MASSIVE SULFIDES OF VIRGINIA FIELD TRIP

GUIDEBOOK

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Reston, Virginia 22092

78-1068

Field trip, an outgrowth of International Geological Correlation Programme, Project No. 60, Correlation of Caledonian Stratabound Sulphides.

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by

J. E. Gair

Stratabound massive sulfide deposits of Virginia originated in two distinctly different environments in the Blue Ridge and the Piedmont geologic provinces (figs. 1,10). Deposits in the Piedmont are closely and obviously associated with metavolcanic rocks, which originated in an island arc or other volcanic chain; those in the Blue Ridge province are physically associated with metasedimentary rocks formed in a rift zone, and some of those rocks are interbedded with mafic metavolcanic rocks, but the relationship of the sulfide deposits to volcanism, if any, is tenuous.

Blue Ridge Province

Stratabound sulfide deposits in the Blue Ridge province formed during sedimentation and volcanism accompanying or closely following rifting near the eastern edge of the North American continental plate. The rifting initiated the opening of Iapetus, the proto-Atlantic Ocean in late Precambrian to Middle or Late Cambrian time. In the rift zone, probable grabenlike basins bordered both to the east and to the west a horstlike ridge or line of ridges of 1-billion-year-old (basement) granitic gneiss that now forms the core and axis of the Blue Ridge anticlinorium. Sulfide deposits in the Blue Ridge province in Virginia are found mainly at the Great Gossan Lead in the southwestern part of the state and formed in such a grabenlike basin on the east side of the Blue Ridge axis. This basin was underlain by continental crust and was bounded to the southeast by a horstlike outlier of continental crust which now forms the core of the Sauratown Mountains anticlinorium.

_/ Condensed and slightly modified from Gair and Slack, in press.

Parts of the uplifted basement core of the Blue Ridge were above sea level in late Precambrian (Z) time and were covered by rhyolite-basalt eruptions of the Mount Rogers Formation and associated sedimentary rocks in southwest Virginia, and mainly by basalt of the Catoctin Formation from central Virginia northward to southern Pennsylvania. Basement schist and gneiss in the core of the present Sauratown Mountains anticlinorium formed a shallow ridge or platform southeast of the Blue Ridge axis and were covered by deposits of clean sand, now quartzite. Contemporaneously with the subaerial volcanism in southwestern Virginia and somewhat earlier in west-central and northwestern Virginia, thick submarine wedges of sulfidic and carbonaceous graywacke, siltstone, and shale accumulated in the rift basin or basins flanking the Blue Ridge on the east. These rocks now constitute the Ashe and correlative Lynchburg Formations. Submarine eruptions of mafic lava were common in the rift basin or basins east of the Blue Ridge axis and now are seen as amphibolite making up an integral part of the Ashe Formation.

Metamorphism related to the Taconic orogeny, and possibly also to the Acadian orogeny—these orogenies in turn being related to the closing of the Iapetus Ocean—has affected the rocks and sulfide deposits of the Blue Ridge province (and also of the Piedmont province). In the Great Gossan Lead district, metamorphism reached amphibolite grade, characterized by the index minerals hornblende, almandine garnet, and staurolite. Much original pyrite of the deposits was converted to pyrrhotite by the metamorphism.

The pyrrhotite/pyrite deposits of the Great Gossan Lead are among the largest sulfide deposits of the Appalachians, together having mass of at least 20 million metric tons. The sulfide deposits evidently are located entirely within metasedimentary rocks—metagraywacke, sericitic quartzite, and quartz-muscovite schist and phyllite. Whether the lenses of schist or phyllite rich in chlorite or biotite that occur in or near some sulfide bodies are of sedimentary, volcanic, or strictly metamorphic origin is uncertain. The unequivocal mafic metavolcanic rocks of the Ashe Formation occur both across strike from orebodies, and nearly on strike to the southwest, but apparently are nowhere in contact with any sulfide bodies. In rocks far to the southwest in Georgia that are probably equivalent, sulfide deposits occur in amphibolite and other mafic metavolcanic layers, but not in the metasedimentary rocks.

The sulfide deposits constituting the Great Gossan Lead are generally in lenses 500 meters or less in length and 30 meters or less thick. The entire Gossan Lead, 28 km in length, consists of a number of such lenses, grouped in 8 major segments separated by barren rock or by sulfide zones too thin or low in grade to be of economic interest (fig. 9). Major segments of the Great Gossan Lead, from southwest to northeast, are the Iron Ridge, Chestnut Creek, Copperas Hill, Sarah Ellen, Wildcat, Cranberry, Reed Island Creek, and Betty Baker. Mining has been done principally in the Iron Ridge, Copperas Hill, Cranberry, and Betty Baker segments. The largest deposits mined have been in the Iron Ridge and Betty Baker segments. On this excursion, visits will be made to two deposits in the Iron Ridge segment, about 5 km north of Galax , Va. and to one deposit in the Betty Baker segment, 10 km north of Hillsville, Va.

Piedmont Province

Important stratabound sulfide deposits occur in the Piedmont Province along a nearly continuous belt of felsic and mafic metavolcanic rock and associated pelitic and siliceous metasedimentary rock of probable Cambrian age. The belt extends northeastward 300 km from south-central Virginia to northeastern Maryland. The rocks of this belt are the Chopawamsic Formation in Virginia (fig. 1) and the James Run Formation in Maryland. Known sulfide deposits are present only in the Virginia part of the belt, in the Chopawamsic Formation. The volcanic/volcaniclastic belt probably formed as a chain of volcanoes on submerged sialic crust, underthrust by subducted oceanic crust (see discussion of Chopawamsic Formation by Louis Pavlides). The initial location of the Chopawamsic-James Run belt relative to the North American and Euro-African continental plates and the intervening basin of the Iapetus Ocean is speculative. The volcanic chain may have formed along the east edge of the North American continental plate, along the west edge of the Euro-African plate, or on detached continental crust, a microcontinent, within the Iapetus basin. Whichever of these possibilities was the initial setting of the Chopawamsic-James Run volcanic chain, closure of the Iapetus basin which took place largely during the Taconic orogeny between Late Cambrian and Late Ordovician time, juxtaposed the Chopawamsic-James Run belt with North American supracrustal rocks. In the Maryland part of the volcanic belt, however, the James Run Formation lies east of the ophiolitic rocks of the Baltimore Complex (lower Paleozoic), which evidently formed as oceanic crust in the Iapetus basin during the Cambrian and was later thrust westward (obducted ?) against the Baltimore Gneiss domes (Precambrian) during the closing of the basin. The Baltimore Gneiss domes, similar to the Sauratown Mountains anticlinorium mentioned above, are segments of continental crust that probably were detached from the North American plate during late Precambrian rifting that separated the North American from the Euro-African plate and opened the Iapetus basin. Thus, it is likely that the Chopawamsic-James Run volcanic belt formed both east of detached segments of the North American plate such as represented by the Baltimore Gneiss domes, and east of segments of oceanic crust such as are seen in the Baltimore Complex. From this evidence and reasoning, it is more likely that the Chopawamsic-James Run belt was probably associated in its formation with a microcontinent in the Iapetus basin, or with the Euro-African plate, rather than with the North American plate.

Younger volcanic and argillaceous sedimentary rocks of the Carolina volcanic slate belt, which form a large part of the Piedmont Province south of Virginia, are probably coeval with the Chopawamsic, but their possible correlation with the Chopawamsic is highly uncertain. The slate belt rocks contain the Cambrian trilobite, Paradoxides, of Euro-African affinity, suggesting that the slate belt rocks formed on the east side of the Iapetus Ocean. The south end of the Chopawamsic belt, although near the northwest edge of the slate belt, appears to project somewhat west of the slate belt rocks. The Chopawamsic and slate belt rocks may also originally have been in nearly contiguous positions with one another on the east side of the Iapetus Ocean, or they may have been far apart originally and telescoped into such positions during the closing of the Iapetus.

Metamorphism of the Chopawamsic is in the greenschist facies in the northern part of the belt, but increases to amphibolite facies to the south. Almandine garnet and staurolite are present from the Mineral district southward in rocks of appropriate composition.

