 198 meters of drifting at the 18 and 26 meter levels. The 18 meter shaft was 49 meters north of this and was connected to it on the 18 meter level. The 49 meter shaft was sunk into the hanging wall to try and intercept the vein at 61 meters. The vein is traceable for roughly 400 meters, striking N 35 E and dipping 75 SE, and varies in thickness from 1.4 to 1.7 meters, increasing in width with depth. The mineralization consists primarily of bornite and chalcocite, with smaller amounts of chalcopyrite, malachite, and azurite.

High Hill mine

The High Hill mine is in southeastern Halifax county, Virginia, in the southeast quarter of the Omega 7.5' quadrangle. To get to the mine, travel 0.4 km northwest on VSR 601 to a dirt road on the right (north) side of the road; then travel 1.4 km along the road to the old No. 4 shaft next to an old cemetary.

According to Sweet (1976) in 1976 there were three large openings at the top of the hill that were surrounded by barbed wire. The southernmost was a 6 meter diameter, 12 meter deep shaft containing an exposure of greenstone schist, the schistosity of which strikes N 15 E and dips 80 SE, and a 1 meter wide quartz vein with 21-61 cm wide quartz stringers parallel to it that strikes N 15 E and dips vertically. The other two openings were caved pits. The rim dump around the shaft, contains greenstone schist and white quartz with malachite and hematite; some of the material has been used locally for road construction. There were caved pits, shafts, and trenches to the south for 0.8 km along the strike of the vein. To the north were concrete foundations, wooden frames, timbers, a roasting furnaces, and a large dump at the site of the old mill. Also present nearby was a shaft with a sizeable rim dump and a collapsed headframe.

In 1982, using the sketch map in Newberry, et al (1948, Fig. 3 and 4), 4 out of 11 shafts were located, all roughly on a line trending N 2-3 W. The distance from the northernmost to the southernmost was 1577 meters. The mill site is adjacent to the No. 3 shaft. The vein, which can be followed for the length of the site by outcrop or float, is up to 5 meters wide, and some outcrops stand up to 1.5 meters high.

Watson (1907) stated that there were several veins on the property, and that in 1904 two veins were prospected in detail. The westernmost, named the High Hill vein, for 2957 meters, and a second parallel vein for 1891 meters. The High Hill vein varies in width from 1-5 meters with outcrops from a few cm to 1.5 meters high. Laney (1917) described the country rock as a schistose greenstone, occasionally tuffaceous, striking NE and cutting the trend of the vein about 20-30 degrees. Ore minerals consist of bornite, chalcocite, malachite, azurite, covellite, and argentite(?), and occur both disseminated throughout the vein and segregated into rich zones. A description in December, 1899 stated that there was a leached zone of 4.5-6 meters from the surface. Supergene enrichment was not mentioned. The gangue mineralization consists of quartz, epidote, chlorite, calcite, and hematite in order of abundance.

The development of the mine began in 1899 with 14 pits and shafts being sunk to depths ranging from 8 to 38 meters deep. The No. 1 shaft was 15 meters deep, with drifts at the bottom extending 55 meters north and 40 meters south that connect to the No. 2 shaft. The No. 4 shaft was 38 meters deep with drifts 30 meters north and 5 meters south at the 18 meter level, and a 5 meter drift at the 29 meter level, and the 22 meter deep No. 8 shaft had two 3 meter drifts at its bottom. Prior to 1901, the No. 3 and No. 4 shafts were sunk to 76 and 107 meters, respectively, with two levels driven from No. 3 and three from No. 4. From there stoping and drifting was accomplished to the degree shown in Fig. 13 in Laney. Several different unsuccessful attempts were made from 1901 to 1907 to concentrate and treat the ores. The mine was not reopened after 1907. A commercial report in 1905 stated that some 10,014 tons of ore was removed from the mine, although not all of it was shipped. Calculations indicate an average grade of about 3.91% copper and 1.55 oz. silver and 0.022 oz. gold per ton.

In September 1942, the Bureau of Mines began extensive study of the property (Newberry, et al, 1948) which lasted until April 1943. This included 258 meters of trenching, rehabilitating shaft No. 4 and parts of the mine, collecting assay samples, and 695 meters of diamond drilling. The trenching was done between shafts No. 2 and No. 3, as well as on a smaller vein 300 meters southwest of the No. 8 shaft; slight showings of the veins were found. The shaft was opened to 69 meters and inclined 80 degrees for 9 meters, then bent to 59 degrees. The water level was 19 meters below the collar. Samples taken from the walls, an underground ore bin, and the surface dumps matched the earlier (1905) analyses. Eleven holes were drilled to intercept the vein and determine its persistence. All 11 intersected the vein at varying depths (Fig. 6-14, Newberry, et al, 1948), and confirmed the continuation of the ore at depth.

Holloway mine

The Holloway mine is in Granville county, North Carolina, in the southwest quarter of the Virgilina 7.5' quadrangle. To get to the mine, travel 0.8 km south on NCSR 1328 from the intersection of NCSR 1328 and 1331. The mine is 122 meters off the right (west) side of the road, behind a white frame house belonging to I.W. Hodges at the present time.

According to Carpenter (1976, pg. 29), in 1966 the workings consisted of four shafts and a large dump. The southernmost shafts were caved shut within 5 meters of the surface, but the northern ones were open. He described the country rock as altered volcanics, either rhyolite or andesite, that had been sheared, chloritized, sericitized, and epidotized. Throughout the rock are stringers of quartz, calcite, epidote, and feldspar. Also noted was silicified mylonite(?) with epidote, sericite, quartz, malachite, and azurite on the dumps, along with the quartz vein ore of chalcocite, covellite, malachite, and azurite. Carpenter mentions the presence of quartz monzonite with chalcocite(?) and bornite(?), and epidotized granite/quartz monzonite dikes(?) with bornite(?) and malachite(?). The felsic intrusive in this area was not mentioned by Watson (1902), Weed (1911), Laney (1917), or Newberry, et al (1948), and none was found in two visits in 1982-1983 The quartz monzonite is probably not indigenous.

In 1982-1983, five shafts were located, apparently corresponding to all those described by Laney. Four of the shafts lie on a line trending N 15 W. The fifth (No. 4) is 36 meters N 60 E of No. 3, the southernmost of the main shafts. Shafts No. 3 and No.4 are trash filled to within 5 meters of the surface and display no veins, only saprolitic greenstone with occasional quartz stringers. Seventy-six meters N 15 W of No. 3 is No. 1, which was the main operational shaft. It is about 6 meters across, water filled about 9 meters below the surface, and is inclined 15-20 degrees from the vertical. The No. 2 shaft is about 20 meters from No. 1, and has about the same width, depth and inclination. The walls of both are sheared greenstone schist that strikes about N 35 E and dips 70-80 SE. Shaft No. 2 also has a quartz vein in it that strikes about N 15 W and dips about 80 NE. About 46 meters from No. 2 along the trend are several pits trenches and the No. 5 shaft which is surrounded by a large dump.

Laney (1917) states that indications of copper were found in 1880, and that the property changed hands at least seven times, closing and reopening until 1905, when it closed permanently. Serious development began in 1897, and by 1901 the main shaft was 134 meters deep. Ore was shipped continuously then and sporadically afterwards until 1909 and 1910 when the dump material was sold for road building and railroad ballast. The main shaft, at the final closing, was 137 meters deep with levels at 18, 43, 61, 88, 117, and 132 meters. Shafts No. 2 and No. 5 connected at the 18 meter level, and No. 2 was also connected at the 43 meter level. Shaft No. 3 was about 30 meters deep, with a level at 15 meters, and No. 4 was roughly 24 meters deep. All told there was about 550 meters total of drifting. The ore body was irregular, roughly 90 meters long and from 1-30 meters in width. Data Laney obtained from operation of the mine between 1897 and 1901, indicated that overall the shipped ore was about 9% copper.

There are two major veins on the property. The main vein, striking about N 15 W, and the other, in which shaft No. 4 was sunk, about N 5 E. The main vein has little surficial expression, while the second has considerable outcrop. Weed (1911), said that the main vein varied in width from 1-23 meters. These probably represent distances across pinches and swells. The ore occurred in two shoots, one shortly south of the main shaft, the other about 36 meters north. Both had pitches of about 70 degrees south. Weed stated that the south shoot was 10 meters wide on the first level, and 5-10 meters wide further down. The north shoot was narrower (from 1-3 meters). Apparently a second sizeable ore body was uncovered at 134 meters. The country rock consists of both the tuffaceous and porphyritic phases of the Virgilina greenstone, more massive and less epidotiferous than usual. The strike of the schistosity was listed as N 20-35 E and the dip as 70-80 SE.

The gangue mineralogy, not including shards of country rock found in the vein, consists of quartz, epidote, chlorite, hematite, calcite, and feldspar. The ore mineralogy is chalcocite, bornite, argentite(?), malachite, azurite, cuprite, copper, and silver. Occasional malachite was found along a fault as far down as 90 meters, but no other mention is made of the extent of supergene mineralization.

Jeffers prospect

The Jeffers prospect is in eastern Person county, North Carolina, in the southwest quarter of the Triple Springs 7.5' quadrangle. To get to the mine, travel 0.16 km north on NCSR 1542 from the intersection of NCSR 1542 and 1574. The mine is 90 meters N 25 W from the left side of the road, directly behind the northernmost barn.

According to Carpenter (1976), the workings in 1966 consisted of an 2 x 3 meter water filled shaft with a small pit off to the southeast. He states that the shaft was sunk in a quartz vein in sheared andesitic tuff that strikes N 20 E and dips vertically. The ore minerals, bornite, chalcocite, and malachite occur in fractures in the vein and the country rock, and gangue minerals include quartz, hematite, chlorite, and sericite. In 1982 there was no change in the workings, although there was little mineralization, either sulfide or malachite seen. Laney (1917)does not mention this prospect, although the location is noted on his map.

Kay mine

The Kay mine is in southeast Halifax county, Virginia, in the northeast quarter of the Omega 7.5' quadrangle. To get to the mine, travel 1.45 km east-northeast on VSR 730 from the intersection of VSR 730 and 876 to a private dirt road leading to the Dan River Hunting Club on the left (north) side of the road. Travel 1.3 km down the road. The mine is 161 meters off the left (west) side of the road.

According to Sweet (1976, pg. 30), the site contained two shafts and a caved pit. The pit, which was the furthest north, had an exposure of Aaron striking N 10 E and dipping 75 SE, and a small dump with weathered country rock and some quartz fragments. Further south was a 3 meter wide, water filled shaft with a rim dump of greenstone, greenstone schist, sandy chloritic schist, and quartz showing some malachite staining. The southernmost shaft was 3.5 x 2 meters wide, 6 meters deep, water filled, and inclined approximately equal to the dip of the country rock, which is a yellow brown sandy chloritic schist that strikes N 9 E and dips 57 SE. There was also a large dump of greenstone schist, sandy chloritic schist, and conglomerate, also with some malachite staining. In 1982, only the southernmost inclined shaft was open, the others being partially filled in.

According to Laney (1917), there were 3 or 4 prospect pits and two shallow shafts that were sunk in the Aaron slate. The veins here are not regular or well defined, and although most of the ore occurs associated with the vein quartz, a sizeable portion is in the country rock. The ore consists of bornite and chalcocite with azurite, malachite, cuprite, and some gold and silver. Although Laney and Sweet both listed the Kay mine as the only one occurring in the Aaron formation, both the maps by Laney and Kreisa (1980) show the Morong mine as also located in a wedge of the Aaron.

Littlejohn mine

The Littlejohn mine is in southeast Halifax county, Virginia, in the northeast quarter of the Virgilina 7.5' quadrangle. To get to the mine, travel 1.5 km on a logging road that extends south from the intersection of VSR 602 and 737 to a fork in the road. Take the fork to the northwest for 300 meters to an abandoned tobacco drying barn and the southernmost shaft. The northernmost shaft is 130 meters north of this shaft.

According to Sweet (1976) there were two shafts 210 meters apart. The northernmost is about 4.5 meters in diameter with a 1.5 meter high rim dump, and the southernmost is 5.5 meters in diameter and 2 meters deep with a large rim dump. The north shaft had an exposure of the tuffaceous phase of the Virgilina formation in the east wall that strikes N-S and dips 65 SE. In the south shaft, it strikes N-S with a vertical dip. The dumps at both contain greenstone schist, white vein quartz with malachite staining, and chalcocite. No change had occured by 1982.

Laney (1917) stated that the property had a number of closely spaced veins some of which show considerable copper staining, and that three shallow prospect shafts, the deepest about 30 meters in depth, were opened in one of the more promising veins. The vein is apparently narrow, but well mineralized, the ore mostly chalcocite with little bornite.

McNeny mine

The McNeny mine is in northeastern Charlotte county, Virginia, in the northeast quarter of the Drake's Branch 7.5' quadrangle. To get to the mine, travel 2.9 km north-northeast on a fire road that intersects VSR 623. The mine is 1200 meters off the left (west) side of the road.

According to Sweet (1976), there was a 3 meter wide water-filled shaft with a surrounding dump, several small dump piles, a small cut and a small water-filled shaft(?) on the site in February 1976. The dumps contained greenstone schist with malachite staining, and white quartz with bornite and chalcocite. Just north of the main shaft was an exposure of greenstone schist that strikes N 29 E and dips 32 SE. It contains quartz stringers of 0.6-10 cm in width that parallel the schistosity. The site was unchanged by 1983.

Laney's description (1917) is rather perfunctory, since the mine had been closed for some time prior to his work. He stated that the main shaft sunk in the vein was 46 meters deep and that the vein, which varied in width from a few cm to 1.2 meters, occurred in pinches and swells, and followed the greenstone in strike and dip. The ore mineralization is bornite and chalcocite, and the gangue is quartz with calcite, epidote, chlorite, and hematite.

Morong ("Mother Lode") mine

The Morong or "Mother lode" mine is located in southeast Halifax county, Virginia, in the northeast quarter of the Virgilina 7.5' quadrangle. To get to the mine, travel 0.8 km west on VSR 602 from the intersection of VSR 602 and 734. The mine is 400 meters off the right (north) side of the road.

According to Sweet (1976), there was a 4 meter deep, 6 meter diameter caved shaft with a 1 meter wide quartz vein present in 1976. The greenstone in the shaft strikes N 5 E with a vertical dip. T/e vein has a N-S strike and a vertical dip. A 9 meter deep, 2.5 meter high adit where the greenstone strikes N 3 E and dips 65 SE is located 97 meters N 20 W of the shaft. Twenty-seven meters N 15 E of this is a 6 meter wide, 5 meter deep caved pit with a large rim dump. The conditions were the same in 1982.

Laney (1917) reports the shaft to have been sunk in a well defined vein that was traceable for more than 1 km, but that no commercial ore had been found. However, examination of the maps of Laney (1917) and Kreisa (1980) indicate that the mine is located in a block of the Aaron formation instead of the Virgilina formation as do the bulk of the other mines. Examination of the mineralization found on the site indicates that it is primarily pyrite disseminated through the vein and country rock, with very small amounts of chalcopyrite and covellite.

Old Durgy mine

The Old Durgy mine is in northeastern Person county, North Carolina, in the southwestern quarter of the Triple Springs 7.5' quadrangle. To get to the mine, travel 0.22 km east on NCSR 1559 from the intersection of NCSR 1559 and 1542 to a logging road on the left (north) side of the road. Follow the road for 695 meters, then travel 15 meters N 45 E to the first pit. A second pit is 8 meters north of the first. There are also two rectangular water filled trenches 9 and 30 meters south of the pits along the road.

According to Carpenter (1976)), the workings consisted of two pits in 1966. The northernmost 8 meters square and filled with water, and the southernmost 9 meters square and open to a depth of 4 meters. In 1982, little had changed except that the southern pit was dry and partially filled with trash. There are sizeable rim dumps around the pits.

The location corresponds to that given by Laney (1917) for the northeast shaft on the Durgy vein. However the description therein lists only a single shaft about 30 meters deep with a small drift and little stoping at the bottom. If this does correspond to Laney's northeast shaft, then considerable developmental work had been done since his report.

The country rock around the prospect is a chlorite-mica-sericite schist with some andesitic tuff. The veins are fractured quartz, calcite, and chlorite that have been healed by silica. Near the veins the rock is heavily epidotized. Mineralization appears to be largely supergene consisting mostly of chalcocite with quartz, malachite, cuprite, limonite, calcite, hemimorphite, bornite and covellite. Carpenter also reported a few flakes of gold in the tuff.

Pandora mine

The Pandora mine is in southeast Halifax county, Virginia, in the northeast quarter of the Virgilina 7.5' quadrangle. To get to the mine, travel 2.3 km north on VSR 734 from the intersection of VSR 734 and 736. The mine is 80 meters off the right (east) side of the road.

According to Sweet (1976), there was a pit 5 meters in diameter and 2 meters deep with a dump of greenstone schist, some of which was highly epidotized, and quartz with malachite, chalcocite, and bornite. Schistosity in the pit has a N-S strike and a vertical dip, and there was no evidence of any quartz vein. By 1982, there was little change in the site except that the pit was nearly filled with trash.

Laney (1917) indicates that the data on the mine was sketchy and contradictory. He noted that the country rock was greenstone schist, but more epidotized and less schistose than normal. The ore consists of bornite, chalcocite, azurite, malachite, and some cuprite in both the quartz and the country rock. Also noted were crystals of plagioclase, probably albite, associated with the ore in quartz.

Pannebaker prospect

The Pannebaker prospect is in northwestern Granville county, North Carolina, in the southeast quarter of the Virgilina 7.5' quadrangle. To get to the prospect, travel 0.37 km south-southeast on NCSR 1328 from the intersection of NCSR 1328 and 1330. The pit is 15 meters N 40 E of the road in a fenced in pasture.

According to Carpenter (1976), several prospects are known, but only this pit (5 x 5 x 2 meters) could be located in 1966. In 1982 the pit was entirely trash filled well above the rim, and no dump was visible.

Laney (1917) states that the prospects were opened in sheared, epidotized, chloritized, sericitized banded felsic tuff, or bedded argillite, or graywacke, showing irregular areas and stringers of quartz that show copper staining. The mineralization consists of native copper disseminated through the country rock as plates parallel to the schistosity, and as irregular blebs in the quartz and epidote, with supergene cuprite and malachite. No sulfides were seen either by Laney or Carpenter. Native copper was also reported in two other nearby prospect pits occurring in amygdules in the country rock.

Pontiac mine

The Pontiac mine is in southeastern Halifax county, Virginia, in the southeast quarter of the Omega 7.5' quadrangle. There are two main shafts: The Tuck shaft and the Glasscock shaft. To get to the

Tuck shaft, travel 82 meters S 20 W from the intersection of VSR 733 and 737. The shaft is in the middle of a pasture.

According to Sweet (1976), the Tuck site consisted of a 3 meter diameter water filled shaft with a low surrounding dump containing greenstone schist, epidote, and quartz with azurite and malachite staining. Some of the dump material has probably been used for road building locally. Approximately 55 meters S 80 W was a 5 meter diameter water filled shaft with a 1.5 meter high rim dump of greenstone schist with small amounts of vein quartz. There is little mineralization or vein quartz, and it appears to have been either an exploratory or prospect shaft. Along VSR 737 just north of these shafts is an exposure of greenstone schist, the schistosity of which strikes N 22 E and dips 55 SE. The conditions hab not changed by 1982.

Laney (1917) listed the Tuck shaft as being on a separate and distinct vein from the Glasscock. The country rock is less epidotiferous, and the vein is narrow, varying from a few cm to 1 meter, and appears to follow the strike and dip.

To get to the Glasscock shaft, travel 0.2 km east on VSR 733 from the intersection of VSR 733 and 737, then 265 meters N 20 W following an old road. The road passes by 3 or 4 small prospect pits before reaching the shaft. In addition, a quartz vein crops out about 11 meters from VSR 733 near the abandoned road, and strikes N 45 E and dips 50 NW. The site consists of the main shaft, now a caved pit 9 meters in diameter and 9 meters deep, a large dump, and a small, water filled pit 12 meters S 40 W of the main shaft. There is no major vein outcrop in the walls of the pit, but there are quartz stringers spread throughout the country rock, the schistosity of which strikes N 4 E and dips 81 SE. The dump consists mostly of greenstone schist with azurite and malachite stainings, and very little sulfide mineralization. The site described by Sweet as being the Glasscock shaft, and located on the map by Kreisa (1980) is not the Glasscock, but probably a prospect pit associated with the property.