Stratabound sulfide deposits occur in the Chopawamsic Formation principally at: (1) the Cabin Branch deposit near the north end of the Chopawamsic exposure about 50 km south-southwest of Washington, D.C., (2) at several places in north-central Virginia, the most important of which is the Mineral district, (3) just south of the James River near New Canton in central Virginia, and (4) near Andersonville in south-central Virginia (fig. 1). Mining began as early as the Revolutionary War near New Canton and in 1834 in the Mineral district for gossan iron, and some years later, for copper. Mining in the 20th century, until 1922, was done mainly in the Mineral district and at the Cabin Branch deposit, for sulfur. The Valzinco deposit about 20 km north of Mineral was mined intermittently between 1909 and 1945, principally for zinc and lead.

The greatest volume of sulfide (largely pyrite) occurs in the Mineral district where several deposits totalling at least 10 million metric metric tons occur within a few kilometers of one another. The deposits of the Mineral district are mainly in felsic metavolcanic rock and quartz-muscovite phyllite of uncertain origin. The phyllite, however, probably was formed by the metamorphism of either felsic volcanic rock or pelitic sedimentary rock derived from volcanic rock. Greenstone, biotite schist, and amphibolite commonly are interbedded with the felsic metavolcanic rocks and phyllite in the Mineral district. Chert pods and layers are present in places; some are close to sulfide bodies. There are no surface exposures that show the relationships between sulfide bodies and wall rocks, or between the varieties of wall rock in the Mineral district, but extensive exploration drilling has been done in the district during the past 20 years and these relationships are well displayed in drill cores. During the field trip, three drill cores from the Mineral district will be laid out for detailed examination through the courtesy of the New Jersey Zinc Company and the Callahan Mining Corporation.

Pyrite is by far the most abundant sulfide mineral in most stratabound deposits in the Virginia Piedmont. Pyrrhotite is a minor constituent in the northern and middle parts of the Chopawamsic belt; it is fairly common only near the south end near Andersonville. The change from the middle to the south parts of the belt is probably the result of a somewhat higher metamorphic grade to the south. Small amounts of chalcopyrite and sphalerite are present in most sulfide bodies; the amount of galena in some bodies is as much as 1 percent or so, but only traces are found in other bodies. A small number of sulfide lenses in the Mineral district contain a high proportion of sphalerite and a few percent galena. The 250,000-ton Valzinco deposit, 20 km north of Mineral, is essentially an ore of zinc and lead. The grade of ore mined there until the year 1918 was 12.5 percent Zn and 5 percent Pb.

Reference cited

Gair, J.E., and Slack, J.F., in press, Stratabound (massive) sulfides of the U.S. Appalachians *in* IGCP Review Paper on Correlation of Caledonian Stratabound Sulfides: Geol. Survey of Ireland.

Massive Sulfides of Virginia Field Trip

Piedmont province

The Chopawamsic Formation of the Piedmont of Virginia

STOP 1

by Louis Pavlides

Introduction

The Chopawamsic Formation was named by Southwick, Reed and Mixon (1971), for Chopawamsic Creek, the type section in the Joplin 7 1/2 minute quadrangle, about 40 km south of Washington, D.C. The Chopawamsic is a sequence of interbedded metavolcanic and metasedimentary rocks on the northwest limb of the Quantico Syncline (fig. 1). The Quantico Slate everywhere overlies the Chopawamsic in the Quantico Syncline. They described the Chopawamsic as resting on and interfingering with pebbly gneiss of the Wissahickon Formation. This pebbly gneiss has since been redefined as a diamictite, formed as a sedimentary slide; indeed it may even by an olistostrome. The diamictite does not extend much farther south as a stratigraphic unit than the area studied by Southwick, Reed and Mixon. Rather, for a considerable distance along strike to the southwest, the lower part of the Chopawamsic has been intruded by plagiogranitic rocks and locally by metamafic rocks of the Mafic Complex at Garrisonville (Pavlides, 1976, fig. 6). Farther to the southwest, beyond the belt of plagiogranitic intrusions, the Chopawamsic appears to grade downward into schist and silty schist.

Lithology

Southwick, Reed and Mixon (1971, p. D1-D2) divided the Chopawamsic into three principal lithologic units:

(1) metamorphosed medium- to thick-bedded mafic to intermediate volcanic rocks derived from andesitic to basaltic flows, coarse breccias, and finer tuffaceous clastic rocks; (2) metamorphosed medium- to thick-bedded felsic volcanic rocks derived from flows and associated volcanicalstic sediments; and (3) metamorphosed thin- to medium-bedded volcaniclastic rocks of felsic to mafic composition, locally containing felsic to mafic flows and beds of non-volcanic quartzose metagraywacke and green to gray phyllite. Units 1 and 2 grade vertically and laterally into unit 3 and appear to be tongues or lenses within a complex volcanic-sedimentary pile.

My own mapping of the area immediately to the southwest of that mapped by Southwick, Reed and Mixon also suggests that the Chopawamsic consists of a series of intertonguing lenses, chiefly metavolcanic rocks, containing lesser amounts of metasedimentary rocks. The descriptions that follow pertain to the area that I studied.

Metavolcanic rocks are mostly of felsic and intermediate compositions. Felsic rocks are commonly light gray in color and have visible small phenocrysts of quartz and (or) feldspar. Some felsic rocks are highly sodic (keratophyres) and contain fine-grained feldspar and quartz insets in a finely crystalline quartzofeldspathic matrix. Epidote occurs as a minor alteration of some plagioclase phenocrysts in felsic rocks having plagioclase that was originally more calcic than albite. Dark-green metavolcanic rocks are of intermediate composition as indicated by their SiO_2 content, which ranges from about 55 to 65 percent. In thin section, they commonly have a nematoblastic groundmass texture formed by alined prismatic amphibole, which is intergrown with fine-grained quartz and feldspar. Blue-green actinolitic amphibole occurs locally as fine-grained porphyroblasts that, in some rocks, is arranged in small bundles (fascicles). Epidote, chlorite, and accessory magnetite are common minor constituents of these amphibolitic rocks. Locally, carbonate (or) quartz-filled vesicles are present. Pillow lavas have been observed in small outcrops at two places: (1) along Aquia Creek in a small pit near the head of Aquia Reservoir, and (2) along Long Branch, which is now covered by the reservoir waters.

Metasedimentary volcanic rocks occur in relatively sparse amounts, and consist of relatively amphibole-free quartzose layers that interfinger or lies between ampnibole-rich quartzose streaks and thin layers. Metavolcanic tuffs and conglomerates are sparser. The tuffaceous clasts commonly consist of both volcanic rocks and individual generally well formed feldspar crystals, suggesting that the rocks may have originated as mixed lithic and crystal tuffs. Volcanic conglomerate is rare and consists of volcanic clasts and rounded quartz grains having slightly embayed margins that are set in a fine-grained quartz-feldspar groundmass.

The Chopawamsic has a marked magnetic signature that allows it to be traced southwestward where it merges into the megavolcanic rocks on the northwest flank of the Columbia Syncline (fig. 1; Higgins and others, 1973; Pavlides and others, 1974) with which it is both coextensive and probably coeval. Also, the Quantico and Columbia Syncline have been shown to be continuous into each other and have been designated the Quantico-Columbia synclinorium (Pavlides, unpublished data).

Age

The Chopawamsic is tentatively considered to be chiefly of Early Cambrian age on the basis of discordant radiometric zircon ages obtained from felsic rocks (Higgins and others, 1971). Similar zircon ages obtained from the metavolcanic James Run Formation in Maryland (Tilton, Doe, and Hopson, 1970) suggest that the Chopawamsic and James Run are correlative (Southwick, Reed, and Mixon, 1971). A Cambrian age assignment for both formations is only as meaningful, however, as the zircon ages upon which it is based (see discussion of zircon ages).