Laney (1917) states that the shaft was sunk to a depth of 62 meters with a drift at 26 meters driven 15 meters south and 6 meters north. The vein is irregular in width (1-2 meters), strike and dip, has poorly defined walls, contains a large amount of epidote, and often has little quartz, making it difficult to follow. The ore is atypical of the district in that it is up to 1/3 chalcopyrite. Laney lists the ore minerals, in order of their abundance, as chalcopyrite, bornite, chalcocite, malachite, azurite, covellite, and cuprite, and the gangue minerals as epidote, quartz, chlorite, calcite, and minor hematite.

Seaboard mine

The Seaboard mine is located in southeast Halifax county, Virginia, in the northeast quarter of the Virgilina 7.5' quadrangle. To get to the mine, travel 0.96 km east on VSR 776 from the intersection of VSR 776 and 734 just across a creek to a dirt road trending northwest; follow the road for 1.22 km to the mine.

According to Sweet (1976) in 1976 the site contained 10 caved and water filled pits and shafts, old timbers for shaft lining, a large pile of copper fines extending from the site to a small creek (a distance of about 60 meters), several large dumps, and the remains of a concentrating plant. One shaft and pit was surrounded by barbed wire, and a shaft that is just to the southwest of this had a small concrete foundation and probably represents the main or No. 2 shaft. It was about 8 meters wide and 12 meters deep. The greenstone schist in the shaft strikes N 4 E, and an exposed quartz vein strikes N 8 E an dips 75 NE. The dump contained greenstone schist and quartz with bornite, chalcocite, malachite and azurite. This material is occasionally used for local road building. In 1982 the site was in basically the same condition. The No. 2 shaft was caved to a depth of 25 feet, but both shafts were dry. The No. 3 shaft is meters S 80 E of the N2 shaft. There are numerous trenches on the property as well.

Laney (1917) states that copper was reportedly first discovered here in 1899 in three ore shoots, and that three main shafts were sunk: N1 to a depth of 33 meters, N2 on the same vein 34 meters south of No. 1 was 107 meters deep, with levels at 30 and 60 meters. The 30 meter level was driven about 69 meters north and intersected shaft No. 1, and the 60 meter level was driven 32 meters north and 27 meters south. On the first level the vein averaged about 1.4 meters wide. On the second it was slightly narrower, but both averaged 2-2.5% copper. No ore was removed except that in the development work. The No. 3 shaft was 275 meters south of No. 2 and was 32 meters deep with no drifting. It was sunk on a different vein from the other two, but the mineralogy was the same. The third vein, which was smaller, was about 60 meters west of the main vein and had a shallow shaft on it 366 meters south of shaft No. 1.

The veins, all of which are well defined, strike N 5-10 W and dip about 80 E, while the schistosity of the greenstone schist strikes N-S with a vertical dip. It was noted during mining operations that the ore shoots were well mineralized with a slight pitch to the south, and that the main vein was terminated by a small fault in the south end of the drift at the 60 meter level.

The ore minerals, as described by Laney, consist mostly of bornite and chalcocite with minor supergene malachite near the surface. Some areas of the mine showed nearly all bornite. The gangue mineralization, in order of abundance, is quartz, calcite, albite, and hematite. Occasional vugs contain well formed crystals of quartz, calcite and albite.

A 50 ton mill was erected in 1907 for concentrating the ore produced, based on a design developed at MIT. It was operated briefly on about 2200 tons of ore left after hand-picking, and produced about 77 tons of concentrate. Hand picked ore averaged 7.45% copper, 1.5 and 0.01 oz silver and gold, respectively. Table concentrates were 23.85% copper and 2.89 and 0.02 oz silver and gold.

The work by the Bureau of Mines (Newberry, et al, 1948) was rather perfunctory: 280 meters of hand trenching, and rehabilitaion of the No. 2 shaft for 10 meters. After this, the project was abandoned in favor of other mines in the district. The greatest vein width seen was 46 cm, and the No. 2 shaft was 1.5 x2.3 meters and inclined 80 degrees.

Yancey mine

(see Durgy mine)

Wall mine

The Wall mine is in southeastern Halifax county, Virginia, in the northeast quarter of the Virgilina 7.5' quadrangle. To get to the mine, travel 0.64 km north-northeast along VSR 737 from the intersection of VSR 737 and 736. The mine is 69 meters from the right side of the road.

According to Sweet (1976), the site consisted of a debris filled shaft 5 meters in diameter, surrounded by a dump of greenstone schist with azurite, malachite, and hematite staining, and quartz with bornite and chalcocite mineralization. An exposure of schist near the top of the shaft strikes N 25 E and dips vertically. A quartz vein is also present that strikes N 12 W. By 1982, the dump material had been bulldozed into the shaft, closing it off.

According to Laney (1917, pg. 159), a shaft of 41 meters in depth with a 30 meter long drift, and several prospect pits were sunk in the tuffaceous phase of the Virgilina greenstone. The gangue mineralization consisits of quartz, chlorite, epidote, and calcite. The ore mineralization consists of bornite and chalcocite, which Laney states display the best examples of the bornite/chalcocite intergrowths that are typical of the district.

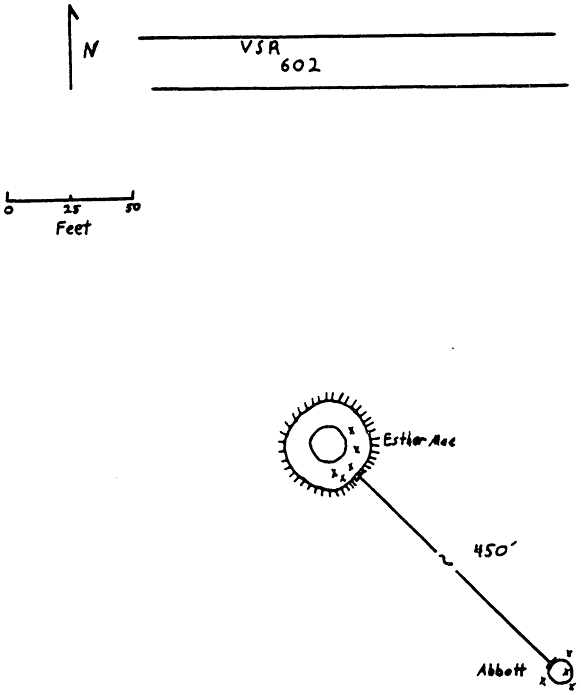
APPENDIX B

SITE MAPS FOR MINES LOCATED IN VIRGILINA DISTRICT

All maps are drawn on a scale of 50 feet equal one inch. Roads, streams, nearby buildings, and other salient features are labeled. Where multiple pages are required for a site, the maps either overlap or vectors are drawn to other features. Only features visited in 1982-1983 are drawn.

Key:
- Dumps: ☼
- Shafts/Pits/Trenches: ○
- Vein outcrops or traces: ⫽
- Sample locations: X X X X

Abbott/
EstherMae



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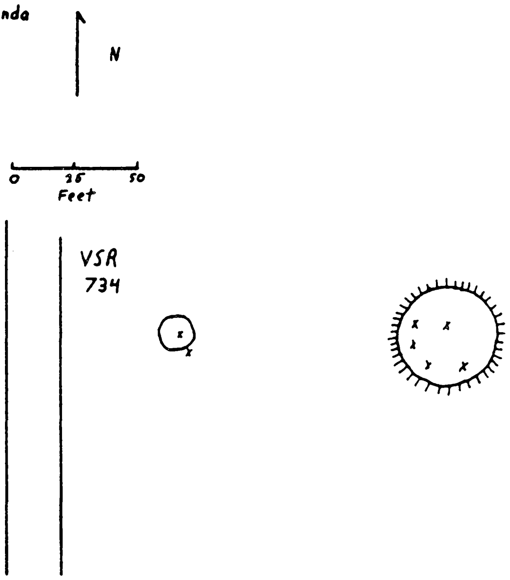

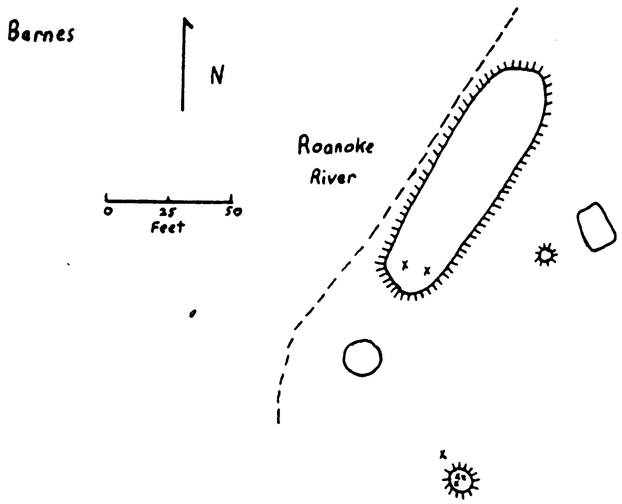
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Roanoke
River
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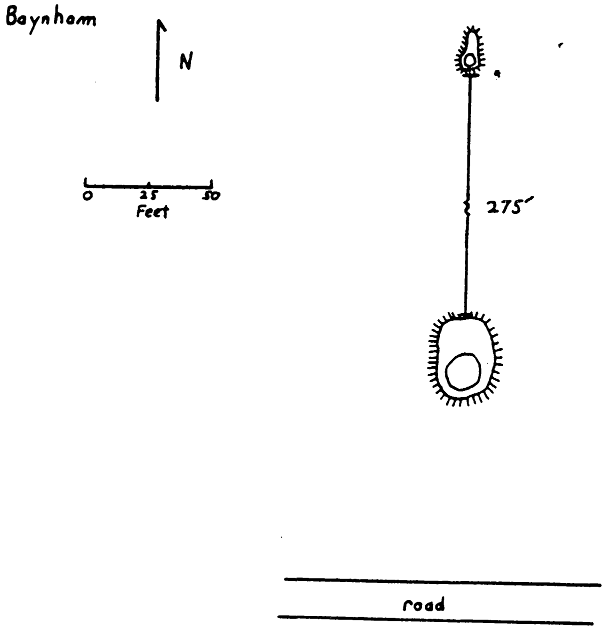
Feet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Feet
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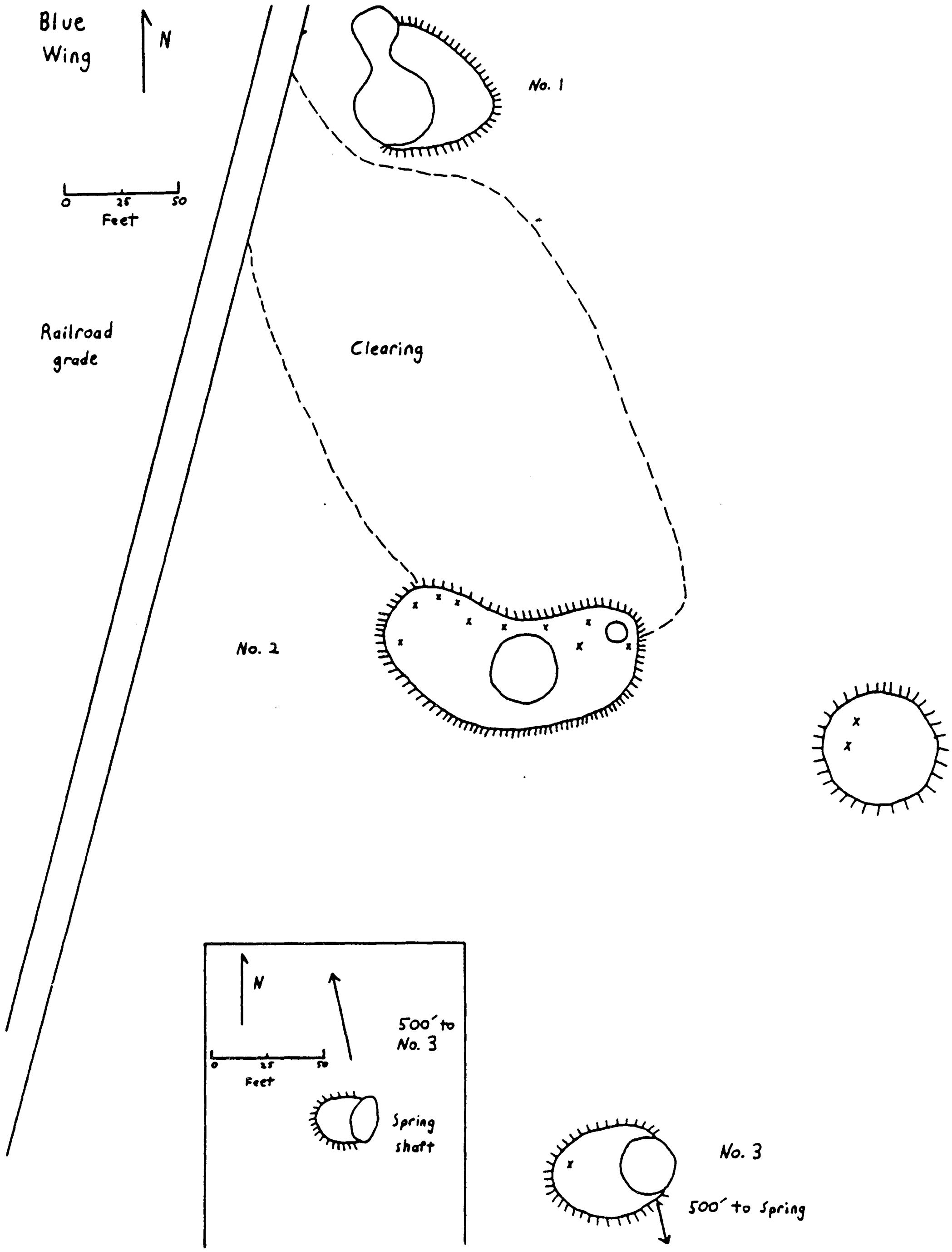
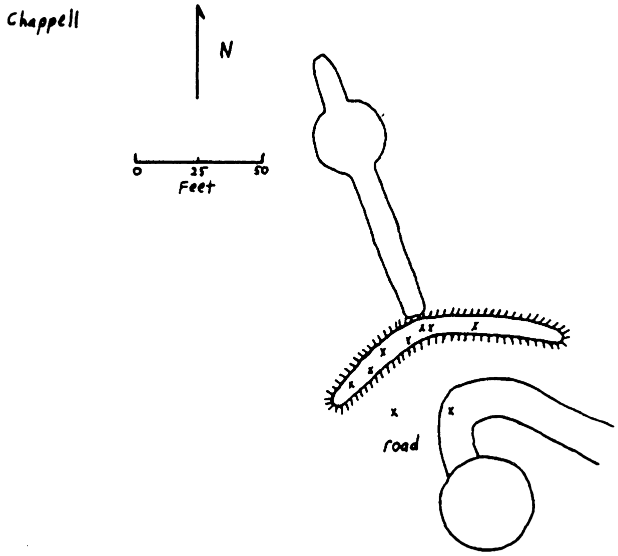
road


Blue Wing
N
0 25 50
Feet
No. 1
Railroad grade
Clearing
No. 2
N
0 25 50
Feet
500′ to No. 3
Spring shaft
No. 3
500′ to Spring


Chappell
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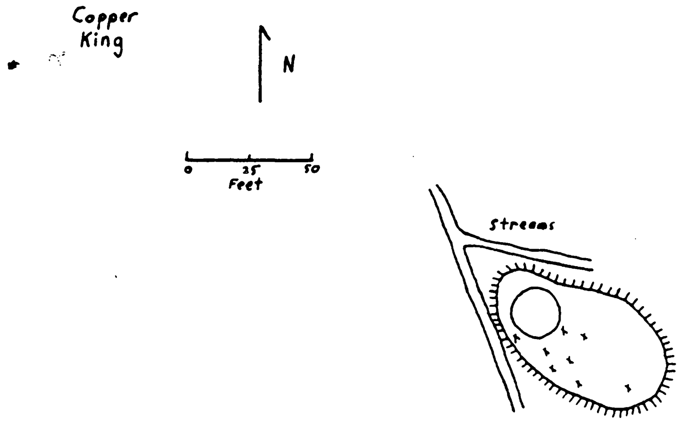
25
50
Feet
road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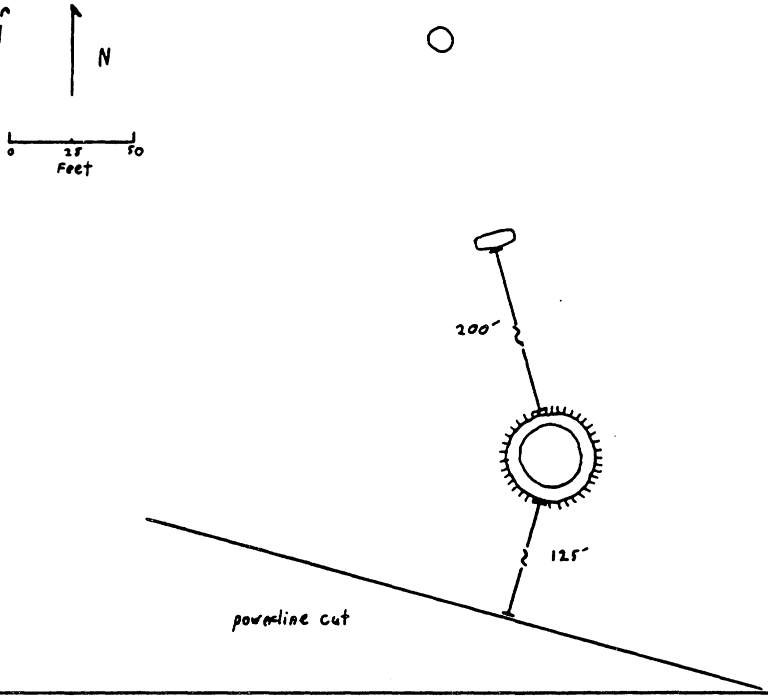
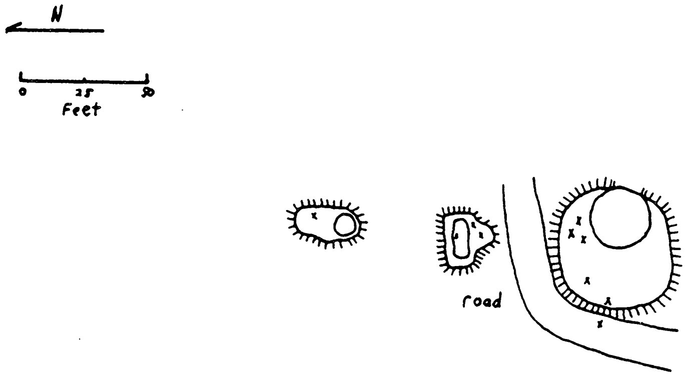
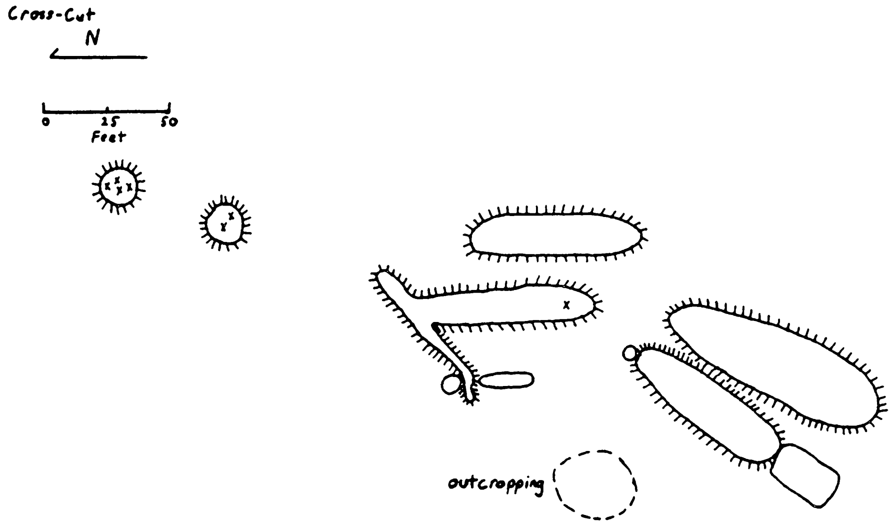
25
50
Feet
Streams

Copper World



Crenshaw




Cross-Cut
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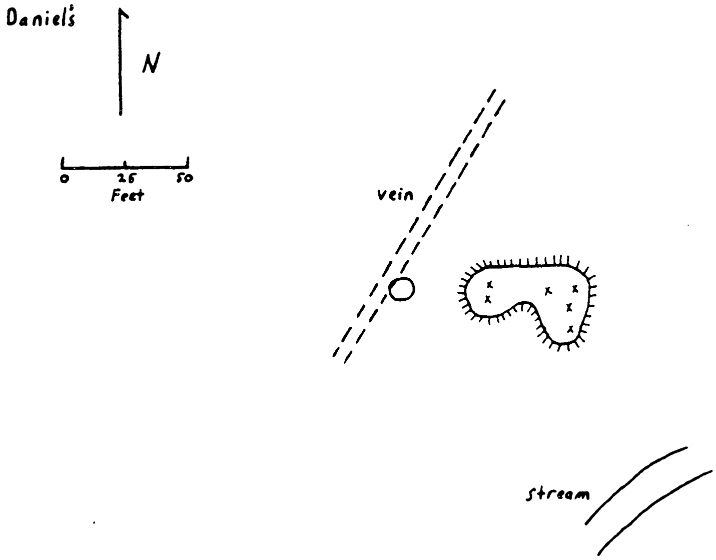
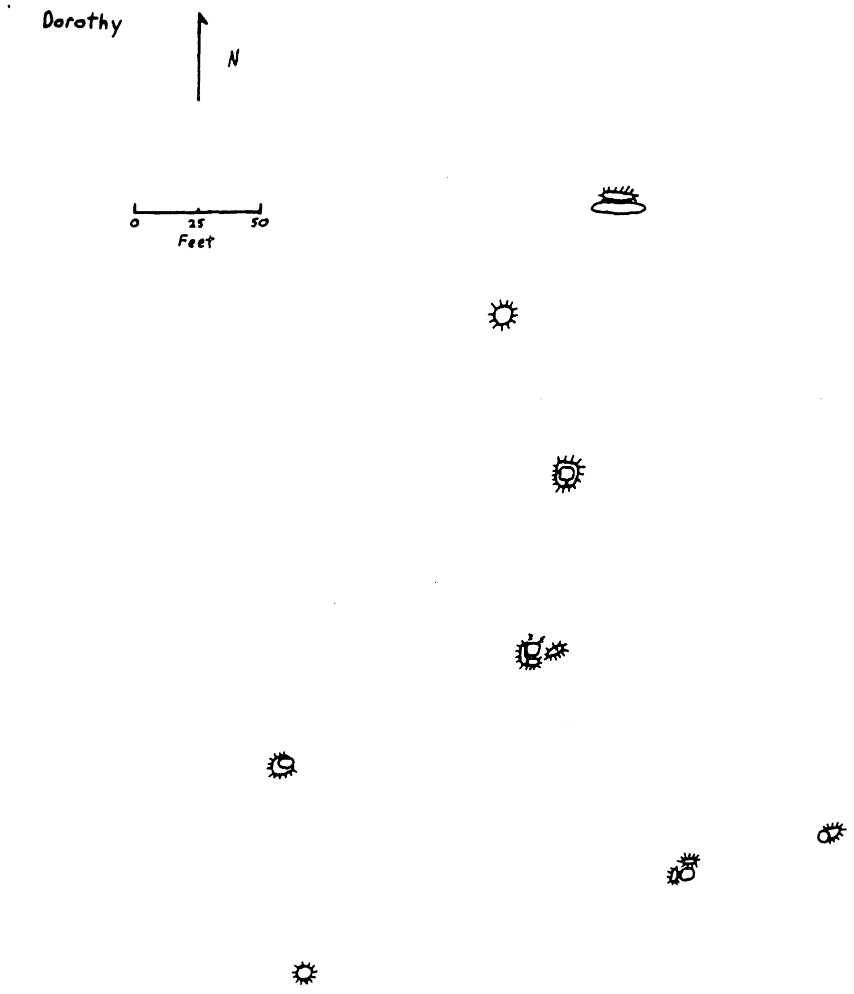
25
50
Feet
outcropping


Daniel's
N
0
25
50
Feet
vein
stream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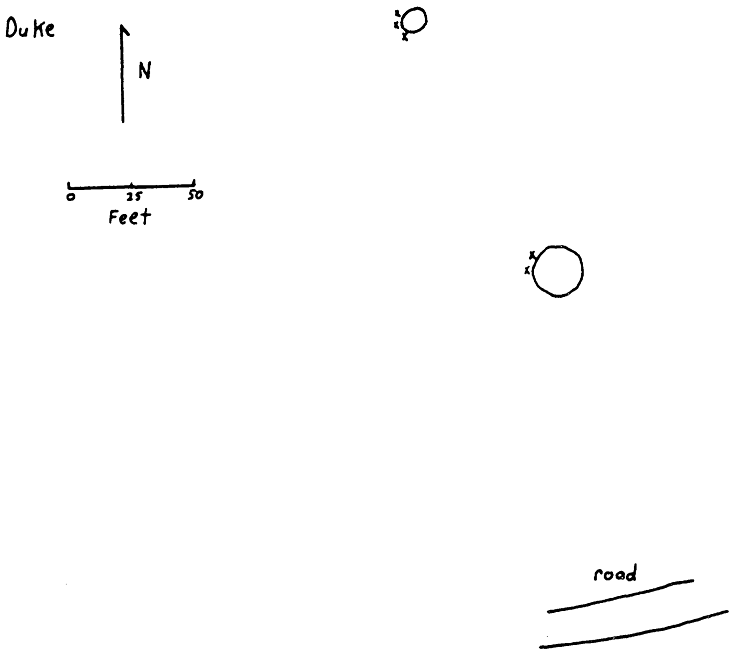
50
Feet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Feet
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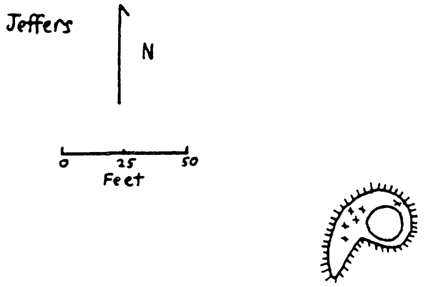
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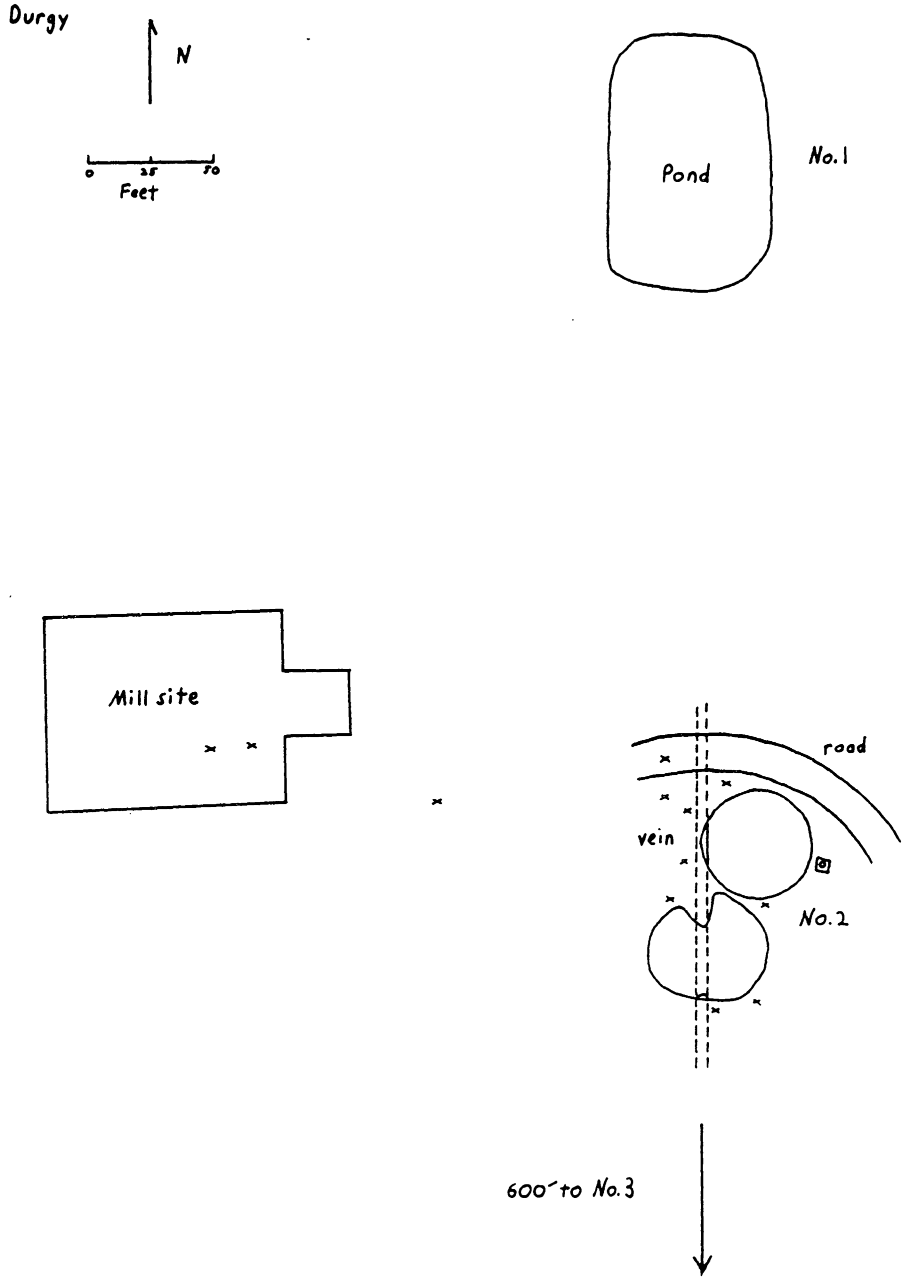
25
50
Feet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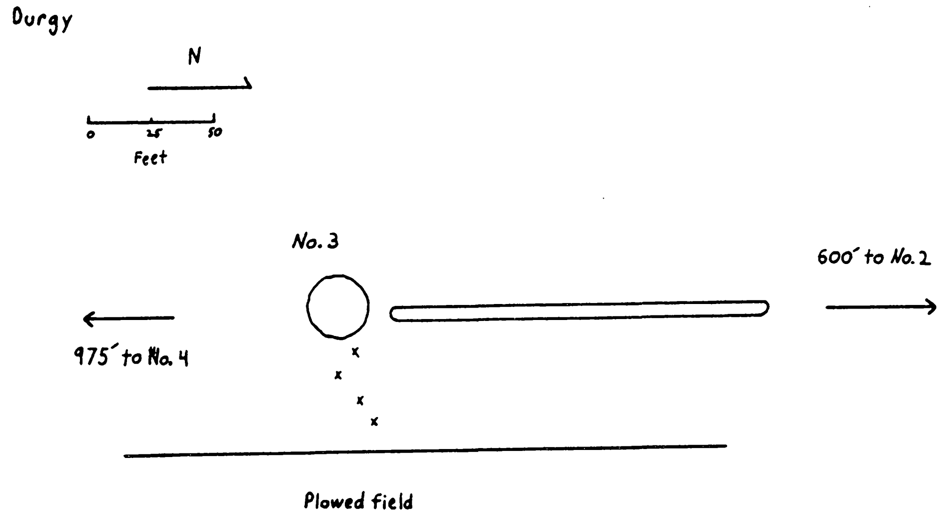
25
50
Feet
Pond
No. 1
Mill site
road
vein
No. 2
600' to No. 3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25
50
Feet
No. 3
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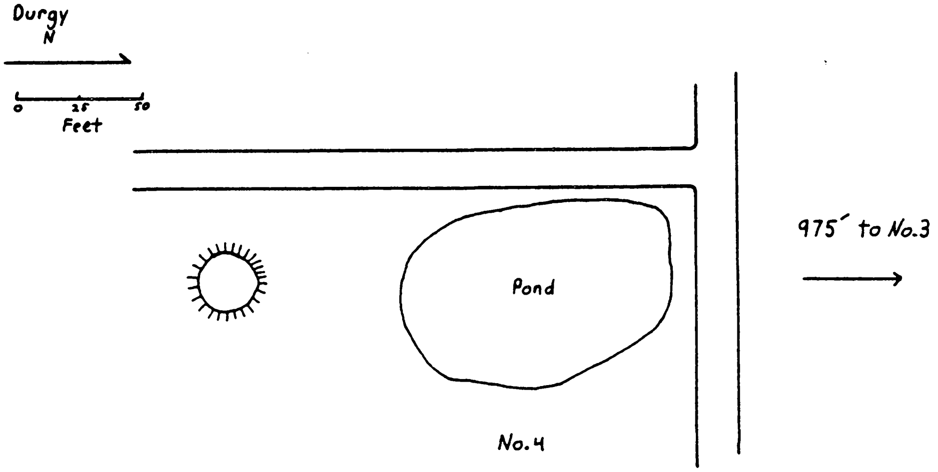
975′ to No. 4
Plowed field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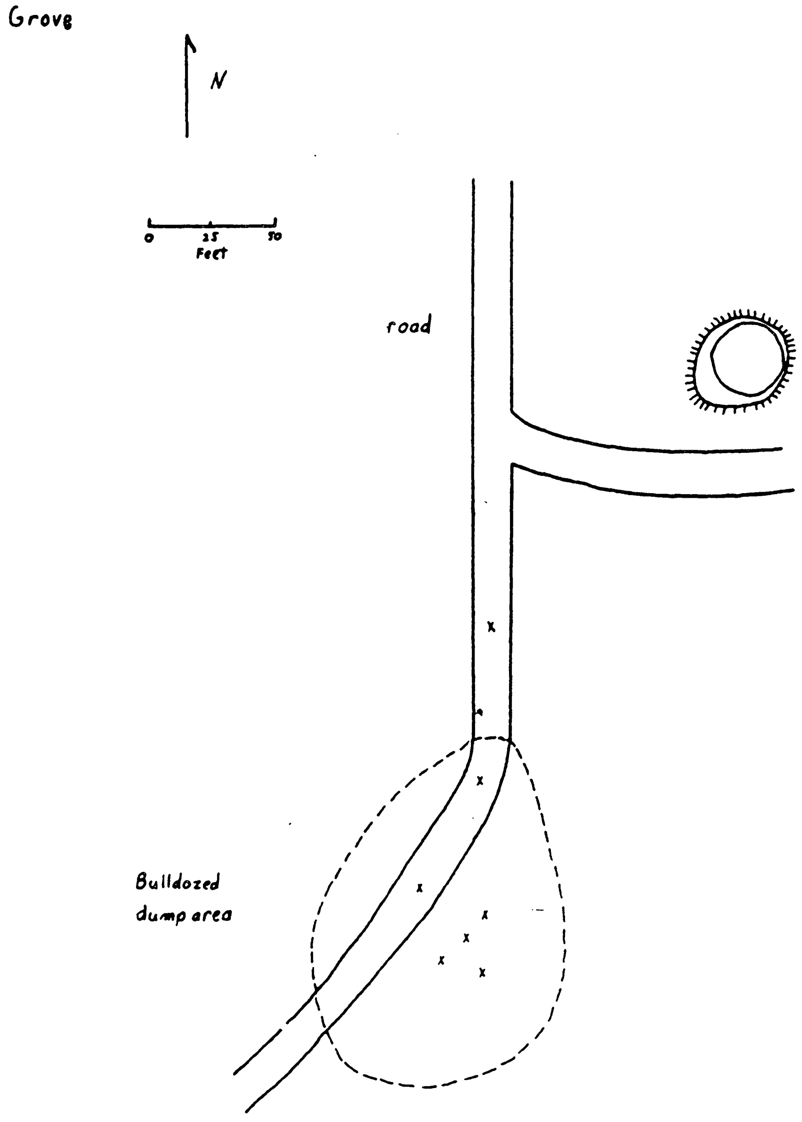
25
50
Feet
975′ to No. 3
Pond
No. 4


Grove
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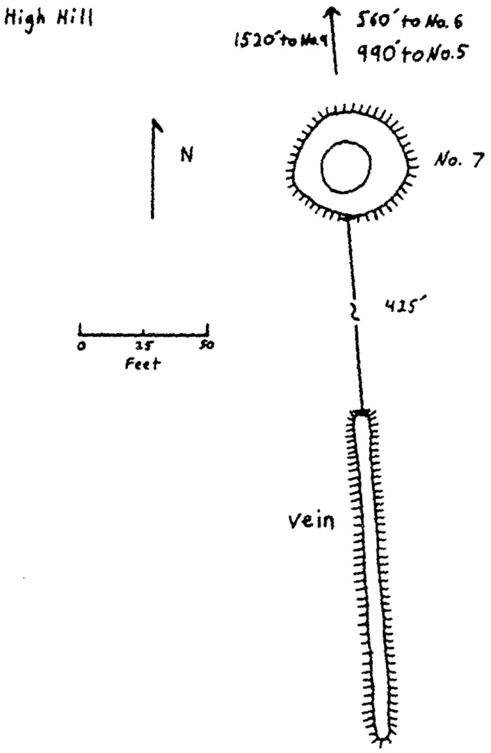
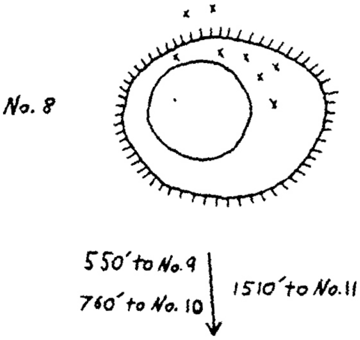
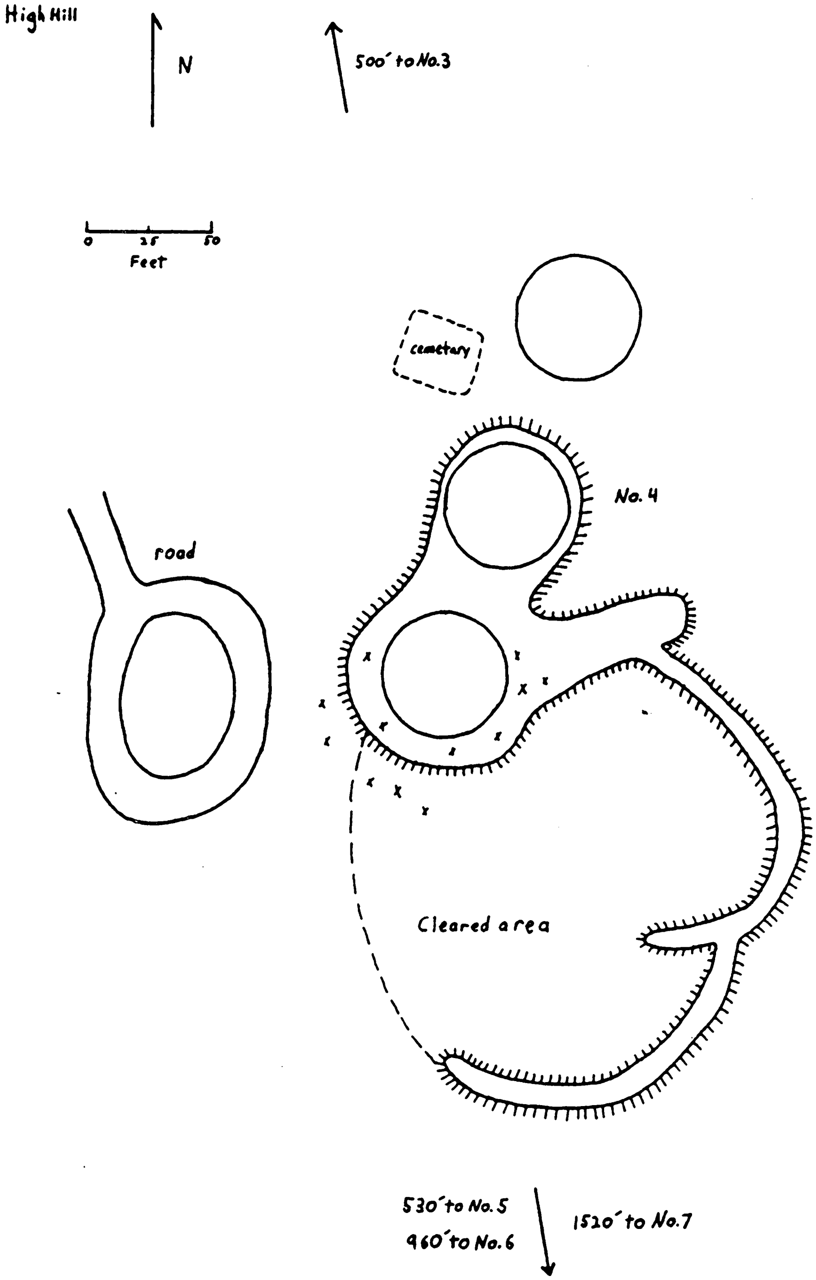
25
50
Feet
road
x
Bulldozed
dump area