The nature of the contact of the Chopawamsic with the overlying Quantico is controversial as is the age of the Quantico. I have recently summarized these problems (Pavlides, 1976, p. 10-11) as follows:

"The Chopawamsic is described as conformably underlying the Quantico Slate in a gradational manner (Southwick, Reed, and Mixon, 1971; Seiders and others, 1975). However, within the Stafford quadrangle, map-scale folds have been recognized locally within the Chopawamsic strike belt that are not present in the adjacent Quantico Slate. Also, an orthoquartzitic unit as much as 182 m thick is present between the Chopawamsic and the Quantico from the vicinity of Long Branch southwestward along strike to the Rappahannock River where it is a metaquartzwacke with schist layers. These fold and lithologic relationships were interpreted as suggesting that an unconformity occurs between the Chopawamsic and the Quantico (Pavlides _in_ U.S. Geological Survey, 1973, p. 38). The age of the Quantico, until recently, was accepted as Late Ordovician on the basis of a fossil collection identified by R.S. Bassler of the U.S. National Museum found and collected by J.L. Watson and S.L. Powell within the Quantico Slate along Powell Creek in the Quantico Quadrangle (Watson and Powell, 1911). This collection has been lost, and the fossil locality is now beneath roadfill of U.S. Interstate Highway 95 so that additional collections from the locality can no longer be made. Seiders and others (1975, p. 507-508) reported that fossil-like inorganic impressions were found in the Quantico Slate 4.8 km north of Powells Creek. On the unstated inference that similar inorganic objects may have been incorrectly identified as fossils, they felt that Bassler's determinations of the Quantico fossils may be erroneous and should not be a '...factor bearing on the age of the Quantico' (Seiders and others, 1975, p. 508). On the basis of the fact that a body of quartz monzonite which cuts the Quantico has zircons that yielded discordant Pb-U ages interpreted by them as 560 m.y., and because they accepted the Quantico as conformable with the underlying Chopawamsic that is dated by zircons interpreted as 550 m.y. old, Seiders and others (1975) believe the Quantico is of Cambrian rather than Ordovician age. However, there are now serious discrepancies appearing in the literature concerning the absolute reliability of zircon ages in dating their host rock in particular situations. This problem has been investigated by Higgins and others (1977) who conclude that zircon ages from metavolcanic and metaplutonic rocks in this part of the central Piedmont do not represent real rock ages because

(a) Piedmont zircons may have been contaminated by seed crystals derived from a Precambrian basement complex and thus may have inherited old radiogenic lead, and (b) Piedmont zircons may also have lost lead and uranium during post-plutonic and volcanic Paleozoic metamorphism. Higgins and others (1977) further concluded that because the ages from Piedmont zircons are suspect and there is evidence for an unconformity between the Chopawamsic and Quantico (Pavlides _in_ U.S. Geological Survey, 1973), the original Ordovician age of the Quantico should be reinstated on the basis of its fossil content as reported by Watson and Powell as well as its regional correlation.

Recently, along Powell Creek in the Quantico quadrangle, I collected a loose slab of Quantico Slate within the outcrop belt of the Quantico from along the creek bed, that contains forms I thought might be graptolites. William B.N. Berry of the University of California at Berkeley examined this slab and reported (written commun., June 13, 1975) 'I have split the slate piece up and note that pyrite is pretty evenly sprinkled around through the piece and that it seems to be in cubes or near-cubes except for the few streaks that caught your eye as possible graptolites.

I have looked at those streaks several times now and think I can see a definite form in them. The forms taper and what could have been thecae do seem to be there. I have lifted the pyrite off the streaks and the shapes stay--indeed this pyrite looks different from that in the remainder of the slate piece. It is smeared out in a definite form and occurs as a thin film, whereas the pyrite on the rest of the rock is in cubes. Then, looking at the forms closely, not only do they taper, but they appear to curve at the tapered end, just as do many graptolites. So, on the basis of these observations, I am willing to say that there are some structures in the rock that have the appearance of graptolites.' If this slab is indeed graptolitic, and contains graptoloids, as the thecea suggest, then it indicates an age for the Quantico no older than Ordovician."

The Quantico Slate is correlated regionally southwestward with the Arvonia Slate of the Arvonia Syncline (Watson and Powell, 1911). The Arvonia Slate is clearly Ordovician as indicated by its fossils of undisputed late Middle to middle Late Ordovician age. However, a correlation between the rocks contained in the Arvonia syncline and the Quantico-Columbia synclinorium is not entirely straightforward.

Rocks of the Hatcher Complex of Brown (1969), intervene for about 8 km between the Arvonia and Columbia synclines (fig. 1). Because of the various uncertainties that now becloud the age of the Quantico Slate, it is herein regarded as of uncertain early Paleozoic age, and provisionally as of Ordovician age. In the Arvonia syncline (Brown, 1969) an unconformity also separates the Arvonia Slate from the underlying metavolcanic rocks of the Evington Group and of the Hatcher Complex of Brown (1969, pl. 1) on the southeast limb of the syncline and the metavolcanic rocks of the Evington Group on the northwest limb of the syncline. These metavolcanic rocks of the Evington Group have striking lithologic similarity to the Chopawamsic Formation and are herein assigned to it. Some of the amphibolitic gneisses and amphibolites of the Hatcher Complex of Brown (1969) along the southeast limb of the Arvonia syncline are considered to be more metamorphosed equivalents of the Chopawamsic Formation (Pavlides, unpublished data). Therefore, a marked similarity in stratigraphic sequences of the Arvonia syncline and the Quantico-Columbia synclinorium supports the correlation of the volcanic-slate (schist) sequences in the two folds.

Regional relationships

The Chopawamsic Formation of the Piedmont of northeastern Virginia as well as the James Run Formation of the eastern Piedmont of Maryland, has been designated the "Atlantic Seaboard volcanic province" by Higgins (1972, p. 1020). His inclusion of volcanic rocks of the Carolina Slate belt in this volcanic province, however, may not be warranted. The slate belt rocks of late Precambrian (Z) to Early Cambrian age probably belong to a different lithotectonic belt, more comparable to the Avalon belt of eastern Newfoundland of late Precambrian (Z) age, rather than to the Piedmont belt that includes the Chopawamsic and related metavolcanic rocks. The recent discovery of Precambrian fossils in the slate belt rocks near Durham, N.C. strengthens the correlation between the slate belt and the Avalon province where Precambrian fossils also are found. Discordant zircon ages from metavolcanic rocks of the slate belt suggest that it includes rocks from the time interval of 740 to 575 m.y. ago (Glover and Sinha, 1973, p. 242-243) and thus spans late Precambrian (Z) and part of Cambrian time. The youngest ages from the Carolina Slate belt are close to those (550 m.y.) of the Chopawamsic-James Run metavolcanic belts. However, because of the problems associated with interpreting discordant ages of zircons in central Piedmont rocks (Higgins and others, 1977), correlations of these two terranes on the basis of their apparently nearly coeval ages is not deemed conclusive at present. The paleontologic data is considered more meaningful and permits comparing the slate belt and Avalon Peninsula as similar geologic provinces. The single trilobite *Paradoxides* (St. Jean, 1973) found in the slate belt rocks is of the "Atlantic-type" trilobite fauna found in the Cambrian of the Avalon Peninsula.

In contrast, the only known fossils in the Quantico-Arvonia belt are of Ordovician age and occur in black carbonaceous slate of the Arvonia Slate and possibly the Quantico Slate. Such black slate is not known from the Carolina Slate belt rocks. For all the above-stated reasons, the Carolina slate belt and the belt of metavolcanic and metasedimentary rocks underlying the Quantico-Arvonia belt are probably parts of different geologic provinces. The rocks beneath the Quantico and Arvonia Slates are probably a northeastward extension of the Charlotte belt as shown on the map compiled by John C. Reed, Jr. (in Fisher and others, 1970, p. 438) and as modified by Wright and others (1975, Fig. 2).

The Evington Group (Brown, 1970; Espenshade, 1954, 1970) including the metavolcanic rocks now assigned to the Chopawamsic Formation, was folded prior to the deposition of the immediately overlying Arvonia Slate (Brown, 1969, p. 31). The resulting unconformity between the Evington and the Arvonia compares with one that I suggested separates the Chopawamsic and the Quantico and that may represent or be nearly coeval with the Penobscot orogeny of Cambrian to Early Ordovician age of the northern Appalachians (Pavlides, in U.S. Geol. Survey, 1973, p. 37-38). The folding of the Arvonia and the Quantico, therefore, involves at least Late Ordovician and younger orogenic events. Thus, on structural and stratigraphic evidence, the older rocks of the Virginia Piedmont appear to have been deformed by a Cambrian to Early Ordovician event, followed by additional folding of several episodes, commencing in about Late Ordovician time. The unraveling of Penobscot, Taconic, Acadian, and possible later deformational features in the Piedmont awaits detailed structural analysis supplemented by unequivocal geochronologic dating.