High Hill
1520'to No.9
560' to No.6
990' to No.5
N
No. 7
425'
0
25
50
Feet
vein


No. 8
550' to No.9
760' to No.10
1510' to No.11


High Hill
N
500´ to No.3
0
25
50
Feet
cemetary
No. 4
road
Cleared area
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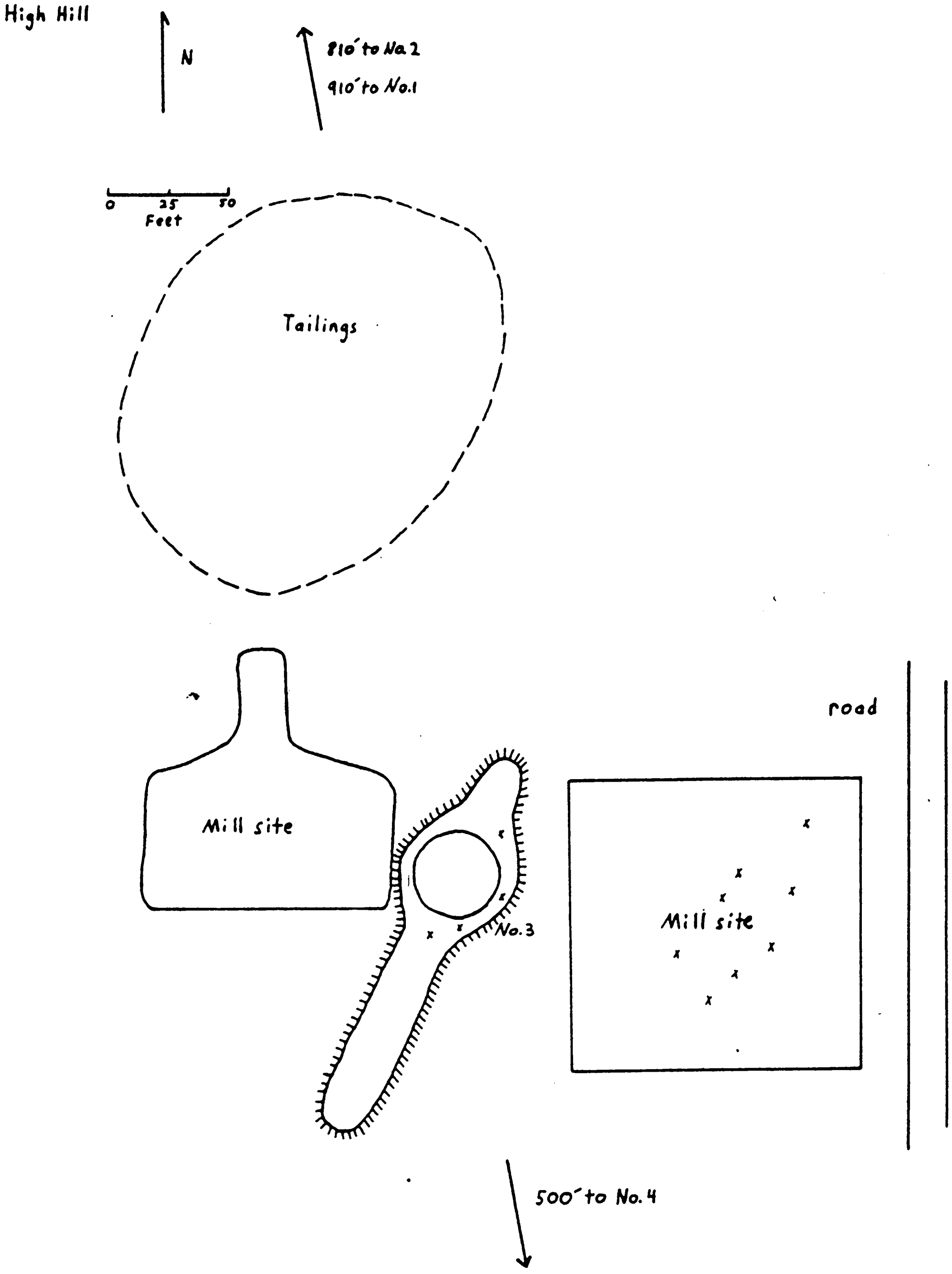
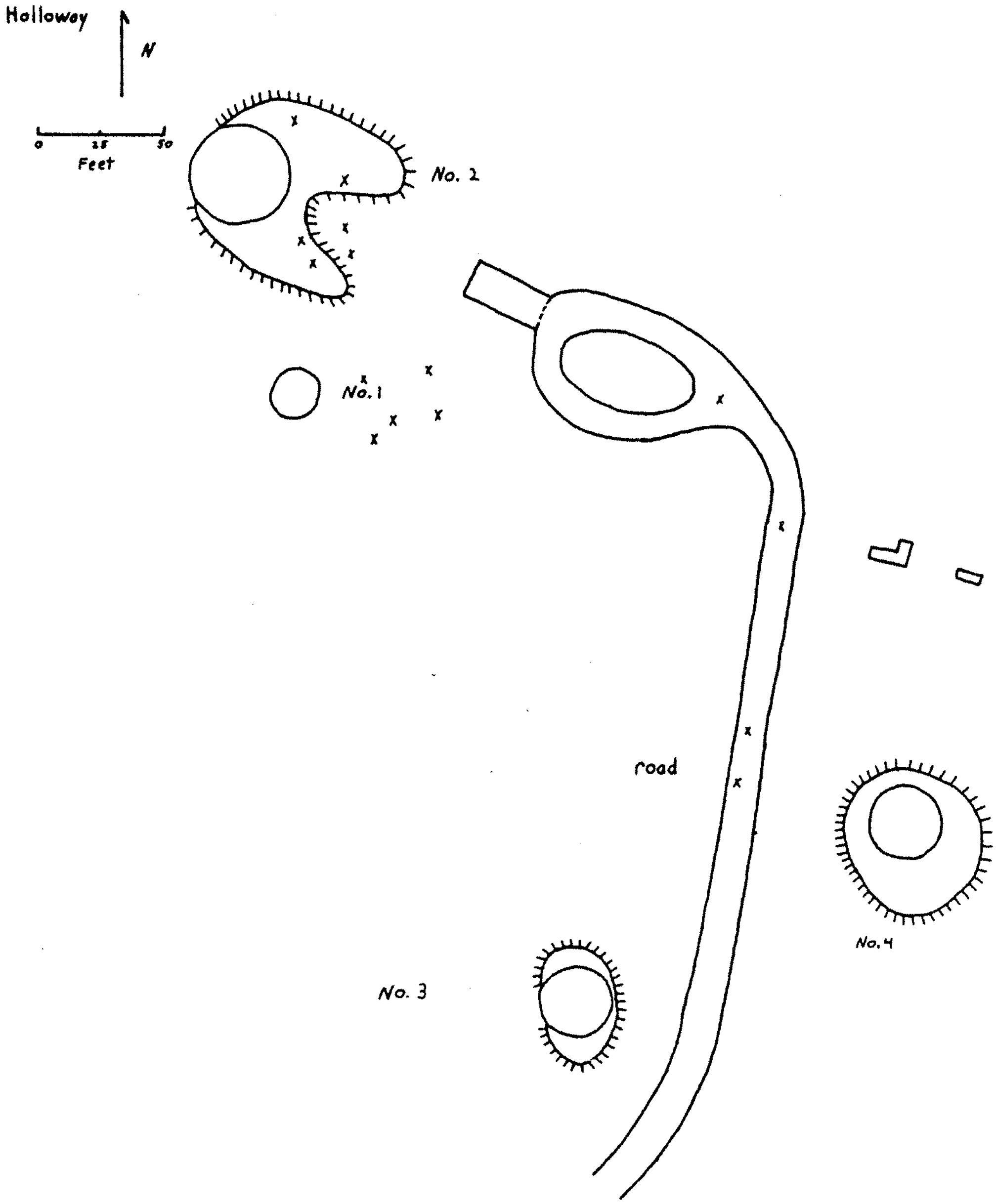
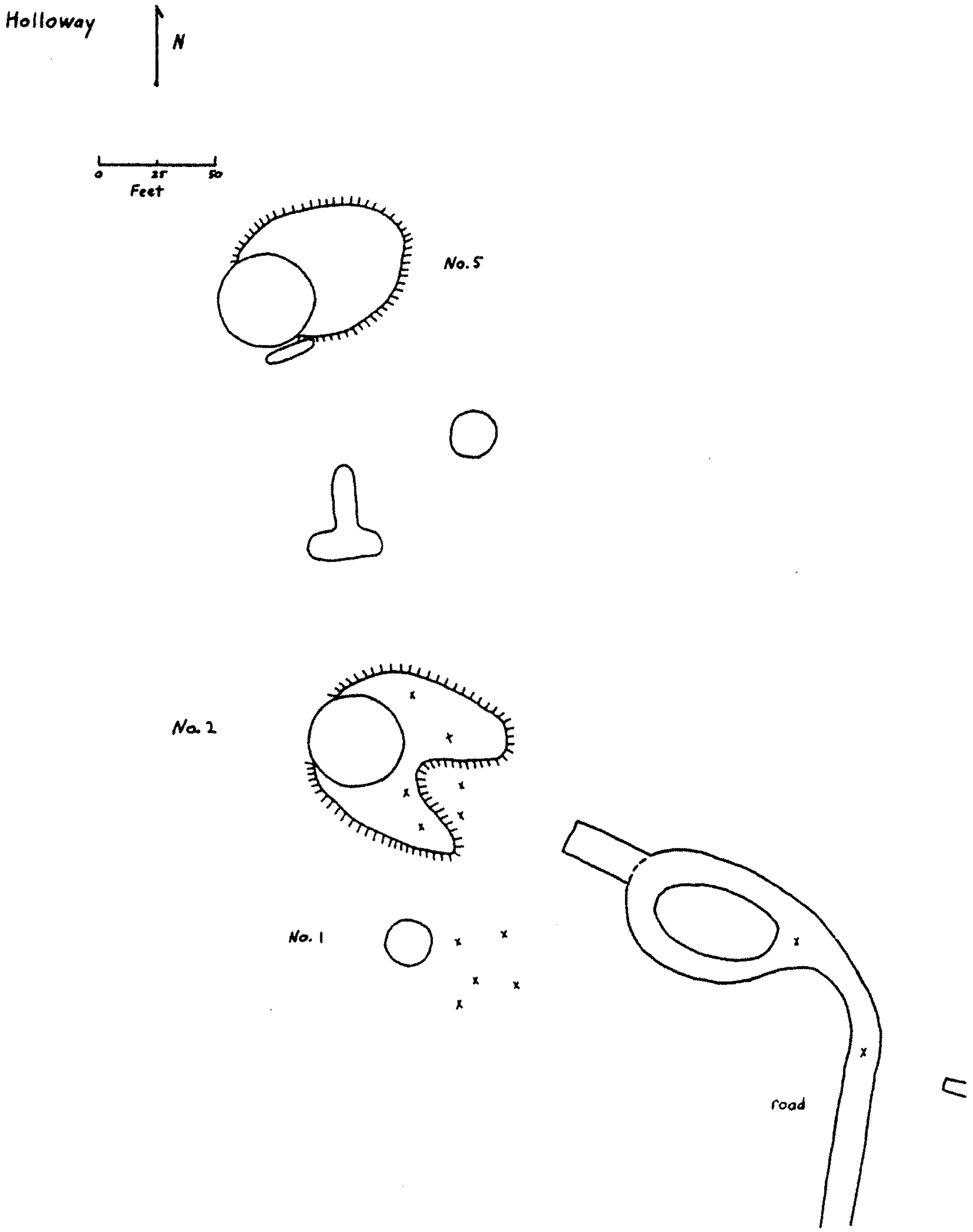
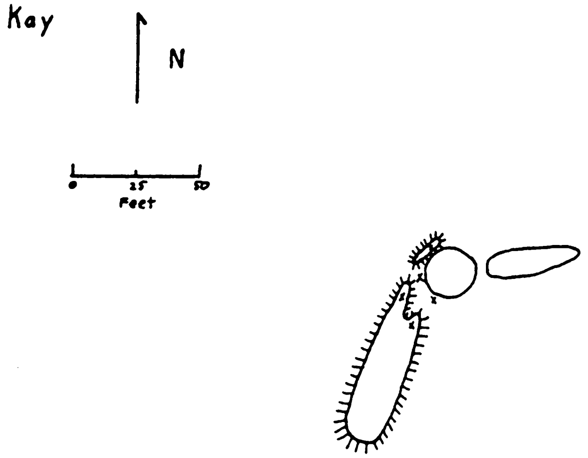
960´ to No. 6
1520´ to No. 7


High Hill
N
810' to No.2
910' to No.1
0
25
50
Feet
Tailings
Mill site
No.3
Mill site
road
500' to No.4


Holloway
N
0
25
50
Feet
No. 2
No. 1
road
No. 4
No. 3


Holloway
N
0
25
50
Feet
No. 5
No. 2
No. 1
road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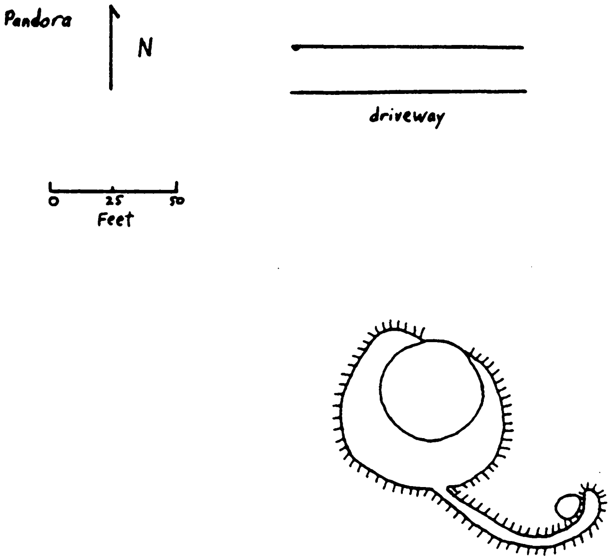
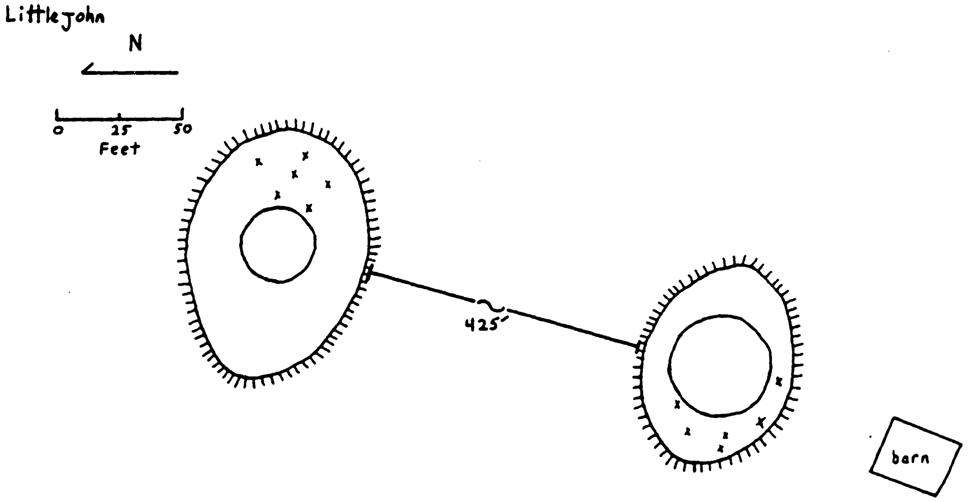
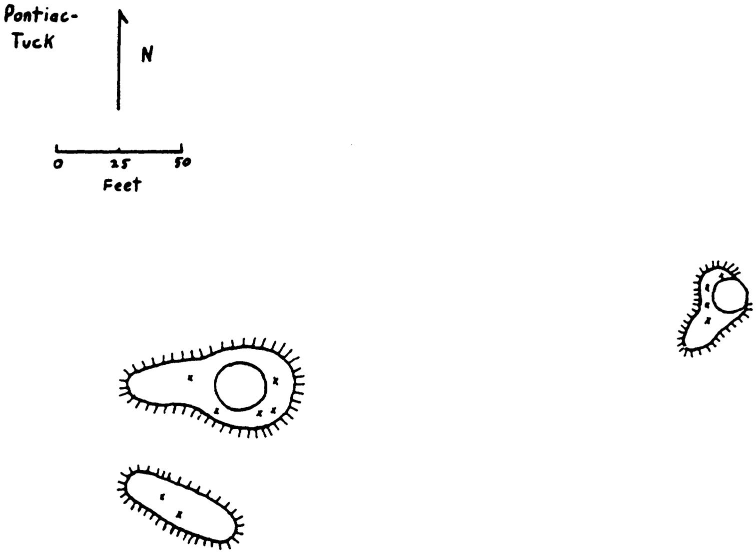
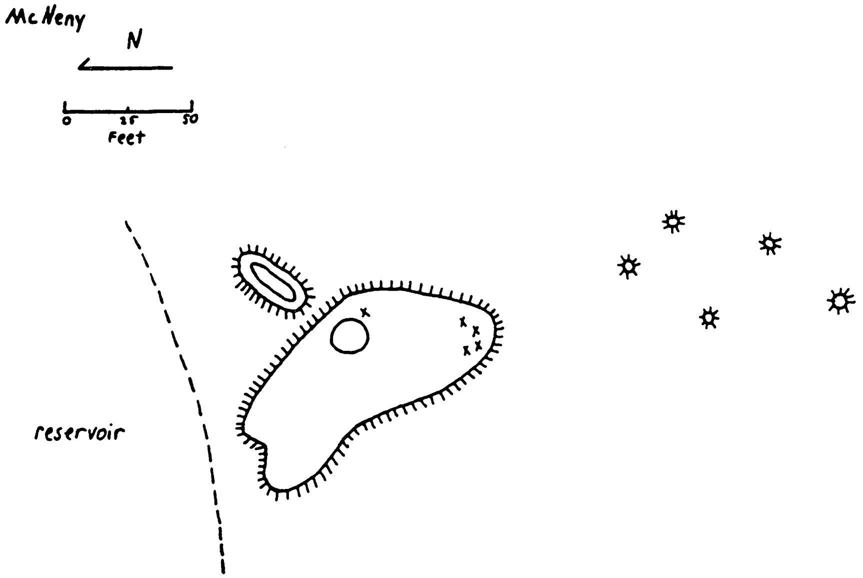
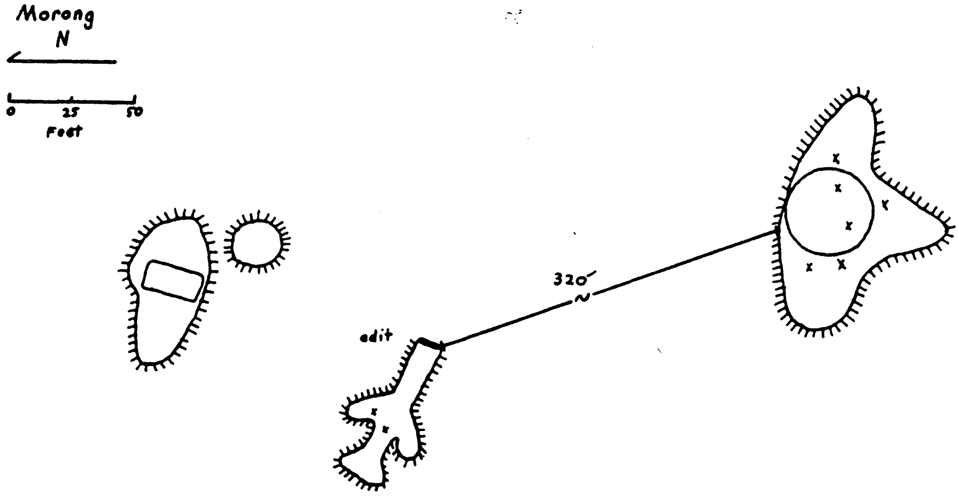
25
50
Feet