Speculation

The volcanic rocks of the Chopawamsic Formation and the coeval pre-Arvonia volcanic rocks of the central Virginia Piedmont may have formed as part of a volcanic chain along or close to an ancient continental margin. Possibly additional volcanic chains, perhaps true island arcs, existed seaward (toward the east). Such island arc volcanics may be represented in part by the pillow lava sequence that constitutes the Gilpins Falls Member of the James Run Formation in Maryland (Higgins, 1973, fig. 1). This implies that the Chopawamsic and James Run Formations, although of about the same age are not coextensive nor necessarily the same volcanic belt. A westward-dipping subduction zone may have existed beneath this hypothetical island arc. Thus, the Chopawamsic Formation and related rocks would form in an inner ensialic volcanic chain. Following Karig's model (1971), if tension developed behind the seaward volcanic chains as they moved toward the subduction zone, small ocean basins could have developed behind them, permitting the emplacement of mafic rocks in such developing marginal seas. The gabbroic Baltimore Complex may have been oceanic crust formed in an interarc basin and eventually transported westward onto the sialic Baltimore Gneiss domes and Glenarm Group terrane of Maryland. The linear positive gravity anomalies east of the Chopawamsic belt and generally beneath the Coastal Plain sedimentary rocks (Johnson, 1973; Pavlides and others, 1974, fig. 7) may also, in part, represent mafic rocks emplaced behind such island chains. The Chopawamsic volcanic chain, being ensialic, probably did not develop a small ocean basin behind it. Instead, small mafic diapirs such as the mafic complex at Garrisonville were intruded into it as well as landward (west or northwest) of it (Pavlides, 1976, fig. 2). Other small, widely separated mafic intrusions occur west of the Chopawamsic volcanic belt (Pavlides and others, 1974, fig. 8) and may also be such back-arc mafic rocks diapirically emplaced in the folded rocks of the Evington Group and equivalents.

STOP 1. Leave bus and walk northwestward to powerline (fig. 2). Turn left (south) and follow powerline to edge of bluff on north side of Rappahannock River.

Stone-constructed lock visible along south bank of the Rappahannock River is a remnant of the old Rappahannock Canal (Callahan, 1967). This canal extended 50 miles upstream from tidewater at Fredericksburg and was put into operation in 1849. It was short lived; by 1853 the company ceased operation, never having realized a profit duiring its entire operation. The canal, which actually consisted of 47 locks and 23 dams, was begun in 1829 in the heyday of America's canal building era during the 1820's and 1840's. It never had the financial support or the backing of the upstream farmers and communities upstream, and its doom was sealed when the Alexandria and Orange Railroad was completed in 1852 and serviced the upstream region that the canal originally was envisioned to serve. The canal generally consisted of locks on one or both banks of the Rappahannock to lift boats around rapids, and of dams that formed slack water for barges at various places along the river. Boats were 65 feet long, 9 feet-9 inches wide, and drew about 20 inches. They were designed to carry about 200 barrels. The chief cargoes during the operation of the canal were grain and lumber shipped downstream and general merchandise, fertilizer, and brick shipped upstream.

Our traverse along the north bank of the Rappahannock is along some of the canal ruins.

STOP 1a. Use footpath along powerline to descend bluff. Examine outcrops on right (west) side of footpath near upper part of bluff. Outcrops here consist mostly of mafic metavolcanic rocks of the Chopawamsic Formation cut by dikes and irregular intrusions of trondhjemite that in thin section is characterized by granophyric texture and is similar to a trondhjemitic pluton immediately to the northeast of STOP 1. At one place the trondhjemitic rock at its intrusive contact contains abundant amphibole, probably indicating contamination from the intruded mafic rock. Two analyses show that the rocks from the pluton to the northeast respectively contain 75.8 and 77.4 percent SiO_2, 4.6 and 5.1 percent Na_2O, and 0.54 and 0.02 percent K_2O. After descending the bluff, turn left (east) and follow the footpath along the base of the bluff. Observe the metamorphosed felsic and mafic rocks that constitute the Chopawamsic Formation in this section. Near the powerline additional trondhjemitic intrusions are present within the volcanic section.

Follow footpath eastward to first main stream that flows into the Rappahannock from the north, observing volcaniclastic conglomerate a few hundred feet before reaching stream.

STOP 1b. Turn upstream and observe metavolcanic rocks exposed in stream. Steeply dipping metasedimentary section consisting of impure quartzite locally interlayered with a two-foliation mica schist can be seen in contact with the metavolcanic rocks. At stream junction take tributary to the right, continuing to observe impure quartzitic exposure. Just above tributary junction the Quantico Slate is found. The contact between the Quantico and the quartzitic rocks is not exposed. The Quantico here consists of a two-foliation muscovite-biotite schist, which is locally garnetiferous. Although staurolite is absent here, it is very common eastward or downstream along the Rappahannock River.

Retrace traverse back to powerline and continue upstream (westward) along footpath. Shortly after crossing first major stream entering Rappahannock from the north, observe outcrops of "hobnail" or plagiogranite. Continue westward along bank of Rappahannock to STOP 1c.

STOP 1c. Large exposure of intrusion breccia consisting of large blocks of mafic rocks of the Chopawamsic intruded by plagiogranite. Note local apophyses of plagiogranite intruding mafic blocks.

Return to powerline, ascend bluff, and return to bus.

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Massive Sulfides of Virginia Field Trip

Piedmont province

Mineral district

STOP 1A

By J.E. Gair

Chopawamsic Formation at Contrary Creek

Many weathered exposures of the Chopawamsic Formation occur along Contrary Creek both upstream and downstream from the bridge where U.S. Highway 522 crosses the creek (fig. 3). The former Sulphur mine, the northernmost mine of the Mineral district (figs. 1,3), is approximately 150 meters upstream from the bridge (south side of creek), and this part of the Chopawamsic thus is stratigraphically close to the principal mineralized zone of the district.

Most of the exposures on the downstream side of the bridge consist of muscovite-quartz schist and muscovite-rich phyllite containing biotite seams and porphyroblasts. Parts of the exposure have a lenticular foliation that might have been derived from the stretching of clasts or pyroclastic fragments. Also present are garnet porphyroblasts and lenticular quartz veins, 2-6 cm thick, trending parallel to foliation. Beneath the bridge is an exposure of light gray-yellow-green layered phyllitic schist containing mainly muscovite, chlorite, and quartz. Feldspar also might be present but cannot be identified without thin sections which have not been made. Porphyroblasts of hornblende(?) are conspicuous in some layers about 1 cm thick. Upstream near the site of the former Sulphur mine there are exposures of thinly layered muscovite-chlorite-quartz phyllite and greenish chloritic or biotitic phyllitic schist containing coarse hornblende porphyroblasts in some layers, especially those richer in chlorite than the other layers. Pyritic seams are common in these schists and phyllites.

Samples collected in the past from dumps (now largely or entirely graded and covered by soil) show pyrite-rich rock, virtually massive sulfide (about one half sulfide) with a gangue of very coarse hornblende.

The rocks at this stop have not been studied in thin section, so their composition is imperfectly known and the degree of their derivation from detrital sediments or volcanic material is not known. However, studies of the drill core, to be seen at STOP 2, indicate that the muscovite-rich rocks are metapelite, and the greenish layers, particularly those containing hornblende, are metavolcanic.

Massive Sulfides of Virginia Field Trip

Piedmont province

Ores of the Mineral district

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Introduction

The Mineral district of Louisa County is in the heart of the gold-pyrite belt of the Virginia Piedmont. The district served as a source of metals from Revolutionary times until the 1920's and is now an area of renewed interest for base metals. Mineralization occurs in the area along two major sub-parallel trends that extend northeastward near the town of Mineral (fig. 3). The east trend along, and extending southward from, Freshwater Creek includes small deposits that were worked for the native gold present in massive quartz veins containing dispersed pyrite and trace base metal sulfide minerals. Although many were little more than prospect pits, the largest operation extended to a depth of 60 meters and had more than 600 meters of lateral workings. Little recent work has been done along this trend and the old mine workings are now heavily overgrown. The western trend (which may actually consist of two subsidiary trends) includes the Cofer, the Arminius, Sulphur, Boyd-Smith, and Julia deposits, and is characterized by the presence of massive pyritic ores that contain significant amounts of sphalerite, galena, chalcopyrite, and trace precious metals. The production history of the better known deposits is summarized in table 1.

Gossan iron ore was no doubt extracted from the district in the 1700's and early 1800's but the first documented mining was at the Arminius mine in 1834 when gossan was mined for smelting at the nearby Rough and Ready Furnace (Luttrell 1966). Mining of supergene copper ore began at the Arminius in 1847 and continued until 1865 when attention turned to pyrite for the manufacture of sulfuric acid. Copper was recovered as byproduct. In the 1880's pyrite and copper production also began at the Boyd-Smith and Sulphur mines and during the 1890's, mines of this district and its extension into Prince William County to the northeast accounted for more than 50% of the national output of pyrite (Watson 1907). Development of the more economical Frasch process of sulfur extraction from Gulf Coast salt domes in the 1920's resulted in closing of the pyrite mines (Hickman 1947).

Several of the deposits were evaluated for their base metal content by the U.S. Bureau of Mines in the 1940's and by the New Jersey Zinc Company in the 1950's and 1960's. In Spotsylvania County, the Valzinco deposit was mined for base metals between 1942 and 1945 (Luttrell 1966). During the 1970's there has been renewed exploration in the Mineral district by Callahan Mining Corporation primarily in the west base metal trend. This included driving a decline and drifts on two levels at the Cofer property which at this time is on stand-by status.

Ore Mineralogy of the Arminius and Cofer Deposits

The ores of Mineral district are presently the subject of several investigations which, although incomplete, permit a brief summary of their characteristics (Miller, 1978; Cox, in prep., Hodder, Kazda, Bojtos, 1977). Base metal occurences of the western trend in the Mineral district are all metamorphosed stratiform massive pyritic-bodies, but each has a distinct mineralogy (table 2).

The Cofer deposit consists of at least four sub-parallel lenses which vary in thickness from more than 10 meters to less than 10 centimeters. Although broadly characterized as pyritic, the ore varies from massive pyrite to dominantly sphalerite-bearing. Pyritic parts of the ore are granular (0.5 mm to 5 mm) compact masses of subhedral pyrite with interstitial sphalerite, chalcopyrite, and galena admixed with variable amounts of silicate gangue. The sphaleritic ore consists of anhedral granular dark brown sphalerite with included angular fragments of gangue and well defined primary bands of pyrite. In the approximately 500 meters of exploration drifts exposed in 1976 there is an apparent increase in pyrite content in the ore toward the north.

The Arminius deposit is several large massive pyritic bodies from which approximately 2 million tons of massive sulphides have been mined. One of the lenses now being studied is dominately pyrite with minor interstitial sphalerite, galena and chalcopyrite. Magnetite, which occurs only as a trace at Cofer, is present as a minor but ubiquitous constituent at the Arminius. The Arminius, as well as Cofer, has little evidence of deformation but appear to have been thoroughly recrystallized.

The general geology of the Mineral District and of the area around the Cofer deposit is shown in figures 4,5, and 6.

Table 1. Mining history of some major sulfide deposits of the Mineral District (data from Luttrell 1966).

Deposit	Mining History
Sulphur (Crenshaw, Victoria Furnace) mine	- pre-1860 - mined for gossan iron ore - 1882-1922 - Pyrite mining by Sulphur Mines Co. of Virginia; name later changed to Sulphur Mining & Railroad Co. - total production not known but approximately 1 million + tons of massive pyrite
Boyd Smith (Smith, Lennig, Groome) mine	- 1845 - gossan iron mined - 1880's - mined for pyrite and copper by Charles Lennig and Boyd Smith - 1886-1906 - operated by U.S. Fidelity and Guaranty Co. - 1915-1922 - purchased by Boyd-Smith Mines, Inc. of E. I. DuPont de Nemours and Co. mined for pyrite - production not known
Arminius mine	- 1834 - gossan iron ore mining begun - 1847 - supergene copper mining by Virginia Central Copper Mines Co. and later by Arminius Copper Mines Co. - 1865-1877 - pyrite mining begun - 1883 - purchase of mine by W. A. Adams - 1894-1921 - Arminius Chemical Co. mined pyrite - 1953 - purchased by New Jersey Zinc Co. - total production approximately 2 million tons of massive pyrite ore
Julia	- 1913-1920 - Sinking of 3 shafts, minor workings. Approximately 15,000 tons of pyritic ore mined. - 1950's - Exploration by New Jersey Zinc Co. through drilling program.
Allah-Cooper (Valcooper) mine	-1915 - opened by Boyd-Smith Mines, Inc. for gold and silver - 1916 - purchased, but not operated by, Virginia Lead and Zinc Corp. - 1929 - Ventures Ltd. purchased property - 1942 - Panaminas, Inc. purchased property - total production not known
Cofer deposit	- 1950's - discovered by New Jersey Zinc Co. - 1975-1976 - decline and 500 m of exploration drifts 60 m and 110 m below surface by Piedmont Mineral Associates (a joint venture of Callahan Mining Corp. & New Jersey Zinc Co.)

Table 2. Ore minerals of the Cofer and Arminius deposits (data from Miller (1978) and Cox (in prep.).

Cofer		Arminius	
pyrite	30-90%	pyrite	85%
sphalerite	5-69%	sphalerite	8%
chalcopyrite	<5%	magnetite	3%
galena	<5%	chalcopyrite	1%
arsenopyrite	<3%	galena	1%
tetrahedrite -tennantite	trace	arsenopyrite	<1%
pyrrhotite	trace	pyrrhotite	<1%
bismuth	trace	tetrahedrite	trace
mackinawite	trace	marcasite	trace
molybdenite	trace	mackinawite	trace
gudmundite	trace	ilmenite	trace
electrum	trace		
digenite	trace		
chalcocite	trace		
covellite	trace		
marcasite	trace		
Cu-Pb-Bi-Sb-sulfosalts	trace		
magnetite	trace		
hematite	trace		
rutile	trace		
ilmenite	trace		

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Massive Sulfides of Virginia Field Trip

Piedmont Province

STOP 2

by J.E. Gair

Drill core, Mineral district

Stratabound (massive) sulfide deposits were mined in the Mineral district during the second half of the 19th century and until 1922. Initially, as in other areas in the southeastern United States, mining started for gossan iron that capped the sulfide deposits, and the sulfides were discovered and mined only as the gossan cap was removed. Mining of the sulfides for base metals, principally copper, in the 19th century and the first years of this century gave way to mining for pyrite for sulfur. The principal deposits in the Mineral district during this period were the Arminius, Boyd Smith, and Sulphur, located ½ to 3 miles north of Mineral (figs. 3,4). The deposits are separate sulfide lenses at approximately the same stratigraphic horizon in the Chopawamsic Formation.

Extensive exploration drilling was done in the district in the 1950's by the New Jersey Zinc Company and in the mid-1970's by Piedmont Minerals, a combination of New Jersey Zinc and the Callahan Mining Corporation. The drilling in the 1970's and concurrent underground (mining) exploration evaluated the Cofer deposit east of the Arminius-Boyd Smith-Sulphur zone (figs. 4-6). Because of the common lensing out of lithologic units, it is not known whether the Cofer deposit is on a fold of the same horizon that contains the Arminius, Boyd Smith and Sulphur deposits, or whether it is at a stratigraphically higher horizon in the Chopawamsic.

The drill cores to be seen at Mineral are well representative of the sulfide mineralization and the variety of wall rocks in the district. Two of the cores cut the Arminius deposit, and one cuts the Cofer deposit. The mineralization is dominantly pyritic, with considerable chalcopyrite and sphalerite in places. Galena is present only very locally in some of the sulfide bodies. Wall rocks consist of felsitic, intermediate, and mafic metavolcanic rocks, and pelitic rocks rich in quartz and micas. The wall rocks and sulfide deposits have been metamorphosed up to garnet/staurolite grade (amphibolite facies). Because of the metamorphism, particularly the similar-looking results of the metamorphism of felsite and of quartz-mica (originally clay?) pelites, many such rocks are not readily distinguished from one another as volcanic or pelitic during logging of the drill core. Generally, petrographic examination shows that such rocks consist dominantly either of quartz and mica or of untwinned sodic plagioclase, quartz, and mica; the quartz or quartz-feldspar has formed fine-grained mosaics, which are not distinguishable from one another by naked eye or hand lens. The rocks that have a substantial component of feldspar in the mosaics were probably volcanic. The volcanic or detrital origin of similar-looking rocks in which the mosaics consist largely of quartz is more equivocal. One might readily interpret all rocks that have quartz-rich mosaics and intervening sericitic seams as pelitic, except that some contain quartz phenocrysts and clearly are volcanic. A small amount of the drilled rock consisting of alternating laminae of quartz and epidote is probably metapelitic, presumably deposited originally as laminae of fine-grained quartz or chert and clay-carbonate. Therefore, uncertainty exists about the correct classification of some units in the logged drill cores that were not studied in thin section, and even about the classification of some units that were so studied. At a number of places in the drill-core logs this uncertainty is reflected by terms such as "metavolcanic and (or) metapelitic rock".