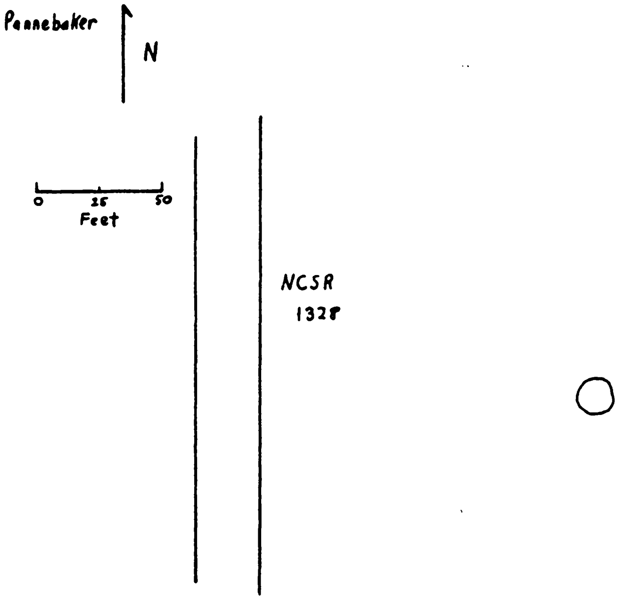

Pandora
N
driveway
0
25
50
Feet

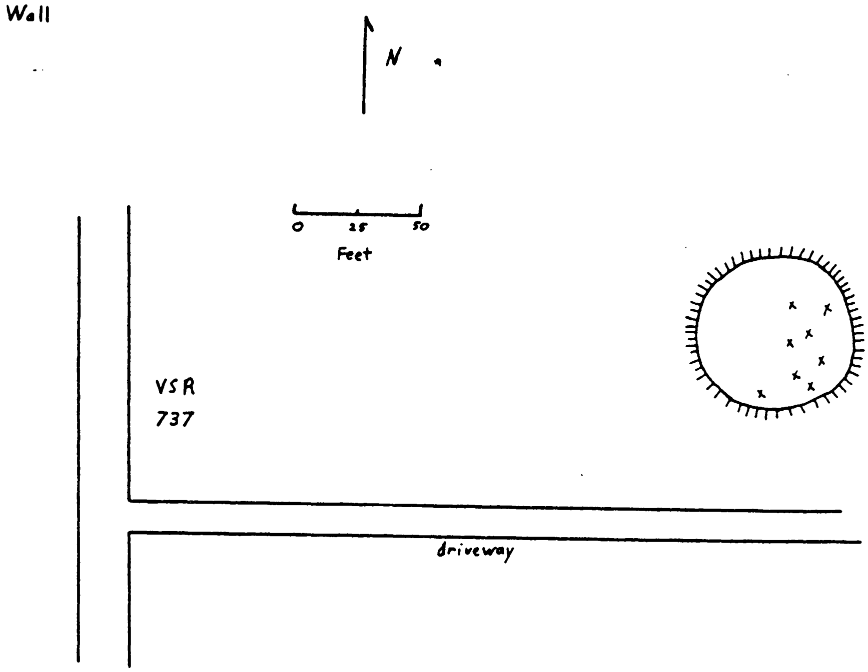

Littlejohn
N
0 25 50
Feet
425'
barn

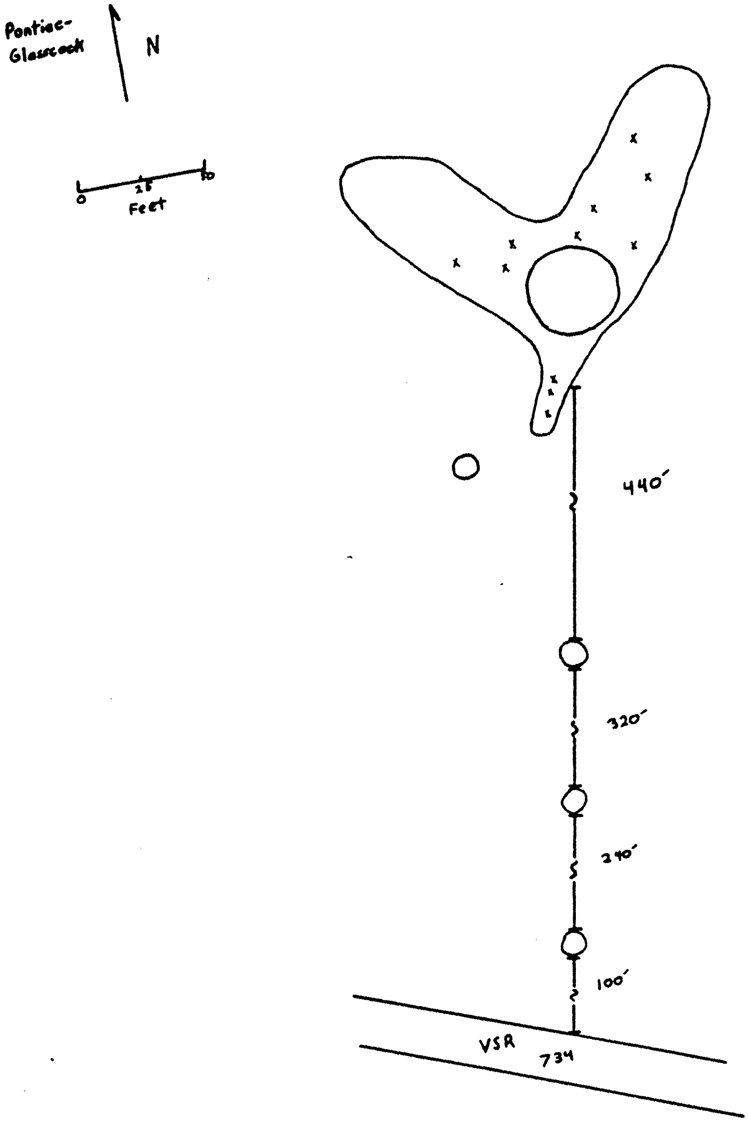

Pontiac-
Tuck
N
0 25 50
Feet

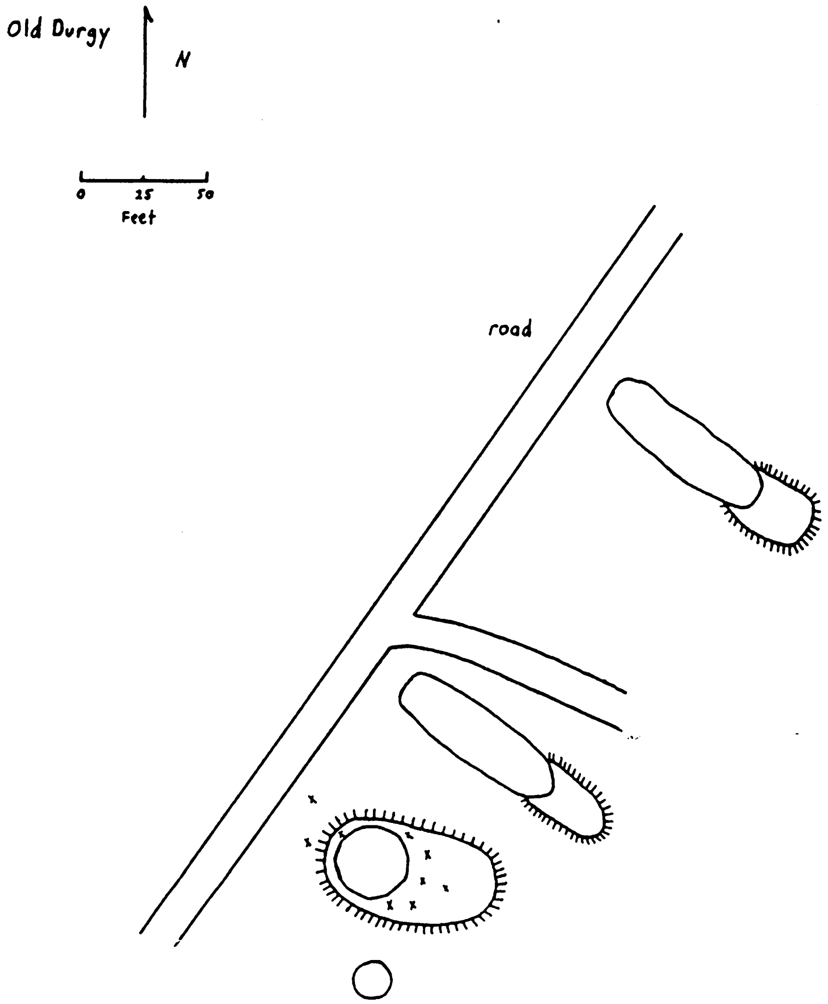

McHeny
N
0
25
50
Feet
reservoir


Morong
N
0
25
50
Feet
320'
adit

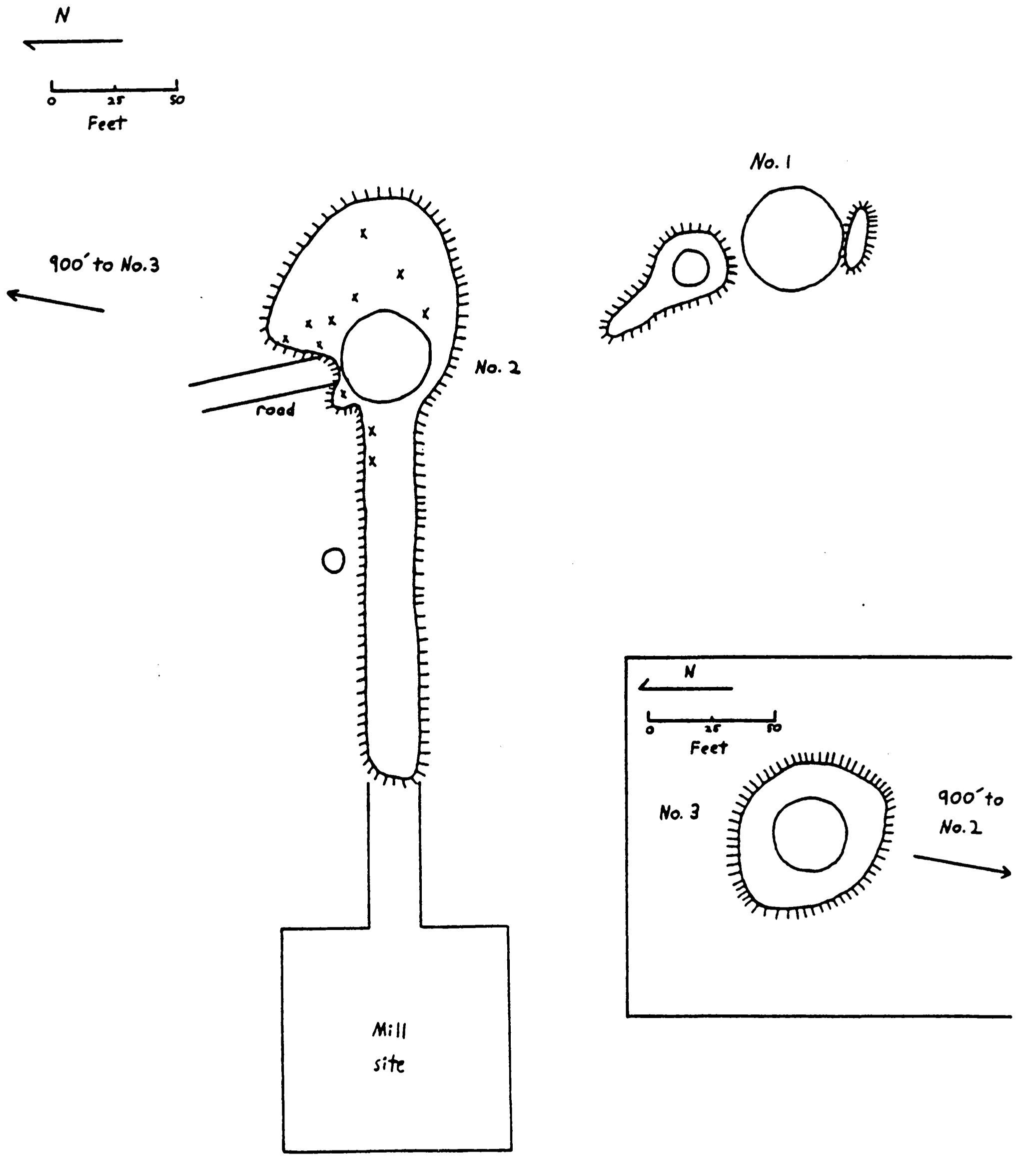

Pennebaker
N
0 25 50
Feet
NCSR
1328


Wall
N
0 25 50
Feet
VSR
737
driveway


Pontiac-Glasscock
N
0
25
50
Feet
440'
320'
240'
100'
VSR
734


Old Durgy
N
0
25
50
Feet
road

Seaboard


N
0
25
50
Feet
900′ to No.3
No. 1
No. 2
road
Mill
site
N
0
25
50
Feet
No. 3
900′ to
No. 2

APPENDIX C

REGIONAL GEOLOGY

Introduction

The Virgilina district (Figure 2) forms part of the Carolina slate belt, a band of low grade metamorphic rocks approximately 150 km wide and 640 km long that trends northeast-southwest, and comprises a portion of the Piedmont of the central and southern Appalachians. The district consists of an 88 km long strip of volcanic, volcaniclastic, and epiclastic rocks metamorphosed to greenschist facies and folded into the broad Virgilina synclinorium (Brown, 1953).

The formations that make up the synclinorium are the Precambrian Hyco formation, and the Precambrian-to-Cambrian Aaron and Virgilina formations (Harris, 1982). Although all three formations are intruded by multiple generations of quartz veins, the copper mineralization is almost entirely restricted to those veins occurring in the Virgilina formation.

Also included in or adjoining the district are several intrusive bodies: the Redoak granite and Abbyville gabbro in the north (Laney, 1917); the Roxboro metagranite to the southwest (Glover and Sinha, 1973; Briggs, et al, 1978);and several unnamed intrusives ranging in composition from quartz diorite to gabbro in the central and southeast portions of the district (Glover and Sinha, 1973; Kreisa, 1980). Also occurring are scattered dikes of granitic to basaltic composition (Laney, 1917; Hadley, 1973; Kreisa, 1980). The district is bounded by higher rank metamorphic rocks to both the west (Charlotte belt), and to the east (Raleigh belt).

Detailed geologic mapping in the district is incomplete. Kreisa mapped the Virginia part of the South Boston 15' quadrangle at 1:24,000 scale in 1972-74 (Kreisa, 1980), and Glover (Glover and Sinha, 1973) mapped in reconaissance fashion an area containing the North Carolina portion of the district. However, the only comprehensive map remains that of Laney (1917).

Hyco formation

The oldest formation of the district, the Hyco (pCh), occurs on the outer portions of the limbs of the synclinorium. Laney (1917) in his original description named the western exposures the Hyco quartz porphyry and the eastern exposures the Goshen schist. Conley (1978) was unable to distinguish the two in the field and concluded that the name Goshen schist was superfluous. Kreisa (1980) renamed these rocks the Hyco formation after his work and that of Glover and Sinha (1973), and Wright (1974) had indicated that the equivalent lithologies of the formation include felsic, intermediate, and mafic pyroclastics and lavas (Harris, 1982).

Laney considered the the Hyco to be unconformable with the underlying gneisses of the Charlotte belt, but Tobisch and Glover

(1969, 1971), Glover, et al (1971), and Kreisa (1980) found that the metamorphic grade increased to the west, and that Laney's contact was probably an isograd.

The upper contact with the Aaron formation was considered by Laney (1917) and Kreisa (1980) to be conformable, but mapping by Green, et al (1982), Harris (1982), and Newton (1983) indicate that it is unconformable. Harris (1982), in a detailed stratigraphic study southwest of the district, broke the Hyco into five distinct lithologic members, from oldest to youngest:

A) Andesitic to dacitic tuff breccia, lapilli tuff, and crystal tuff

B) Andesitic to dacitic pyroclastics, andesitic lavas, and volcanic breccias and conglomerates

C) Dacitic(?) pumaceous lapilli crystal tuff, tuff breccia and vitric tuff

D) Andesitic to basaltic(?) tuff breccia, lapilli tuff, and crystal tuff, with minor amygdaloidal basalts

E) Volcaniclastic conglomerate, lithic crystal-rich arenite, tuffaceous siltstone, dacitic lapilli crystal tuff, and vitric tuff.

The Hyco is 15,000 to 16,000 feet thick in the area of study (Kreisa, 1980; Glover and Sinha, 1973) and is intruded by several quartz diorite-diorite plutons. Glover and Sinha (1973), suggest that the presence of welded tuffs and poor sorting indicate a subaerial environment of deposition; however, Harris (1982) considers at least part of the deposition to have been subaqueous. Zircons from near Virgilina which yielded an U-Pb date of 620 million years (Glover and Sinha, 1973), and Edicarian fauna from Durham, N.C. (Cloud, et al,

1976) indicate that the Hyco is late Precambrian in age. For this report, the Hyco quartz porphyry and Goshen schist of Laney (1917), Unit II of Glover and Sinha (1973), and the Hyco formations of Kreisa (1980) and Harris (1982) are considered the same map unit.

Aaron formation

The Aaron formation (pCCa) overlies the Hyco formation and thus occurs closer to the axis of the synclinorium. Laney (1917), who named the formation the Aaron slate described it as containing both epiclastic sediments and mafic to felsic pyroclastics and lavas. Glover and Sinha (1973) separated the two lithologies, placing the epiclastic sediments in their Unit III, and the dominantly volcanic sequence in their Unit IV. Kreisa (1980) mapped an epiclastic sequence on top of the volcanics that Laney had considered part of the Aaron. In view of the lithologic similarity of the epiclastic sediments above and below the volcanics, Kreisa deleted the name Virgilina greenstone, named the epiclastic/volcanic/epiclastic sequence the Aaron formation, and assigned it three members, one for each lithology (Conley, 1978).

Harris (1982) considered that the lithologic differences and relative thicknesses of the Aaron and the Virgilina merited separation; however, his work does not deal with the Virgilina formation directly, as it is not exposed in his study area in central North Carolina. For the purposes of this report, the Aaron slate of Laney (1917), Unit III of Glover and Sinha (1973), the lower Aaron of Kreisa (1980), and the Aaron of Harris (1982) are considered to be the same map unit.

Harris (1982) was unable to rigorously characterize the depositional environment of the Aaron, but suggested that it may be analogous to a submarine fan sequence. He divided the formation into four facies associations as follows, from oldest to youngest:

A) Framework supported massive to graded(?) conglomerate, massive to stratified coarse-grained to pebbly arenites, and laminated to thin bedded siltstone;

B) Coarse-grained to pebbly arenite, trough cross bedded pebbly arenite, horizontally stratified arenite to pebbly arenite, and laminated to thin bedded siltstone;

C) Coarse-grained to pebbly arenite, stratified to pebbly arenite, siltstone, laminated argillite, and vitric tuff;

D) Coarse-grained to pebbly arenite, siltstone, argillite, and vitric tuff.

The Aaron is 3,000 to 6,000 feet thick in the area of study (Glover and Sinha, 1973; Kreisa, 1980) and is bracketed as being Late Precambrian-to-Early Cambrian in age by the 620 million year ago (mya) date for the Hyco and the 575 mya date for the Parks Crossroads granodiorite (Tingle, 1982).

Virgilina formation

The Virgilina formation (pCCv) lies along the axis of the synclinorium. Laney (1917), in his original description of the Virgilina greenstone recognized three lithologies; a tuffaceous phase, a porphyritic phase, and an amygdaloidal phase. The Unit IV of Glover and Sinha (1973) includes all of these as well as the volcanic upper lithologies of Laney's Aaron slate. As previously noted, Kreisa (1980) grouped these lithologies as the middle member of his Aaron formation, but Harris (1982) proposed that the volcanic and pyroclastic deposits retain the name Virgilina formation.

Obviously, an important question of slate belt geology that needs to be addressed is the correct stratigraphic sequence in this area and how this sequence correlates with the rest of the slate belt; however, a detailed unraveling of the stratigraphy in the district is beyond the scope of this study. Because the copper mineralization is virtually confined to the volcanic and pyroclastic rocks, this report will adhere to the convention that the Virgilina greenstone of Laney (1917), Unit IV of Glover and Sinha (1973), and the middle and upper Aaron of Kreisa (1980) are the Virgilina formation.

The Virgilina formation is 2,500 to 5,000 feet thick in the area of study and the age constraints late Precambrian to early Cambrian are the same as those of the Aaron formation. Although there has been no detailed sedimentological study in the district, a sequence that likely is correlative has been described in central North Carolina by Green, et al, (1982) as their units C_1, C_2, D and E, from oldest to youngest:

> C_1: Intermediate to mafic volcanics, including amygdaloidal basalt and andesite, tuff, mixed flows, and epiclastic volcanic breccias and conglomerates.
>
> C_2: Greywacke containing intermediate to mafic detritus, occasional volcanic conglomerate and breccia, siltstone, claystone, and locally, andesitic tuffs.
>
> D: Flow banded aphanitic to sparsely porphyritic rhyolites and dacites, finely laminated silty argillite and epiclastic sandstone, coarse lapilli tuff, medium and fine grained pyroclastics containing felsic lithic fragments, plagioclase crystals, and locally, rounded volcanic pebbles and cobbles.

E: Laminated mudstone with well-developed grading from silt to clay, grading upward to finely laminated sandstones and fine-grained greywackes.