The intermediate to mafic metavolcanic rocks typically have a substantial content of chlorite intergrown with fine-grained sodic plagioclase and a comparatively small amount of quartz, generally less than about 15 percent. Porphyroblasts (metamorphic origin) are common, but in general are not of critical value in distinguishing volcanic from pelitic rock, except for hornblende porphyroblasts, which probably are common only in the intermediate to mafic metavolcanic rocks. The presence of staurolite in many areas is considered an indication of pelitic rock, but in the Mineral district, although this is true in part, staurolite is also present in feldspar-rich (volcanic) layers of some banded, possibly mixed volcanic/pelitic rocks. Porphyroblasts of hornblende and (or) biotite and of garnet are common in these rocks, and epidote is moderately abundant in some. Porphyroblasts of biotite, garnet, and staurolite also are common in the pelitic rocks. The porphyroblasts generally overprint the fine-grained and more or less foliated fabrics of both types of rock. Porphyroblasts of garnet and biotite evidently formed indiscriminately in both volcanic and pelitic rocks. However, abundant biotite in dark, probably intermediate to mafic metavolcanic rocks cannot be a product entirely of isochemical metamorphism because the potassium content of such rocks is abnormally high relative to SiO_2, which is in the expected range for such rocks. Evidently, potassium was highly mobile during the waning of regional metamorphism and was brought into and concentrated in many of the present biotitic rocks.

Massive Sulfides of Virginia Field Trip

STOP 2

Drill core, Mineral district 1/

Diamond drill hole, Arminius No. 1

Depth (footage from collar)	
0-119	Overburden, weathered rock
119	Felsite and hornblende meta-andesite(?). Gray-blue and green rocks with considerable color variation caused by variations in amount of dark green hornblende crystals from nearly absent to coarse aggregates to vague layers. Some grass green layers interbedded with gray-blue and dark green layers. Samples from 222 feet and 242 feet, combined and chemically analyzed, have 54.3% SiO_2, 16% Al_2O_3, 11.5% Fe oxides, 3.8% MgO, 5.3% CaO, 4.8% Na_2O, 0.19% K_2O, 1.4% TiO_2, and 0.02% CO_2. Groundmass is fine-grained chloritic quartz-plagioclase mosaics. Scattered garnet and seams of sulfide, especially associated with aggregates of hornblende.
264	Cherty felsite. Blue gray color. At 288 feet blue-gray cherty fragments are in a green moderately magnetic groundmass.
347	Felsite and hornblende meta-andesite(?). Rock similar to that in interval 119-264 feet. Large crystals of dark green hornblende are scattered in interval 347-363 feet and in layers below 363 feet.
372	Cherty chloritic metavolcanic rock—metadacite and (or) meta-andesite. Indistinctly layered. Some fragmental zones, for example, at 460 feet and below 496 feet. Scattered pyrite in crystals and pods and in places in thin seams. Widely spaced seams of hornblende above 444 feet.
	384½-386 feet. Metafelsite. Light gray-green rock containing centimeter size quartz phenocrysts.
	408-437 feet. Mottled rock, probably fragmental.
	Below 444 feet. Hornblende increases in amount and pyrite is relatively abundant in pods, thin layers, and irregular aggregates. Scattered garnet.

1/ Logged by J.E. Gair, September, 1975; parts of logs presented here have been modified on basis of petrographic and chemical data.

	Below 496 feet.	Blue-gray cherty fragments in green groundmass; some cherty fragments contain cores of pyrite and in places cores of garnet; numerous patches of coarse hornblende.
	Below 500 feet.	Garnet in coarse porphyroblasts and pods.

575 Quartz-muscovite phyllite. Light gray blue green color. Thin seams of pyrite in foliation surfaces, crossing drill core at angle of about 70 degrees. Sulfide generally associated with seams of biotite or chlorite; some sulfide seams lie at angle to foliation.

630 Amphibolite. Coarse hornblende in gray-green and blue-green chloritic quartz-feldspar groundmass is slightly concentrated in vague laminae. Scattered garnets.

634½ Quartz-muscovite phyllite. Light gray green to light blue green.

674 Intermediate metavolcanic rock and (or) metapelite. Alternating green internally laminated layers (meta-tuff?), garnetiferous hornblendic layers, and layers of quartz-hornblende-epidote-pyrite, quartz-biotite, and epidote. Seams of pyrite are common parallel to rock laminations. White vein quartz and associated coarse hornblende at 693-695 feet, 697 feet, and 707 feet.

707½ Quartz-muscovite-chlorite(?) phyllite. Banded blue-gray and white. Pyritic seams parallel to bands and generally confined to darker (chloritic?) bands.

715 Garnetiferous amphibolite. Coarsely fragmental in interval 717-719 feet.

719 Quartz-muscovite phyllite, similar to rock in interval 575-630 feet.

725 Intermediate metavolcanic rock and (or) metapelite. Laminated. Similar to rock in interval 674-707½ feet.

730 Sericite-chlorite schist speckled with coarse porphyroblasts of biotite, garnet, and hornblende. Contains coarse fragments of laminated quartz-garnet metasedimentary rock. Porphyroblastic schist is probably metapelite. Mainly white vein quartz in interval 738-741½ feet.

751 Intermediate metavolcanic rock (meta-andesite, metadacite(?). Hornblendized, layered, and internally laminated gray-green rock. Garnetiferous. Hornblende concentrated in seams that form poorly defined laminae; laminae are grouped into layers in places.

765 Quartz-muscovite phyllite. Light gray to nearly white with scattered speckles and some laminae of biotite(?).

779 Amphibolite (?). White vein quartz at 785-803 feet, 806-809 feet, and 813-814 feet.

820 Quartz-feldspar-muscovite-biotite and quartz-muscovite schists. Some phyllitic zones. Light gray green speckled with biotite. Scattered garnet porphyroblasts. Coarsely fragmental at 824 feet. Some zones faintly laminated from concentrations of biotite or epidote. Parent rocks uncertain--probably mixed intermediate to felsic tuffs and sedimentary rocks derived from them. One thin zone (in thin section) has relict diabasic/gabbroic texture.

827-828 feet. Pyrite seams about 1 cm thick.

861-879 feet. Numerous seams of vein quartz make up approximately half the thickness of this interval.

901 Metabasalt or metadiabase. Abundant hornblende, some forming poorly defined layers. Groundmass is mainly mosaics of quartz and sodic plagioclase, but mosaics probably replace coarse plagioclase laths. Below 931 feet, quartz-plagioclase dominant and hornblende is thinly disseminated.

953 Amphibolitic greenstone with irregular yellow-weathering carbonate pods in places, down to 1,004 feet. Hornblende/biotite in clumps and along laminations, interspersed with mosaic patches of quartz-feldspar that probably originally were plagioclase crystals. Disseminated magnetite, pyrite, and pyrrhotite. Contorted (slumped?) in interval 958½-973 feet.

964, 965 feet. 6-inch and 3-inch fresh strongly magnetic diabase dikes, probably of Triassic age.

Below contorted zone are alternating lenses of quartz-feldspar-carbonate and hornblende.

1,004-1,024 feet. Strongly foliated biotite-hornblende-quartz-feldspar schist--probably mafic meta-tuff.

1,062-1,062½ feet. Felsite containing phenocrysts of blue quartz as much as 1/2 cm diameter.

1,084-1,118 feet. Light blue-gray quartz-feldspar mosaic patches are more abundant than scattered green crystals and aggregates mainly of biotite/chlorite with finely disseminated magnetite.

1,124-1,128 feet. Fragmental rock with numerous carbonate-rich fragments and lenticles (flattened fragments?).

Below 1,172 feet. Blue-green material dominant, and less dark green biotite/hornblende than above.

1,182 Amphibolite. Coarse aggregates of hornblende in blue-green lavender chloritic (?)-quartz-feldspar groundmass. Some carbonate seams and pods.

1,199 Amphibolitic greenstone. Hornblende-chlorite-carbonate-feldspar rock. Chemically analzyed sample at 1,204½ feet contains 43.7% SiO_2, 12.8% Al_2O_3, 7.3% Fe oxides, 11.2% MgO, 9.3% CaO, 2.1% Na_2O, 0.81% K_2O, 0.23% TiO_2, and 10.1% CO_2. Zones of medium-grained blocky carbonate crystals—metacrysts or replaced plagioclase phenocrysts—in intervals 1, 212-1,216 feet, 1,230-1,231 feet, 1,241-1,242 feet. White vein quartz at 1,233 and 1,242 feet.

1,245½ Porphyritic schistose felsite. Groundmass is somewhat foliated matte of fine-grained quartz and feldspar, and with small phenocrysts of quartz and twinned feldspar. Scattered coarse metacrysts of biotite.

1,246½ Interlayered felsite and medium/coarse-grained quartz-sulfide-biotite. Sulfides are pyrite, chalcopyrite, and sphalerite. Felsite layer (as seen in thin section) has bladed chlorite porphyroblasts with blades at large angle to layer. These chlorite blades may be pseudomorphs of chloritoid. Felsite layer also contains small porphyroblasts of gahnite. One quartz-sulfide-biotite layer (as seen in thin section) contains scattered green tourmaline.

1,247½ Schistose metafelsite or metapelite. Light gray to white, quartzose, sericitic, with scattered hornblende or biotite and some thin layers of hornblende or biotite.

1,255 Massive sulfide. (Arminius orebody). Dominantly pyrite. Scattered disseminated chalcopyrite and sphalerite. Merest trace of galena. Gangue contains mainly quartz, carbonate, blue-green hornblende, and chlorite. In general, areas of hornblende/chlorite gangue are distinct from areas of quartz-carbonate gangue and probably the two types are interlayered, with the sulfide being indiscriminately distributed with respect to the two types of gangue.

Interbedded muscovite-rich schist in intervals 1,275-1,277 feet and 1,277-1,279 feet.

Considerable magnetite intergrown with pyrite near base of sulfide body, in interval 1,281½-1,284 feet.

1,285½	Quartz-sericite phyllite. Mixed (interlayered) metapelite and metafelsite. Light gray color. Near 1,344 feet and 1,363-1,364 feet, rock is metapelite in which layers of fine-grained mosaics of quartz alternate or are interlensed with matted sericite in which are scattered chlorite plates and quartz grains; micaceous layers also contain disseminated coarse pyrite, fine- and coarse-grained magnetite (at 1,363-1,364 feet), and porphyroblasts of garnet and staurolite. Samples from 1,286 feet and 1,313½ feet combined and chemically analyzed; the composite sample contains 64.6% SiO_2, 14.9% Al_2O_3, 6.5% Fe oxides, 6.8% MgO, 0.32% CaO, 0.57% Na_2O, 2.2% K_2O, 0.37% TiO_2, and 0.04% CO_2.
	1,301-1,304 feet. Scattered yellow sulfides.
	1,343-1,344 feet and 1,363-1,364 feet. Fairly abundant yellow sulfides.
	1,344-1,360 feet. Rock is fairly strongly magnetic.
	1,480½-1,500 feet. Felsite with phenocrysts of blue quartz as large as 2-3 mm diameter. Some quartz phenocrysts are resorbed (as seen in thin section).
	White vein quartz at 1,377, 1,381-1,383, 1,403, 1,410, 1,412-1,413, 1,471, and 1,481 feet.
1,500	End of drill hole.

Massive Sulfides of Virginia Field Trip

STOP 2

Drill core, Mineral district

Diamond drill hole, Arminius No. 13

Depth (footage from collar)	
0-90	Overburden and weathered rock.
90	Coarsely fragmental intermediate metavolcanic rock. Fragments adjacent to one another consist of cherty or mosaic-textured quartz-feldspar, mosaics mainly of feldspar and a small amount of quartz, foliated assemblages of chlorite-feldspar-quartz, and sulfidic hornblende-feldspar and hornblende-feldspar-quartz. Hornblende crystallized during metamorphism and much is concentrated at edges of fragments. Typically, some biotite occurs with the hornblende. Fragments may have been flattened into layers. Some chert-textured material may be in continuous layers, but many terminations of layers (ends of fragments) are evident and all apparent layers may be fragments that terminate short distances beyond the drill core. Disseminated fine- and medium-grained magnetite in some layers. Garnet porphyroblasts in some chloritic and hornblendic parts of rock. Hornblende partly rims some fragments, and selvages between fragments are mainly hornblende, magnetite, garnet, and sulfide. Most of rock (selvage) is sensibly magnetic (pulls to a hand magnet). Rock is probably a meta-andesite.
	151 feet. Both pyrite and pyrrhotite present.
	223-302 feet. Increases of sulfide.
352	Amphibolite. Dark green hornblende (porphyroblasts) predominates to 380 feet and densely overprints blue-green to green groundmass of feldspar-chlorite (plus minor quartz). Below 380 feet, zones with densely packed dark hornblende alternate with zones of predominantly green groundmass material (feldspar, chlorite, quartz). Small scattered garnets in places, for example, near 398 feet. Rock is moderately magnetic.
	359-360. Zone containing phenocrysts of blue quartz.
	417 feet. Pods or fragments of groundmass material, some with cores of yellow sulfide-hornblende-garnet. Some clustering of coarse hornblende occurs at edges of the pods or fragments.

450 Intermediate metavolcanic rock. Metadacite and (or) meta-andesite, containing irregular small amphibolitic patches. Most of rock is cherty looking, light gray green, fragmental, with crude foliation-layering crossing drill core at angle of about 60°, composed largely of feldspar, chlorite, and epidote. Elongate pieces of cherty looking metavolcanic rock in some zones alternate with hornblende-rich (amphibolitic) lenses or irregular patches. Hornblende rims some of the cherty looking material. Hornblende-rich (amphibolitic) parts of rock may be selvages between coarse fragments. Groundmass in hornblende-rich rock is largely mosaic-textured untwinned feldspar. Scattered garnet and some clusters of garnet alined parallel to foliation-layering.

Pyrite is in scattered crystals and small pods. Some pods aline with foliation-layering; others cut across it.

This unit has many similarities to units in DDH Arminius No. 1 at 119-264 feet, 347-372 feet, and 372-575 feet, and to unit at 90-352 feet in this drill hole.

562 Amphibolite. Coarse hornblende in groundmass of mosaic-textured feldspar. Garnetiferous. Disseminated small grains of pyrrhotite(?).

570 Intermediate metavolcanic rock. Pale gray green. Fine- even-grained feldspar-chlorite. Few hornblende-rich seams and scattered hornblende crystals. Scattered grains and small pods of pyrite/pyrrhotite.

607 Banded mafic metavolcanic rock (hornblendic greenstone). Green layers rich in chlorite and feldspar(?) overprinted by coarse hornblende porphyroblasts. Green layers interbedded with pale gray green layers and fragments of feldspar-quartz(?)-chlorite rock. Scattered coarse granites.

664 Intermediate metavolcanic rock. Pale green foliated fine-grained feldspar-chlorite (plus minor quartz) in layers and patches (fragments ?) separated by seams and pods of mosaic-textured quartz, which may have entered the rock during metamorphism. Some feldspar in the feldspar-chlorite assemblages (as seen in thin section) is in strongly alined laths (relict trachytic texture(?).Scattered medium-size and finely disseminated magnetite and some disseminated pyrite. Pyrite and magnetite intergrown in places. Rock similar to that in unit at 570-607 feet in this drill hole.

690 Phyllitic layered quartz-sericite rock. Probable metapelite. Layers of finely matted sericite and cherty quartz. Some cherty layers are studded with fine/medium-size quartz grains. Sericite layers commonly contain scattered biotite porphyroblasts. Layers of medium coarse-grained pyrite-garnet-biotite-chlorite-quartz (porphyroblasts) overprint some sericite and sericite-chert layers to form sulfidic seams as much as several cm thick. Scattered gahnite porphyroblasts in some of the sulfidic layers (seen in thin section).

White vein quartz at 690, 694, 697-698, 735-736, 766-768, 792-794, and 815 feet.

848 Amphibolite. Laminated, garnetiferous.

857 Phyllitic rock, similar to that in interval 690-848 feet. Seams and pods of pyrite are common.

890 Intermediate metavolcanic rock. Crudely layered. Bulk of rock is fine-grained cherty-textured feldspar containing well-alined chlorite flakes betwee many of the feldspar grains. Medium-grained quartz is spotted throughout the feldspar-chlorite assemblage and also is concentrated in pods and lenses. Porphyroblasts of biotite and garnet are common in lenses of medium/coarse quartz along with pyrite. These coarser-grained minerals appear to have crystallized after development of the foliation caused by the well-alined chlorite, but possibly they formed contemporaneously, but in coarser grains than those of the surrounding rock, in channelways or zones containing more water than in adjacent areas.