Redoak granite

The Redoak granite, the northernmost of the major intrusive bodies, intrudes the sedimentary sequences in Charlotte county, Virginia. Laney (1917), in the only published description described the Redoak as a medium-grained, light grey, quartzose biotite granite, which contains orthoclase and plagioclase in roughly equal amounts. The rock is deeply weathered and virtually unexposed, hence, Laney mapped its contacts by changes in the nature of the overlying soil. An attempted study by Speer (J.A. Speer, personal communication) was prevented by the lack of exposures. Speer noted that most of the land had been cleared for farming when Laney studied the area, and further noted that any natural outcrops were probably submerged by the rise of the John H. Kerr reservoir.

Laney's map seems to indicate that the granite was intruded prior to at least one period of deformation. In view of this, and its position in the slate belt, a detailed petrologic and geochronologic study would seem to be in order; such a study would have great bearing on the tectonic modeling of the slate belt.

Abbeyville gabbro

Slightly southeast of the Redoak is the Abbeyville gabbro, also in Charlotte county. Laney (1917), provides the only description of the unit. He described the rock as dirty greenish-grey, containing hornblende, altered plagioclase, zoisite, clinozoisite, epidote, kaolin, sericite, chlorite, calcite, quartz, opaques, and in one thin section, traces of original pyroxene. Recent study has been hampered by the lack of exposures (J.A. Speer, personal communication).

Roxboro metagranite

The Roxboro metagranite occurs in Person county, North Carolina, just southwest of the Virgilina district where it intrudes the Hyco and Aaron formations on the northwest limb of the synclinorium. The first study of the pluton was by Glover and Sinha (1973), who described it as a granodiorite and determined that it was intruded after the formation of the synclinorium, but prior to regional metamorphism. Zircon ages (Glover, et al, 1971) indicated formation between 573 and 600 million years ago. .

Briggs studied the pluton in more detail (Briggs, 1974; Briggs, et al, 1978), and determined that it was actually granitic, with a composition that would plot near the granite-leucogranite boundary. He estimated the conditions of formation at 950° C, P =350 bars, and negligible P HO, and the metamorphic conditions as 400°C with a minimum pressure of 3 kb. The data led Briggs to conclude that the pluton may have been a shallow magma chamber that provided a source for eruptive rocks that are no longer present in the district. He also quoted unpublished data by Glover and Sinha indicating that the metamorphism occurred about 350 million years ago and was thus an Acadian event.

Other intrusives

Several other plutonic bodies occur in or adjacent to the district. They include a quartz diorite-granodiorite that intrudes the Hyco on the northwest limb of the synclinorium (Glover and Sinha, 1973; Kreisa, 1980), gabbroic units that intrude the Hyco on the southeast limb (Units II and V of Glover and Sinha, 1973), and porphyritic granodiorite and felsic porphyritic rock that also intrude the southeast limb (Units 1 and 3 of Glover and Sinha, 1973; Hadley, 1973).

The quartz diorite-granodiorite is medium- to fine-grained, with subdiabasic, pilotaxic, and hypidiomorphic textures in the virtually undeformed interior, and is deformed into a micaceous augen gneiss nearer to contacts (Kreisa, 1980). Contained in the pluton are areas of diorite and gabbro, as well as mafic xenoliths.

The gabbroic bodies include a porphyritic gabbro and a hornblende gabbro. The porphyritic unit is medium grained, gabbro to diorite, and occurs as a marginal phase of the porphyritic granodiorite described below (Glover and Sinha, 1973). The pluton is at least partially pre-metamorphic and bears a low greenschist facies imprint.

The hornblende gabbro is poorly exposed, but contact relations, texture, and mineralogical features led Glover and Sinha (1973) to conclude it is post-metamorphic.

The porphyritic granodiorite has the largest areal extent of any pluton on the southeast limb of the synclinorium. It is medium-grained, with phenocrysts of plagioclase, and ranges compositionally from granodiorite to quartz monzonite. Glover and Sinha (1973) infer a late stage volcanic venting of the magma chamber as the cause of graphic intergrowths of quartz and orthoclase.

The felsic porphyritic rock described by Glover and Sinha (1973) has its greatest extent on the southeast limb, but occurs throughout the area as small bodies. They considered the composition as probably dacitic, and believed it possible that this, along with the other intrusives, represents a magma chamber that supplied volcanics to the Hyco.

Dikes

Dikes with compositions ranging from granite to gabbro (Laney 1917) occur throughout the Virgilina district. Hadley (1973) describes dikes of metabasalt (greenstone) occurring east of the district, and Kreisa (1980) noted several diabasic dikes, including one corresponding to a magnetic high on U.S.G.S. Map GP-747 (1971). He interpreted this as evidence of a diabasic body at depth. The dikes cross-cut all of the sediments and some of the intrusive bodies; ages have been variously reported as early Paleozoic to late Triassic. Two of the mines in North Carolina, Durgy and Blue Wing, were discovered to have diabasic dikes cross-cutting the veins and ore.

Triassic sediments

Slightly northeast of South Boston is a small Triassic basin that overlies part of the Hyco formation. Kreisa (1980) described it as containing poorly sorted, fine, medium, and coarse greyish-red feldspathic sandstones interbedded with greyish-red shale, claystone, and locally, pebble-to-cobble conglomerate. The clasts in the conglomerate appear to be derived from the Charlotte belt rocks to the west.

Veins

All of the formations in the district are intruded by veins consisting primarily of quartz and calcite, with smaller amounts of epidote and orthoclase. As noted previously, the copper as well as the gold mineralization is virtually confined to veins occurring in the Virgilina formation.

The veins have strikes and dips generally similar to the schistosity of the country rock, but many are cross-cutting; some of these distinctly follow pre-existing fractures. They range in size from stringers less than 2.5 cm wide, to over 5 meters wide at the High Hill mine. Laney (1917) states that many of the mineralized veins could be followed, either by outcrop or float, for more than 1.5 km.

The ages of the veins are not firmly established: some veins show effects of deformation, indicating emplacement prior to a metamorphic event; others show ribbon structure and contain shards of country rock, possibly indicating emplacement during metamorphism. Probably there are several generations of veins, but a definitive answer awaits detailed mapping.

Structural features

The major structure in the Virgilina district is the Virgilina synclinorium that trends northeast-southwest through the district, and reaches a maximum width of roughly 32 km. It was recognized as a synclinorium by Laney (1917), and named thusly by Brown (1953), but no detailed description was available until the work of Glover and Sinha (1973). According to their data, the folding of the volcanic-volcaniclastic rocks occurred in the late Precambrian to early Cambrian and was limited to simple buckle folding; the major faults post-date this, as does the Roxboro metagranite intrusion. Slaty cleavage is subparallel to the axis of the synclinorium in parts of the map area, but diverges sharply in other parts. This indicates that cleavage development is younger than the folding.

The faults that terminate the Virgilina formation at the southern end of the district are apparently steeply dipping, and mapping of the various blocks (Glover and Sinha, 1973) indicates they have a left lateral offset of at least 16 km. Faulting was followed by the intrusion of the Roxboro metagranite, and then the regional metamorphism that Harris (1982) attributes to the Taconic (420 mya) orogeny. Harris also notes the presence of northeast trending brittle faults postdating the Taconic. These may have contributed to the formation of the dikes discussed previously.

Glover and Sinha (1973), Kreisa (1980), and Harris (1982) all mention the presence of short wavelength folds whose axes plunge with a more northerly trend than does the axis of the synclinorium. Near the axis of the synclinorium Kreisa (1980) also mapped a minor anticline that had been thrust from the west. Other structures are unmappable due to the lack of outcroppings and/or marker beds (Kreisa, 1980; Harris, 1982). Harris also comments that the folds lack discernable interference patterns which are generally an indicator of multiple deformations. He attributes this lack in part to the apparent near coaxiality of the deformations.

Laney (1917) was unable to find any relationship between the faulting in the district and the copper or gold mineralization.

APPENDIX D

MICROPROBE DATA

Microprobe data for sulfide and oxide phases were gathered on the VPI and SU ARL SEMQ microprobe. The operating conditions were 15 kv, 20 na, and counting times were 10 s on peak and background for oxides, 10 s on peak and 4 s on background for sulfides. ZAF corrections were by the method of Bence and Albee. Oxide analyses were recalculated based on procedures used by Rumble (1971) for oxide mineral recalculations. Standards were synthetic chalcocite and chalcopyrite for Cu, Fe, and S; synthetic tetrahedrite for Ag; Rockport fayalite for Fe; and synthetic tephroite and rutile for Mn and Ti.

Bornite analyses

Sample		Cu	Fe	Ag	S	Total
Wall	NEJ 00057	62.34	11.33	0.04	24.97	98.72
	NEJ 00057	62.68	11.26	0.04	24.91	98.89
	NEJ 00057	62.05	11.33	0.04	25.03	98.45
	NEJ 00057	62.40	11.31	0.02	25.10	98.83
	NEJ 00057	62.42	11.32	0.05	24.49	98.28
Holloway	NEJ 00125	64.02	11.22	0.07	25.54	100.85
	NEJ 00125	63.87	11.20	0.06	25.98	101.11
	NEJ 00125	64.07	11.11	0.06	25.87	101.11
	NEJ 00126	62.47	11.26	0.07	24.47	98.27
	NEJ 00126	62.81	11.12	0.08	24.86	98.87
Chappell	NEJ 00161	61.91	11.17	0.02	24.51	97.61
	NEJ 00161	62.07	11.22	0.08	24.50	97.87
	NEJ 00161	61.56	10.97	0.08	25.87	98.44
	NEJ 00161	62.21	11.09	0.06	24.97	98.33
	NEJ 00161	62.10	10.90	0.05	24.92	97.97
	NEJ 00161	62.02	10.86	0.02	24.77	97.68
	NEJ 00161	62.15	11.07	0	25.14	98.36
	NEJ 00161	61.38	10.92	0.05	25.10	97.45
	NEJ 00161	62.80	11.25	0.09	24.55	98.69
	NEJ 00161	62.23	10.78	0.07	24.30	97.38
	NEJ 00161	62.56	11.01	0.03	24.55	98.15
	NEJ 00161	63.37	11.36	0.04	25.00	99.77
	NEJ 00161	61.96	10.88	0.03	26.18	99.05
	NEJ 00161	63.40	11.09	0.08	24.80	99.37
	NEJ 00161	63.53	11.23	0.02	24.60	99.38
	NEJ 00161	63.30	11.07	0.06	24.90	99.38
	NEJ 00161	63.06	10.90	0.05	25.07	99.08
	NEJ 00161	63.58	10.75	0.07	24.12	98.52
Pontiac-Tuck	NEJ 00065	62.80	11.06	0.03	24.88	98.77
	NEJ 00065	62.29	11.02	0.06	25.38	98.75
	NEJ 00065	63.01	11.03	0	25.45	99.49
Littlejohn	NEJ 00190	61.85	10.98	0.08	25.73	98.64
	NEJ 00190	62.69	11.32	0.02	24.51	98.54
Crenshaw	NEJ 00206	60.85	11.88	0	26.00	98.73
	NEJ 00206	62.44	11.71	0.01	25.60	99.76

Bornite analyses

Sample		Cu	Fe	Ag	S	Total
Crenshaw	NEJ 00206	60.84	11.96	0.02	27.60	100.42
	NEJ 00206	61.79	12.27	0.03	26.69	100.78
	NEJ 00206	61.26	12.20	0	26.83	100.29
	NEJ 00206	62.46	11.44	0.05	24.57	98.52
	NEJ 00206	62.48	11.46	0.02	25.92	99.88
	NEJ 00206	62.46	11.31	0.05	26.44	100.05
	NEJ 00206	63.39	11.50	0.02	25.56	100.47
Pontiac-Glasscock	NEJ 00167	62.24	11.29	0.06	25.96	99.55
	NEJ 00167	62.39	11.52	0.01	25.98	99.90
	NEJ 00167	63.08	11.82	0.02	25.91	100.83
	NEJ 00169	61.84	11.23	0	25.46	98.53
	NEJ 00169	62.73	11.22	0.01	25.53	99.49
	NEJ 00169	62.21	11.14	0	25.85	99.15
	NEJ 00169	62.69	11.50	0.05	25.00	99.24
	NEJ 00169	62.68	11.24	0.02	25.53	99.45
	NEJ 00169	63.00	11.45	0.06	25.07	99.58
	NEJ 00169	62.25	11.40	0.04	24.98	98.67
	NEJ 00169	63.28	11.77	0.02	26.04	101.11
	NEJ 00169	62.16	11.31	0.02	25.20	98.69
	NEJ 00169	61.40	11.22	0.03	25.65	98.30
	NEJ 00169	61.89	11.34	0	25.17	98.40
Anaconda	NEJ 00071	62.56	11.37	0	25.12	99.05
	NEJ 00071	62.88	11.37	0.04	25.08	99.37
	NEJ 00071	62.64	11.28	0.01	24.98	98.91
Copper King	NEJ 00040	62.26	11.56	0.04	24.91	98.77
	NEJ 00040	62.84	11.53	0.05	24.87	99.29
	NEJ 00040	62.43	11.56	0.02	24.91	98.92
	NEJ 00040	62.47	11.58	0.06	25.15	99.26
Durgy	NEJ 00042	62.33	11.17	0	25.47	98.97
	NEJ 00042	62.68	11.23	0.23	25.73	99.87
	NEJ 00042	61.64	11.10	0.09	26.23	99.06
	NEJ 00042	61.81	11.18	0.12	25.93	99.04
	NEJ 00042	62.70	11.37	0.09	25.84	100.00
	NEJ 00176	61.54	10.96	0.06	26.16	98.72
	NEJ 00176	62.12	11.23	0.11	25.22	98.68

Bornite analyses

Sample		Cu	Fe	Ag	S	Total
Durgy	NEJ 00176	61.76	11.18	0.12	25.50	98.56
	NEJ 00176	62.26	11.20	0.10	25.60	99.16
	NEJ 00176	62.05	11.30	0.04	25.18	98.57
	NEJ 00176	61.35	11.40	0.03	26.89	99.67
	NEJ 00176	62.53	11.31	0.07	25.13	99.04
	NEJ 00176	62.45	11.40	0	25.27	99.12
	NEJ 00176	62.23	11.10	0.09	25.78	99.20
	NEJ 00176	62.22	11.22	0.08	26.40	99.92
Daniel's	NEJ 00208	61.84	11.09	0.05	25.94	98.92
	NEJ 00208	62.30	11.24	0.10	25.20	98.84
	NEJ 00208	59.55	12.84	0.08	26.63	99.10
	NEJ 00208	63.01	11.32	0.10	26.27	100.70
	NEJ 00208	61.52	11.49	0.08	25.79	99.72
	NEJ 00208	62.39	11.17	0.11	25.20	98.87
	NEJ 00208	62.47	11.12	0.06	25.32	98.97
	NEJ 00208	62.75	11.27	0.09	24.90	99.01
	NEJ 00208	62.28	11.20	0.03	25.11	98.62
	NEJ 00208	62.06	11.24	0.07	25.26	98.63
	NEJ 00208	62.06	11.24	0.07	25.26	98.63
Barnes	NEJ 00193	60.17	11.52	0	26.09	97.78
	NEJ 00193	60.63	11.59	0	26.04	98.26
	NEJ 00193	60.80	12.21	0	26.44	99.45
	NEJ 00193	59.92	12.06	0.05	26.11	98.14
Grove	NEJ 00217	59.73	11.60	0	26.84	98.17
	NEJ 00217	61.32	11.89	0.01	26.20	99.47
	NEJ 00217	61.81	11.87	0.02	25.49	99.19
	NEJ 00217	60.40	11.99	0.06	26.25	98.70
	NEJ 00217	60.72	12.02	0.01	26.05	98.80
	NEJ 00217	60.39	12.61	0.04	25.88	98.92
	NEJ 00217	62.29	11.75	0.07	25.83	99.94
Pandora	NEJ 00072	61.70	11.19	0.10	24.64	97.63
	NEJ 00072	63.01	11.08	0.05	25.38	99.52

Bornite analyses

Sample		Cu	Fe	Ag	S	Total
Pandora	NEJ 00072	62.92	11.28	0.07	24.71	98.98
	NEJ 00072	62.79	10.97	0.10	25.77	99.63
Blue Wing	NEJ 00032	62.58	10.70	0.11	25.25	98.64
	NEJ 00032	63.03	10.82	0.20	24.97	99.02
	NEJ 00032	61.99	11.12	0.26	25.24	98.61
	NEJ 00034	63.67	11.50	0.15	25.70	101.02
	NEJ 00034	63.50	11.06	0.19	25.55	100.30
	NEJ 00034	64.04	11.16	0.16	25.67	101.03
	NEJ 00034	61.97	12.49	0.15	26.84	101.45
	NEJ 00034	62.92	11.34	0.16	26.67	101.09
	NEJ 00034	63.03	10.82	0.20	24.97	99.02
McNeny	NEJ 00199	63.40	11.22	0	25.28	99.90
	NEJ 00199	62.44	11.03	0.03	25.76	99.26
	NEJ 00199	63.26	11.32	0.04	24.36	98.98
	NEJ 00199	62.60	10.90	0.02	25.25	98.77
Seaboard	NEJ 00145	63.22	11.64	0.06	25.80	100.72
	NEJ 00145	63.07	11.40	0.05	25.37	99.89
	NEJ 00145	63.72	11.52	0.02	25.75	101.01
	NEJ 00149	62.02	11.07	0.04	25.77	98.90
	NEJ 00149	62.39	11.11	0.06	24.56	98.12
High Hill	NEJ 00078	62.78	11.37	0.08	25.82	100.05
	NEJ 00078	62.68	11.23	0.07	25.78	99.76
	NEJ 00078	62.41	11.11	0.08	25.97	99.57
	NEJ 00122	61.46	11.62	0.06	26.25	99.37
	NEJ 00122	61.43	11.88	0	26.70	100.01
	NEJ 00122	61.50	11.76	0.01	27.74	101.01
	NEJ 00122	63.12	11.47	0	26.96	101.55
	NEJ 00122	61.17	12.21	0.04	26.69	100.11
	NEJ 00122	63.26	11.65	0.04	26.51	101.46

Chalcocite/Djurleite analyses

Sample		Cu	Fe	Ag	S	Total
Wall	NEJ 00057	77.66	0.03	0.15	20.23	98.07
	NEJ 00057	77.28	0	0.10	20.89	98.27
	NEJ 00057	77.75	0	0.15	20.26	98.11
Anaconda	NEJ 00070	79.38	0.03	0.02	20.73	100.16
	NEJ 00070	77.78	0.01	0.06	20.80	98.85
	NEJ 00071	77.48	0	0.06	21.02	98.34
	NEJ 00071	77.56	0	0.10	20.54	98.20
	NEJ 00071	78.43	0	0.09	20.34	98.86
	NEJ 00071	77.07	0.06	0.07	20.81	98.01
	NEJ 00071	78.55	0	0.05	20.58	99.18
Old Durgy	NEJ 00179	78.20	0.02	0.08	21.01	99.31
	NEJ 00179	77.61	0.03	0	20.68	98.32
	NEJ 00179	79.64	0.03	0.04	21.13	100.84
Chappell	NEJ 00161	78.74	0.04	0.02	20.61	99.41
	NEJ 00161	78.48	0.08	0.01	21.02	99.59
	NEJ 00161	78.65	0.03	0.04	20.95	99.67
	NEJ 00161	79.01	0	0.06	21.15	100.22
	NEJ 00161	78.88	0.05	0.10	20.98	100.01
	NEJ 00161	78.17	0.02	0.04	20.90	99.13
Pontiac-Tuck	NEJ 00065	77.18	0.12	0.19	20.24	97.73
	NEJ 00065	78.82	0.03	0.16	20.24	99.25
	NEJ 00065	78.44	0.06	0.18	21.03	99.71
	NEJ 00065	77.45	0.03	0.17	20.86	98.51
	NEJ 00065	77.78	0.05	0.23	20.63	98.69
	NEJ 00065	78.60	0.04	0.13	20.39	99.16
	NEJ 00065	77.78	0.05	0.16	20.56	98.55
	NEJ 00065	78.16	0.06	0.15	20.84	99.21
Cross-Cut	NEJ 00151	78.26	0.05	0.46	20.64	99.41
Blue Wing	NEJ 00032	78.30	0.04	0.21	21.11	99.66
	NEJ 00032	78.33	0.19	0.27	21.12	99.91
	NEJ 00032	77.88	0.10	0.17	20.38	98.53

Chalcocite/Djurleite analyses

Sample		Cu	Fe	Ag	S	Total
Littlejohn	NEJ 00186	78.17	0.04	0.04	20.94	99.19
	NEJ 00190	78.29	0.04	0.05	21.01	99.39
	NEJ 00190	79.24	0.06	0.07	20.83	100.20
McNeny	NEJ 00199	78.66	0.07	0.11	20.74	99.58
	NEJ 00199	79.16	0.05	0.08	20.80	100.09
	NEJ 00199	78.41	0.09	0.03	20.86	99.39
	NEJ 00199	79.16	0.03	0.04	20.78	100.01
Seaboard	NEJ 00149	78.94	0.10	0.13	20.24	99.41
	NEJ 00149	79.22	0.05	0.14	20.63	100.04
	NEJ 00149	78.66	0.08	0.17	19.85	98.76
	NEJ 00149	78.59	0.05	0.01	20.84	99.49
Holloway	NEJ 00125	79.43	0.08	0.03	20.41	99.95
	NEJ 00125	79.42	0.04	0.04	21.44	100.94
	NEJ 00126	78.33	0.04	0.05	21.11	99.53
	NEJ 00126	79.19	0.09	0.08	20.90	100.26
	NEJ 00126	78.31	0.03	0.10	20.94	99.38
	NEJ 00126	78.94	0.04	0.06	20.70	97.74

Anilite analyses

Sample		Cu	Fe	Ag	S	Total
High Hill	NEJ 00077	77.62	0	0.07	22.04	99.73
	NEJ 00077	77.70	0	0.07	22.20	99.97
	NEJ 00077	77.20	0	0.05	22.38	99.63
	NEJ 00077	77.59	0	0.02	22.35	99.96
	NEJ 00078	77.46	0.05	0.07	22.66	100.24
	NEJ 00078	76.50	0.04	0.18	22.47	99.19
	NEJ 00078	76.11	0.04	0.06	23.10	99.30
	NEJ 00080	77.11	0.03	0.06	22.38	99.55
	NEJ 00080	77.05	0.05	0.08	22.77	99.95
	NEJ 00080	76.50	0.04	0.10	22.79	99.47
	NEJ 00080	77.02	0.06	0.07	22.79	99.94
Durgy	NEJ 00042	76.34	0.04	0.08	22.76	99.22
	NEJ 00042	76.30	0.07	0.08	23.27	99.60
	NEJ 00042	75.00	0.02	0.18	22.38	97.58
	NEJ 00042	77.21	0.04	0.30	22.48	100.03
	NEJ 00042	77.22	0.01	0.04	22.01	99.28
	NEJ 00043	77.45	0.44	0.15	23.67	101.66
	NEJ 00043	77.02	0.46	0.11	23.56	101.15
	NEJ 00043	77.34	0.06	0.07	22.34	99.81
	NEJ 00043	76.98	0.04	0.16	22.29	99.47
	NEJ 00043	77.13	0.04	0.42	22.34	99.93
	NEJ 00043	76.22	0.17	0.10	22.86	99.35
	NEJ 00172	76.84	0.29	0.02	22.49	99.64
	NEJ 00172	75.32	0.22	0	22.85	98.39
	NEJ 00172	75.09	0.05	0.10	23.62	98.86
	NEJ 00176	77.08	0.16	0.13	22.60	99.97
	NEJ 00176	77.08	0.50	0.10	23.51	101.19
	NEJ 00176	76.50	0.20	0.06	22.82	99.58
Blue Wing	NEJ 00034	77.93	0.05	0.13	22.37	100.48
Anaconda	NEJ 00070	76.40	0.02	0.11	22.02	98.55
Holloway	NEJ 00126	76.69	0.03	0.06	22.42	99.20
	NEJ 00126	76.14	0.03	0.10	21.88	98.15

Anilite analyses

Sample		Cu	Fe	Ag	S	Total
Holloway	NEJ 00126	76.37	0.05	0.03	21.28	97.73
	NEJ 00126	76.84	0.05	0.05	21.74	98.68
Pandora	NEJ 00072	77.58	0.12	0.06	22.06	99.82
	NEJ 00072	77.46	0.46	0.15	22.50	100.57
	NEJ 00072	77.76	0.06	0.08	21.83	99.73
	NEJ 00072	77.69	0.08	0.08	22.10	99.95
	NEJ 00072	77.95	0.25	0.08	22.68	100.96
	NEJ 00072	77.58	0.24	0.08	21.95	99.85
Cross-Cut	NEJ 00151	76.63	0.04	0.19	22.09	98.95
	NEJ 00151	77.84	0.03	0.16	22.41	100.44
	NEJ 00151	77.44	0.05	0.21	22.30	99.95
	NEJ 00151	78.15	0.05	0.14	22.52	100.86
	NEJ 00151	77.56	0.05	0.21	22.37	100.19
	NEJ 00151	77.28	0.06	0.24	22.26	99.84
	NEJ 00151	77.05	0.02	0.19	22.21	99.47
	NEJ 00151	77.86	0.03	0.17	22.43	100.49
	NEJ 00151	77.07	0.01	0.16	22.23	99.47
	NEJ 00151	77.08	0.04	0.20	22.22	99.54
Daniel's	NEJ 00208	75.60	0.03	0.08	22.16	97.87
	NEJ 00208	76.91	0.02	0.06	21.64	98.63
	NEJ 00208	77.03	0.03	0.14	22.00	99.20
	NEJ 00208	76.54	0.01	0.16	21.78	98.48
	NEJ 00208	76.95	0.05	0.08	21.94	99.02

Digenite analyses

Sample		Cu	Fe	Ag	S	Total
Chappell	NEJ 00161	75.69	2.13	0.03	22.55	100.40
	NEJ 00161	77.21	0.75	0.08	21.34	99.38
	NEJ 00161	76.97	1.64	0.03	21.69	100.33
	NEJ 00161	77.18	1.06	0.03	21.35	99.62
	NEJ 00161	77.89	0.67	0	20.91	99.47
	NEJ 00161	77.12	1.62	0.04	22.00	100.78
Durgy	NEJ 00042	76.57	0.88	0.16	22.79	100.40
	NEJ 00042	77.46	0.77	0.11	22.50	100.84
	NEJ 00042	76.32	1.46	0.12	22.25	100.15
	NEJ 00043	76.80	1.22	0.06	23.73	101.81
	NEJ 00176	76.81	0.74	0.06	22.24	99.85
	NEJ 00176	76.69	0.77	0.10	21.76	99.32
	NEJ 00176	77.23	0.57	0.03	22.83	100.66
	NEJ 00176	76.90	0.64	0.06	22.49	100.09
	NEJ 00176	76.22	0.64	0.09	22.88	99.83
Daniel's	NEJ 00208	76.59	0.84	0.08	23.21	100.72
	NEJ 00208	75.72	1.58	0.07	21.83	99.20
	NEJ 00208	76.85	1.63	0.26	21.48	100.22
Crenshaw	NEJ 00206	75.44	1.46	0.01	22.70	99.61
Pontiac-Glasscock	NEJ 00169	75.19	2 08	0.10	22.28	99.65
	NEJ 00169	74.92	1.55	0.17	23.17	99.81
	NEJ 00169	74.91	1.66	0.03	22.86	99.46
	NEJ 00169	77.58	0.74	0.24	22.69	101.25
	NEJ 00169	77.82	0.99	0.07	23.43	102.31
	NEJ 00169	77.69	0.98	0.11	22.72	101.50
High Hill	NEJ 00078	76.17	0.59	0.04	22.38	98.18
	NEJ 00078	76.79	0.73	0	22.66	100.18
Seaboard	NEJ 00145	78.31	0.96	0.03	22.28	101.58

Covellite analyses

Sample		Cu	Fe	Ag	S	Total
Cross-Cut	NEJ 00151	66.61	0	0.08	32.69	99.38
	NEJ 00151	65.17	0.01	0.04	32.27	97.49
	NEJ 00151	65.28	0.01	0.13	31.73	97.16
	NEJ 00151	64.74	0	0.05	32.58	97.37
	NEJ 00151	65.65	0.02	0.04	32.20	97.91
	NEJ 00151	64.82	0.03	0.10	32.68	97.63
	NEJ 00151	65.37	0.01	0.05	32.80	98.23
	NEJ 00151	64.71	0.01	0.20	34.23	99.15
	NEJ 00151	65.47	0	0.08	33.09	98.64
	NEJ 00152	66.45	0.02	0.22	32.95	99.64
	NEJ 00152	66.36	0.01	0.16	33.26	99.79
Chappell	NEJ 00159	65.90	0	0.18	32.41	98.49
Durgy	NEJ 00172	66.39	0.18	0.01	32.49	99.07
	NEJ 00172	66.43	0.37	0.04	32.94	99.78
	NEJ 00172	66.53	0.05	0.06	32.83	99.47
	NEJ 00172	64.73	0.47	0.49	32.26	97.95
	NEJ 00172	65.42	0.06	0.24	34.34	100.06
	NEJ 00172	64.32	0.04	0.04	33.91	98.31
	NEJ 00172	65.16	0.51	0.08	33.80	99.55
	NEJ 00172	65.77	0.13	0.23	33.81	99.94
	NEJ 00172	66.30	0.16	0	33.07	99.53
	NEJ 00172	66.88	0.19	0.24	31.12	99.43
	NEJ 00172	65.56	0.23	0.25	33.28	99.32
	NEJ 00172	65.64	0.21	0.20	32.70	98.75
	NEJ 00172	66.21	0.70	0.10	32.94	99.95
	NEJ 00176	67.00	0.48	0.21	32.45	100.14
High Hill	NEJ 00080	65.70	0	0.14	33.44	99.28
	NEJ 00080	66.00	0.02	0.06	33.33	99.41
	NEJ 00080	66.43	0.01	0.06	33.37	99.87
	NEJ 00080	66.66	0.02	0.11	32.81	99.60

Spionkopite and Yarrowite analyses

Sample		Cu	Fe	Ag	S	Total
Blue Wing	NEJ 00029	68.31	0.35	0.12	30.20	98.98
	NEJ 00029	71.28	1.27	0.20	26.42	99.17
	NEJ 00029	68.31	0.38	0.15	31.23	100.07
Durgy	NEJ 00172	68.12	0.14	0.15	32.52	100.93
	NEJ 00172	68.82	0.98	0.22	30.96	100.98
	NEJ 00172	68.37	0.58	0.12	32.22	101.29
	NEJ 00172	67.45	0.30	0.18	32.33	100.26
	NEJ 00172	67.18	1.24	0.54	31.82	100.78
	NEJ 00172	67.32	1.16	0.71	31.37	100.56
	NEJ 00172	67.74	0.28	0.12	30.06	98.20
High Hill	NEJ 00122	70.24	1.40	0.10	29.91	101.65
	NEJ 00122	68.65	0.12	0.02	30.80	99.59
	NEJ 00122	68.88	0.29	0.11	31.02	100.30
Pandora	NEJ 00070	67.03	0.04	0.32	30.82	98.21
	NEJ 00070	66.42	0.10	0.27	31.28	98.07

Chalcopyrite Analyses

Sample		Cu	Fe	Ag	S	Total
Barnes	NEJ 00193	34.06	30.31	0	32.98	97.35
	NEJ 00193	33.54	29.52	0.01	34.54	97.61
	NEJ 00193	34.11	30.13	0	34.27	98.51
	NEJ 00193	34.51	30.31	0.02	33.91	98.75
	NEJ 00193	34.60	30.50	0.02	34.28	99.40
Pontiac-Glasscock	NEJ 00167	34.32	30.09	0	34.42	98.83
	NEJ 00167	33.84	29.92	0	35.38	99.14
	NEJ 00167	34.41	29.84	0.02	34.66	98.93
	NEJ 00167	34.27	30.21	0.01	34.29	98.78
	NEJ 00167	33.52	29.39	0	35.52	98.43
Morong	NEJ 00060	33.31	29.30	0.02	34.07	96.70
	NEJ 00060	33.42	29.16	0	34.42	97.00
Seaboard	NEJ 00145	33.78	30.17	0.01	34.70	98.66
	NEJ 00145	34.43	29.50	0	35.42	99.35
	NEJ 00145	34.24	30.44	0	33.47	98.15

Hematite Analyses

Sample		Fe_2O_3	FeO	TiO_2	MnO	MgO	Al_2O_3	SiO_2	Total	%hem	%ilm
Duke	NEJ 00137	94.10	2.75	2.89	0	0	0.03	0.07	99.84	95.25	5.49
	NEJ 00137	91.38	3.27	3.55	0.03	0	0	0.10	98.33	92.92	6.78
	NEJ 00137	93.98	1.85	2.03	0.01	0.02	0.01	0.07	97.97	95.89	3.82
	NEJ 00137	93.45	1.74	2.29	0	0.30	0.01	0.16	97.94	95.40	3.28
	NEJ 00137	92.42	3.45	3.78	0	0	0	0	99.66	92.69	7.19
	NEJ 00137	93.73	1.86	2.09	0.03	0	0	0	97.71	95.43	4.01
	NEJ 00137	94.56	2.27	2.55	0.02	0	0	0	99.40	95.13	4.81
	NEJ 00137	94.37	2.00	2.45	0.04	0.12	0.01	0.04	99.03	95.30	4.15
Cross-Cut	NEJ 00155	97.73	0.29	0.02	0	0	0.09	0.03	98.16	99.56	0.04
	NEJ 00155	98.09	0.28	0	0	0.06	0	0.06	98.49	99.60	0
	NEJ 00155	98.31	0	0	0.03	0	0	0.01	98.35	99.98	0
	NEJ 00155	97.64	0	0	0.03	0	0	0	97.67	99.98	0
Barnes	NEJ 00193	89.15	3.97	4.15	0	0	0.08	0	97.35	91.57	8.10
	NEJ 00193	96.10	0.72	0.27	0	0.08	0.22	0.01	97.40	98.67	0.21
	NEJ 00193	86.01	5.77	6.30	0	0	0.04	0	98.12	87.66	12.19
	NEJ 00193	89.05	4.09	4.42	0.01	0.04	0.06	0.02	97.69	91.16	8.43
	NEJ 00193	88.76	4.87	5.33	0	0	0.03	0	98.99	89.67	10.23
	NEJ 00193	86.70	5.61	5.95	0	0	0.09	0	98.34	88.15	11.48
	NEJ 00193	89.59	4.26	4.84	0	0.07	0.01	0	98.77	90.72	9.05
	NEJ 00193	96.68	1.21	1.34	0	0	0.02	0	99.25	97.39	2.57
	NEJ 00193	96.68	0.67	0.66	0.02	0.09	0.09	0.01	98.21	98.42	0.91
	NEJ 00193	98.16	0.36	0.10	0	0	0.10	0	98.72	99.44	0.18
	NEJ 00193	86.72	5.49	6.04	0	0	0.03	0	98.28	88.23	11.68
	NEJ 00193	90.72	3.64	4.06	0.01	0.15	0.10	0	98.68	91.92	7.22
	NEJ 00193	97.69	0.36	0.47	0	0.11	0.07	0	98.70	98.94	0.49
	NEJ 00193	97.22	0.35	0.36	0.02	0	0.05	0	98.00	99.16	0.67

Hematite Analyses

Sample		Fe_2O_3	FeO	TiO_2	MnO	MgO	Al_2O_3	SiO_2	Total	%hem	%ilm
Barnes	NEJ 00193	81.99	7.27	8.02	0	0	0.02	0	97.31	84.26	15.67
	NEJ 00196	97.98	0.39	0.13	0	0	0.10	0	98.60	99.37	0.25
	NEJ 00196	92.99	2.97	3.27	0	0	0.01	0	99.24	93.62	6.26
	NEJ 00196	97.18	0.78	0.69	0	0	0.08	0.02	98.75	98.35	1.31
	NEJ 00196	90.05	4.23	4.65	0.04	0	0.03	0	99.00	90.96	8.83
	NEJ 00196	98.98	0.56	0.39	0	0	0.08	0	100.01	98.96	0.75
	NEJ 00196	98.74	0.57	0.46	0	0.02	0.05	0.03	99.87	98.86	0.82
	NEJ 00196	82.80	7.95	8.84	0	0	0	0	99.59	83.14	16.86
	NEJ 00197	84.34	7.46	8.21	0	0.04	0.05	0	100.10	84.26	15.45
	NEJ 00197	97.88	1.10	0.98	0	0	0.08	0	100.40	97.83	1.85
	NEJ 00197	92.27	3.48	3.70	0.01	0	0.05	0	99.51	92.73	7.45
	NEJ 00197	97.33	0.99	0.30	0.02	0.02	0.28	0	99.95	98.38	0.45
	NEJ 00197	95.24	2.59	2.67	0.02	0.06	0.14	0	100.72	94.53	4.76
	NEJ 00197	86.31	6.48	7.13	0	0	0.02	0	99.94	86.36	13.54
	NEJ 00197	93.74	3.18	3.32	0	0	0.06	0.06	100.36	93.39	6.28
	NEJ 00197	100.25	0.23	0.19	0.01	0.07	0.10	0	100.85	99.38	0.07
	NEJ 00197	95.92	2.37	2.68	0	0.13	0.08	0	101.18	94.79	4.45
	NEJ 00197	93.43	3.96	4.20	0.05	0.03	0.10	0	101.77	91.81	7.61
Holloway	NEJ 00128	97.78	0.95	0	0.02	0.18	0.11	0.03	99.07	98.71	0
	NEJ 00128	97.14	1.28	1.35	0	0	0.02	0	99.79	97.33	2.58
	NEJ 00128	100.75	0.04	0.02	0	0	0	0.04	100.85	99.89	0.03
	NEJ 00128	97.18	0.34	0.09	0.01	0.11	0	0.12	97.85	99.32	0
	NEJ 00134	97.81	0.27	0.36	0	0.04	0.01	0.03	98.52	99.26	0.53
	NEJ 00134	97.20	0.70	0.56	0.01	0	0.04	0.12	98.63	98.54	1.04
	NEJ 00134	97.99	0.11	0.12	0.01	0.05	0	0.09	98.37	99.62	0.01
Anaconda	NEJ 00068	99.21	0.58	0.38	0.03	0	0.03	0.17	100.40	98.81	0.66
	NEJ 00068	99.04	0.22	0.19	0	0.07	0	0	99.52	99.68	0

<u>Hematite Analyses</u>

Sample		Fe_2O_3	FeO	TiO_2	MnO	MgO	Al_2O_3	SiO_2	Total	%hem	%ilm
Anaconda	NEJ 00068	99.29	0.66	0	0.02	0.08	0.01	0.30	100.36	98.93	0
	NEJ 00068	97.83	0	0	0	0	0	0	97.83	100.00	0
	NEJ 00068	98.12	0.61	0.30	0	0.26	0	0.19	99.48	98.62	0
	NEJ 00068	98.61	0.69	0.68	0.02	0.02	0	0.11	100.09	98.48	1.19
	NEJ 00068	98.31	0.33	0	0.05	0.01	0	0.31	99.01	99.29	0
Chappell	NEJ 00157	94.23	1.89	2.39	0	0.15	0	0.03	98.69	95.46	4.04
	NEJ 00157	95.20	1.97	2.25	0.01	0.04	0	0.03	99.50	95.67	4.11
	NEJ 00157	98.49	0.03	0.01	0	0	0	0	98.53	99.93	0.03
	NEJ 00157	100.35	0.02	0.03	0	0	0	0	100.40	99.95	0.05
	NEJ 00157	100.36	0.04	0.05	0.02	0.04	0	0	100.51	99.85	0
	NEJ 00157	99.09	0.04	0	0.08	0	0	0.11	99.32	99.77	0
	NEJ 00157	94.06	1.92	2.00	0	0	0	0.11	98.09	95.88	3.88
	NEJ 00157	94.90	1.66	1.81	0	0.05	0	0.11	98.52	96.32	3.28
	NEJ 00157	96.25	1.16	0.92	0.02	0	0.06	0.17	98.58	97.63	1.71
	NEJ 00157	93.17	2.06	2.21	0	0	0.01	0.05	97.50	95.56	4.30
	NEJ 00157	92.65	2.57	2.77	0	0.03	0	0.11	98.13	94.42	5.26
	NEJ 00161	92.59	2.74	2.92	0	0	0	0.10	98.35	94.14	5.63
	NEJ 00161	94.35	2.28	2.67	0	0.08	0	0.03	99.41	94.41	4.79
	NEJ 00161	94.88	1.53	1.55	0.02	0	0	0.14	98.12	96.70	2.97
	NEJ 00161	94.71	1.18	1.78	0	0.28	0	0.10	98.05	96.58	2.35
	NEJ 00161	94.52	1.68	1.85	0.01	0	0	0.03	98.09	96.35	3.56
Crenshaw	NEJ 00202	100.58	0.27	0.02	0.04	0	0.10	0.01	101.02	99.56	0
	NEJ 00202	97.72	0.39	0.05	0	0	0.08	0.32	98.66	98.94	0.10
	NEJ 00202	100.79	0.09	0.08	0.03	0	0.03	0.05	101.07	99.61	0.09
	NEJ 00202	100.53	0.51	0.01	0.03	0.05	0.13	0.04	101.30	99.20	0
	NEJ 00202	99.27	1.00	0.03	0	0.15	0.16	0.06	100.67	98.62	0
Old Durgy	NEJ 00177	99.43	0.09	0.01	0	0	0	0.08	99.61	99.82	0.02

Hematite Analyses

Sample		Fe_2O_3	FeO	TiO_2	MnO	MgO	Al_2O_3	SiO_2	Total	%hem	%ilm
Old Durgy	NEJ 00177	97.07	1.19	1.21	0.01	0	0	0.11	99.59	97.46	2.27
	NEJ 00177	99.46	0.62	0.08	0	0.17	0	0.14	100.47	98.95	0
	NEJ 00177	99.88	0.08	0.09	0	0	0	0	100.05	99.82	0.18
	NEJ 00177	98.78	0.70	0.32	0.01	0.09	0.16	0.11	100.17	98.60	0.27
	NEJ 00177	100.38	0.38	0.02	0	0	0.10	0.08	100.96	99.43	0.04
	NEJ 00177	99.38	0.15	0.02	0.02	0	0.01	0.11	99.69	99.68	0.01
	NEJ 00181	99.18	0.04	0.05	0	0	0	0	99.27	99.91	0.09
	NEJ 00181	99.24	0.32	0.10	0	0	0.06	0.07	99.79	99.45	0.19
	NEJ 00181	99.11	0.72	0	0	0	0.25	0.01	100.09	99.020	0
	NEJ 00181	96.55	0.42	0.62	0	0.08	0	0	97.67	98.85	0.92
	NEJ 00181	100.42	0	0	0	0	0	0	100.42	100.00	0
	NEJ 00181	100.63	0.07	0.07	0.02	0	0	0.02	100.81	99.80	0.09
	NEJ 00181	100.89	0	0.01	0.04	0	0	0	100.94	99.99	0
	NEJ 00181	99.76	0.53	0.03	0	0	0.13	0.12	100.57	99.20	0.05
	NEJ 00181	99.48	0.08	0	0	0	0	0.07	99.63	99.85	0.02
	NEJ 00182	100.89	1.07	0	0	0	0.34	0.09	102.39	98.53	0
	NEJ 00182	100.83	0.45	0.36	0.02	0	0.02	0.09	101.77	99.09	0.64
	NEJ 00182	97.83	1.04	0	0	0	0.37	0	99.24	98.58	0
	NEJ 00182	98.17	0.07	0.02	0	0	0.02	0	98.28	99.89	0.04
	NEJ 00182	98.61	0.08	0.10	0	0	0	0	98.79	99.81	0.19
	NEJ 00182	97.73	1.55	0.60	0	0.06	0.40	0	100.34	97.40	0.89

Magnetite Analyses

Sample		Fe_2O_3	FeO	TiO_2	MnO	MgO	Al_2O_3	SiO_2	Total
Anaconda	NEJ 00068	70.91	29.81	0.01	0.05	0.14	0	0.42	101.34
	NEJ 00068	70.68	29.30	0.01	0.07	0	0	0.26	100.32
	NEJ 00068	70.62	29.47	0	0.08	0	0	0.37	100.54
	NEJ 00068	71.03	29.28	0	0.03	0.02	0	0.21	100.57
Crenshaw	NEJ 00202	70.39	28.54	0.01	0.05	0.01	0.15	0	99.15
	NEJ 00202	70.70	28.74	0.06	0.03	0	0.08	0.01	99.62
	NEJ 00202	70.52	28.77	0.04	0.03	0	0.12	0.03	99.51
	NEJ 00202	70.15	28.58	0.04	0	0	0.06	0.03	98.86
	NEJ 00202	69.39	28.33	0.05	0.03	0.23	0.05	0.04	98.12
	NEJ 00202	70.79	28.79	0.03	0	0	0.12	0	99.73
	NEJ 00202	70.48	28.66	0.02	0.03	0	0.07	0.03	99.29
	NEJ 00202	70.57	28.65	0.01	0.05	0.08	0.09	0	99.45
	NEJ 00204	69.85	28.49	0	0.02	0	0.11	0.06	98.53
	NEJ 00204	71.08	29.21	0.05	0.03	0	0.15	0.11	100.62
	NEJ 00204	70.82	28.75	0.02	0.08	0	0.05	0	99.72
	NEJ 00204	70.77	28.82	0.02	0	0.16	0.04	0.05	99.86
	NEJ 00204	71.36	28.92	0.01	0.03	0.01	0.12	0	100.45
	NEJ 00204	71.58	29.08	0.04	0.03	0.03	0.07	0	100.83
	NEJ 00204	72.40	29.44	0.04	0	0	0.08	0.02	101.98
	NEJ 00204	72.03	29.32	0.01	0.01	0.13	0.10	0.05	101.65
	NEJ 00204	70.68	28.71	0.03	0.02	0	0.08	0.03	99.55
	NEJ 00204	71.74	29.24	0.04	0.06	0	0	0.04	101.12
	NEJ 00204	71.05	28.86	0.04	0.01	0	0.04	0.03	100.03

Ilmenite Analyses

Sample		Fe_2O_3	FeO	TiO_2	MnO	MgO	Al_2O_3	SiO_2	Total	%hem	%ilm
Crenshaw	NEJ 00202	0	43.81	52.69	3.54	0	0.02	0.03	100.09	0	95.58
	NEJ 00202	8.00	38.79	47.65	3.78	0	0	0.02	98.24	8.12	83.68
	NEJ 00202	0.30	40.98	51.19	4.93	0	0	0.04	97.44	0.30	88.87

APPENDIX E

POWDER X-RAY DATA

Powder x-ray data were collected on a 360 mm diameter Gandolfi camera using Ni-filtered Cu K-alpha radiation. Material to be examined was removed from polished sections, mounted on glass fibers and run for 15-48 hours, depending on sample size. Film intensities were estimated visually. Data collected were then compared with ASTM data from the 1979 ASTM Powder Data File.

Djurleite
Durgy mine
NEJ 00043

D-spacing	Intensity
3.767	W
3.590	VW
3.395	M
3.189	W
3.043	M
2.914	W
2.851	W
2.730	VW
2.679	VW
2.583	VW
2.532	VW
2.483	VW
2.401	VS
2.087	VVW
2.040	VVW
1.979	S
1.926	VVW
1.881	VS
1.785	VVW
1.694	M
1.652	W
1.549	VW
1.279	M

Djurleite
Blue Wing mine
NEJ 00034

D-spacing	Intensity
4.31	VW
3.94	VVW
3.76	W
3.59	VW
3.426	M
3.369	M
3.195	W
3.023	M
2.885	M
2.745	VW
2.694	VW
2.594	VVW
2.485	VVW
2.392	VS
2.228	VVW
2.068	VW
1.977	S
1.953	S
1.879	VVS
1.698	M
1.648	W

Djurleite
Holloway mine
NEJ 00134

D-spacing	Intensity
4.28	VW
3.75	VW
3.38	S
3.19	VVW
3.08	M
2.85	W
2.68	W
2.51	W
2.38	VS
2.27	VVW
2.22	VVW
2.13	VVW
2.05	M
1.96	VS
1.87	VVS
1.78	VW
1.69	S
1.64	S

Anilite
Pandora mine
NEJ 00070

D-spacing	Intensity
3.363	VVW
3.206	S
3.010	VVW
2.790	M
2.503	VW
2.327	VVW
2.158	W
1.960	VS
1.391	VVW

Chalcocite
Pontiac mine-Tuck shaft
NEJ 00064

D-spacing	Intensity
4.215	VW
3.723	W
3.597	W
3.255	M
3.164	MS
3.053	VW
2.938	M
2.851	VVW
2.738	W
2.679	VVW
2.614	VVW
2.541	W
2.466	W
2.404	VS
2.332	W
2.248	VVW
2.214	MS
2.132	VW
1.980	VVS
1.914	VVW
1.882	VVS

Djurleite
Chappell mine
NEJ 00160

D-spacing	Intensity
3.766	W
3.593	VW
3.388	M
3.284	VW
3.206	VW
3.214	VW
3.028	MW
2.891	W
2.820	VW
2.716	W
2.665	W
2.571	VVW
2.468	VVW
2.395	VS
2.150	VVW
2.079	VVW
1.961	VS
1.870	VVS
1.782	VW
1.692	MS
1.645	W
1.541	VVW
1.520	W

Chalcocite
Barnes mine
NEJ 00194

D-spacing	Intensity
2.392	S
2.323	VVW
2.231	W
2.119	VW
1.971	VS
1.880	VS
1.801	VVW
1.703	VW

Chalcocite
Wall mine
NEJ 00056

D-spacing	Intensity
4.260	VW
3.746	W
3.608	W
3.278	MS
3.173	MS
3.074	W
2.962	M
2.855	VVW
2.818	M
2.677	VVW
2.611	VVW
2.536	M
2.476	M
2.408	VS
2.335	W
2.244	VW
2.215	S
2.134	W
1.979	VS
1.921	VW
1.888	VS
1.797	W
1.717	M
1.691	M
1.665	VW

Chalcocite
Seaboard mine
NEJ 00145

D-spacing	Intensity
4.235	VVW
3.742	W
3.601	W
3.424	VVW
3.302	M
3.173	M
3.056	VW
2.957	M
2.728	M
2.654	VW
2.536	M
2.481	M
2.403	S
2.332	M
2.212	VW
2.134	VVW
1.978	VS
1.885	VVS
1.798	VVW
1.703	M

Chalcopyrite
Seaboard mine
NEJ 00149

D-spacing	Intensity
3.370	VVW
3.038	VS
2.650	VW
2.322	VVW
1.862	S
1.596	M
1.576	M
1.520	VVW
1.319	W
1.303	VW
1.214	VW
1.206	VW

Anilite
Durgy mine
NEJ 00046

D-spacing	Intensity
3.369	M
3.206	S
2.782	S
2.704	VW
2.616	VW
2.546	W
2.383	VVW
2.202	W
2.128	VW
2.059	VW
1.961	VS
1.934	W
1.674	S
1.566	W

Djurleite
Copper King mine
NEJ 00049

D-spacing	Intensity
3.75	VW
3.38	M
3.28	VW
3.12	VW
3.02	W
2.892	M
2.822	M
2.716	VW
2.661	VW
2.565	VVW
2.523	VVW
2.480	VVW
2.981	VS
2.071	W
1.957	S
1.875	VS
1.690	S
1.650	W
1.515	VW
1.280	VVW

Chalcocite
McNeny mine
NEJ 00199

D-spacing	Intensity
4.205	VW
3.727	W
3.593	W
3.284	M
3.167	M
3.051	VVW
2.942	M
2.853	VVW
2.732	M
2.637	VVW
2.542	W
2.475	W
2.408	VS
2.329	W
2.211	M
2.214	VVW
1.979	VVS
1.879	VS
1.794	VVW
1.710	VVW
1.684	VVW

Chalcopyrite
Pontiac mine-Glasscock shaft
NEJ 00167

D-spacing	Intensity
3.323	VVW
3.048	VS
2.644	VW
1.862	S
1.603	M
1.581	M
1.327	W
1.306	W
1.209	W

APPENDIX F

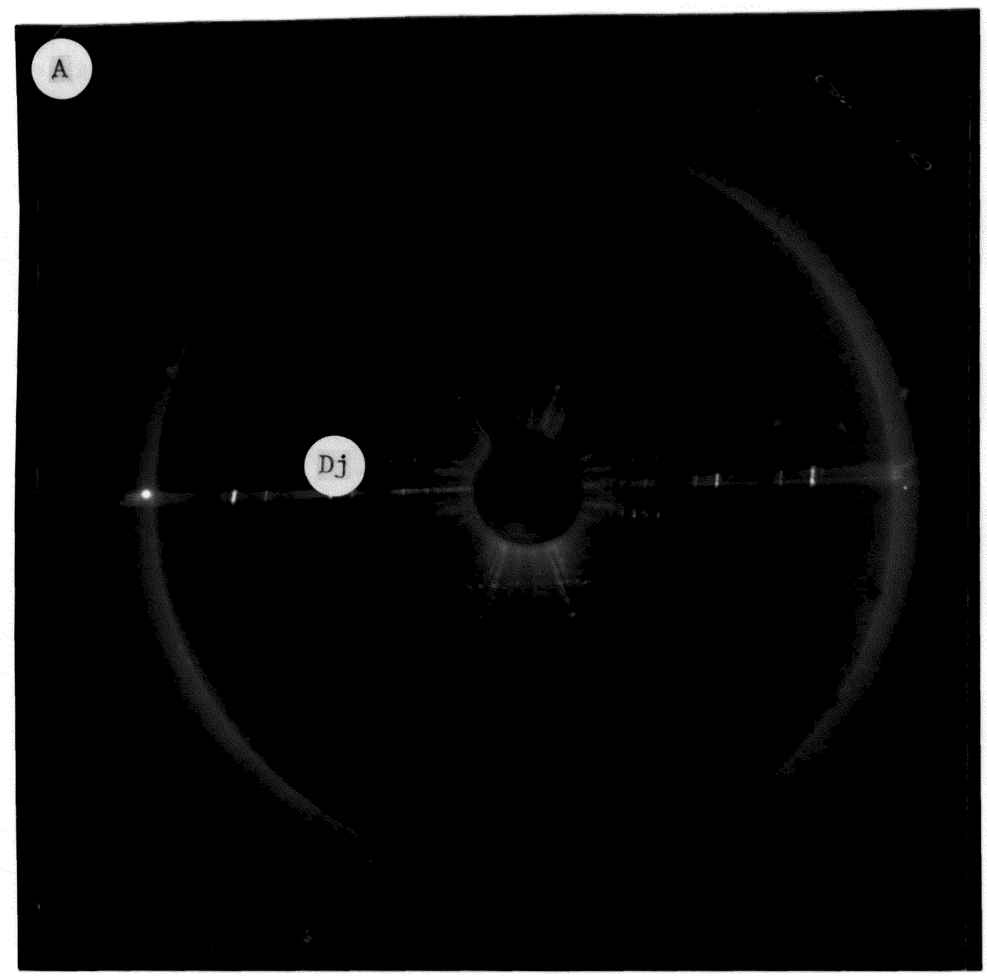
SINGLE CRYSTAL DATA

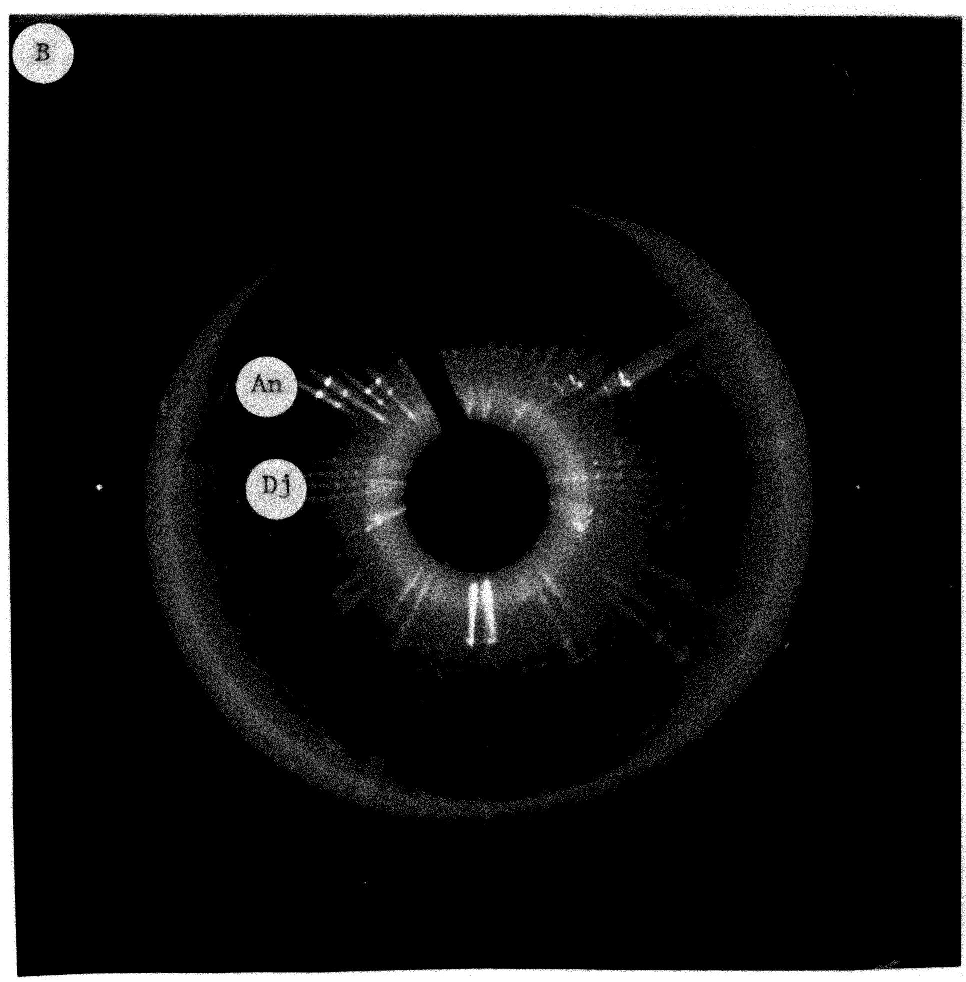
Single crystal x-ray data were collected on a Huber precession camera using Zr filtered Mo K-alpha radiation. Material for examination was removed from polished sections, mounted on glass fibers, and run for 48-240 hours, depending on sample size. Cell dimensions were read from processed films and compared with published cell dimensions for anilite and djurleite.

Anilite is orthorhombic, Pnma, with cell dimensions a= 7.89 A, b= 7.84 A, and c= 11.01 A. The sulfur atoms approximate a cubic-closest packed array, with copper atoms in the interstices, and the close-packed planes are perpendicular to(011) (Koto and Morimoto, 1970). Djurleite is monoclinic, P2/n, with cell dimensions a= 26.897 A, b= 15.745 A, c= 13.565 A, and B= 90.13 degrees (Evans, 1979). The sulfur atoms in djurleite approximate an hexagonal-close packed array with copper atoms in the interstices, and the close-packed planes are perpendicular to (100).

In Figure 24 the diffraction patterns of djurleite and anilite are both labeled. As can be seen, the reflections from the (100) of djurleite are parallel to the reflections from the (011) of anilite, indicating that the anilite-djurleite lamellae are intergrown on their respective close-packed planes.

Figure 25 : Buerger precession photographs of anilite-djurleite intergrowths: A. 0-level, 72 hours, 25 degree precession angle. B. 0-level, 228 hours, 15 degree precession angle.


A
Dj


B
An
Dj

A STUDY OF THE VEIN COPPER MINERALIZATION OF THE VIRGILINA DISTRICT, VIRGINIA AND NORTH CAROLINA.

by

Neil Evan Johnson

(ABSTRACT)

The Virgilina District, which occurs in the Carolina Slate Belt of Virginia and North Carolina, produced over 300,000 tons of copper and significant amounts of silver and gold between 1852 and 1916. A detailed examination of the ore and gangue mineralization from the district reveals that the ores display two stages of hypogene deposition and a significant phase of supergene alteration.

Hypogene mineralization, in decreasing order of abundance, consists of bornite, chalcocite/djurleite, anilite, digenite, hematite, chalcopyrite, pyrite, magnetite, ilmenite, rutile, hessite, and gold (fineness 850). Supergene mineralization, in decreasing order of abundance, is malachite, covellite, cuprite, digenite, hematite, chalcopyrite, chalcocite/djurleite, azurite, spionkopite, and yarrowite. This represents the first reported occurrence of djurleite, anilite, hessite, spionkopite, and yarrowite in the area.

Lamellar intergrowths of anilite and djurleite on their close packed planes, myrmekitic intergrowths of bornite and chalcocite/djurleite, coexisting chalcocite and djurleite, and gradational transitions from anilite to digenite were determined to have formed by secondary hypogene reactions that removed iron and sulfur from the bornite and

increased the copper:sulfur ratio, which shifted the Cu-S binary phases towards copper and produced the decribed textures and intergrowths.

The nature of the source of ore fluids and the timing of the mineralization are not known precisely. Fragments of wall rock contained within the veins with schistosity at an angle to the regional schistosity constrain the veins to be post-Taconic, and the metals are likely derived in part from the metamorphosed mafic volcanics in the area.