903½ Quartz-sericite-chlorite (?) phyllite. Gray green. Probable metapelite.

906 Interlayered metapelitic and metavolcanic rock. Crudely to distinctly layered. Metapelitic rock is mainly mosaic-textured fine/medium-grained quartz with well-alined chlorite and some well-alined sericite between the quartz grains--alined parallel to layers. Metavolcanic rock is mainly mosaic-textured fine-grained untwinned feldspar, commonly with well-alined sericite and some well-alined chlorite between grains. Coarse porphyroblasts of biotite and garnet along some layers (originally probably micaceous pelitic layers). Scattered fine/medium-grained pyrite in some biotitic zones, and lesser amounts of pyrrhotite (?).

933 Metapelite. Mostly fine-grained mosaic-textured quartz. Some well-laminated zones. Laminae are alternately rich in quartz or epidote, biotite, or epidote-biotite. Epidote is in tiny granules; biotite is in porphyroblast blades and plates. Epidote-rich laminae may have been carbonate-clay laminae in the premetamorphic rock. Poorly laminated zones contain scattered biotite porphyroblasts.

White vein quartz at 1,011-1,012 feet and 1,021-1,024 feet.

1,040½ Intermediate metavolcanic rock with some interbedded metafelsite or metapelite (lighter colored layers). Parts of unit are well laminated. Most of unit is moderately magnetic (small pieces pull to hand magnet).

1,116-1,132 feet. Rock gray green, indistinctly banded; some green chloritic laminae.

1,139-1,142 feet, 1,152-1,153 feet, 1,159-1,163 feet. Blue-gray felsitic or pelitic layers.

1,163-1,166 feet. Greenish (chloritic?) layers are conspicuous.

White vein quartz at 1,080, 1,081, 1,084, 1,097, and 1,141-1,142 feet.

1,181 Intermediate metavolcanic rock (metadacite or meta-andesite ?). Dark gray green. Indistinctly layered to well layered. Bulk of material (groundmass) is wormy/mosaic-textured fine-grained untwinned feldspar studded with fine/medium-grained equant quartz, sprinkled with dusty to fine/medium-grained euhedral magnetite grains, and overprinted along some layers by medium- to coarse-grained porphyroblasts of biotite. Lighter colored layers have relatively few small scattered muscovite and biotite flakes and scattered granules of epidote. Some medium/coarse-grained aggregates of quartz may be recrystallized quartz phenocrysts.

1,214½ Greenschist. Well foliated and faintly laminated. Consists of fine-grained plagioclase, chlorite, biotite, and scattered prisms of hornblende. Also contains scattered garnet and magnetite.

1,214-1,274 feet. Zone with carbonate seams, 2 mm thick, parallel to foliation.

1,239 Intermediate metavolcanic rock (meta-andesite?). Plagioclase-hornblende rock, with plagioclase:hornblende ratio of about 4. Minor carbonate, quartz, chlorite, sericite, and epidote. Plagioclase in fine-grained mosaic-textured aggregates through which are studded medium-grained hornblende.

1,255 Greenstone, especially amphibolitic in interval 1,276-1,280 feet. Yellow-weathering seams of carbonate are common.

1,280 Quartz-sericite phyllite. Metapelite or metafelsite, or mixture of both. Light blue gray. Some layers contain porphyroblasts of biotite.

1,284 Amphibolite. May be intrusive rock.

1,285 Quartz-sericite phyllite. Contains some feldspar. Metapelite or metafelsite, similar to that at 1,280-1,284 feet. Coarsely speckled by porphyroblasts of biotite below 1,285½ feet.

1,287½ Massive sulfide. Pyrite and sphalerite.

1,289½ Metapelite or metafelsite. Light gray color. Contains seams of pyrite.

1,290½ Massive sulfide. Pyrite and sphalerite. Gangue is quartz and muscovite plus very minor feldspar.

1,293 Metapelite? Quartz-sericite rock with some zones containing biotite porphyroblasts. Near 1,309 feet is 1-2 inch layer of probable metafelsite--intergrown fine-grained feldspar, quartz, sericite, plus medium-grained biotite prophyroblasts.

1,315 Greenstone schist. Chlorite-plagioclase rock with scattered biotite porphyroblasts and carbonate grains. Minor hornblende, quartz, and sericite. Some carbonate in seams and veinlets.

1,319 Metapelite? Possibly some metafelsite. Rock similar to that in interval 1,293-1,315 feet.

1,325 Greenstone schist, similar to that in interval 1,315-1,319 feet.

1,334 Massive sulfide. Mainly pyrite and chalcopyrite; minor sphalerite. Gangue is carbonate plus quartz, and minor chlorite and epidote, typically much coarser in grain size than the same minerals in wall rocks. Some thin interbedded zones of metapelite and (or) metafelsite, light green and gray green in color.

1,334-1,341 feet. Pyrite and chalcopyrite in about equal amounts.

1,341-1,350 feet. Pyrite with some chalcopyrite.

1,350 Metapelite and metafelsite.

1,350-1,355 feet. Metapelite--muscovite-rich phyllitic schist containing also scattered quartz, medium-size porphyroblasts of biotite, and disseminated pyrite.

1,355-1,380 feet. Most or all is quartz-muscovite phyllitic schist--probable metapelite.

1,380-1,412 feet. Coarsely fragmental metapelite/metafelsite. Fragments are quartz-muscovite rock--probably metapelite; light gray-green brown well-foliated rock surrounding the fragments contains muscovite, biotite, feldspar, and quartz and is probably metafelsite.

1,412-1,424 feet. Phyllitic schist with lenticle structure--probable flattened fragments of felsite, consisting now mainly of equant quartz grains and small aggregates of such quartz grains, grains about 1 mm in diameter, spotted through much finer-grained wormy/cherty-textured patches of recrystallized feldspar. Tiny well-alined flakes of sericite are disseminated throughout the quartz-feldspar lenticles. Well-foliated zones between lenticles consist largely of sericite and biotite plus some intermixed tiny quartz and (or) feldspar grains.

1,432-1,474 feet. Pale bluish-gray to white quartz-feldspar mosaic-textured metafelsite, coarsely fragmental in interval 1,463-1,474 feet.

1,474-1,608 feet. Rock is phyllitic.

1,502-1,528 feet. Crumpled thin layers of quartz-muscovite and of biotite--probable metapelite.

1,532-1,541 feet. Abundant streaky biotite-rich seams, probable metapelite.

Metapelite/metafelsite contains intervals of probable metadiabase at 1,586-1,587, 1,589½-1,590, and 1,601-1,601½ feet.

White vein quartz in intervals 1,530-1,532, 1,535-1,540 feet, 1,543 feet, and at 1,548 feet.

1,608 Biotite schist--metapelite?

1,610½-1,611 feet. Interval of metadiabase?

1,618 End of drill hole.

Massive Sulfides of Virginia Field Trip

STOP 2

Drill core, Mineral district

Diamond drill hole, CV-74-4

Depth (footage from collar)	
0-110	Overburden, weathered rock.
110	Laminated pelitic/tuffaceous phyllite. Alternate laminae of quartz-feldspar-biotite-muscovite rock--probably rhyolitic to dacitic tuff--and muscovite-quartz rock--probably metapelite. Small pink garnet porphyroblasts and scattered pyrite, mainly in probable metatuff layers.
200	Mafic (basaltic?) metatuff. Streaky to well-defined dark and light-colored laminae. Dark laminae consist largely of mosaic-textured quartz with scattered carbonate and with minor epidote and plagioclase. A sample at 205 feet contains roughly 25% quartz, 45% biotite, 20% carbonate, 5% epidote, and a few percent plagioclase. The chemical composition of the same sample at 205 feet is SiO_2 - 47.1%, Al_2O_3 - 14.8%, Fe_2O_3 - 2.0%, FeO - 7.3%, MgO - 6.6%, CaO - 7.8%, Na_2O - 1.5%, K_2O - 3.4%, H_2O+ - 1.4%, TiO_2 - 0.42%, P_2O_5 - 0.06%, MnO - 0.11%, and CO_2 - 7.3%.
207½	Intermediate metavolcanic rock (metadacite ?). Quartz-feldspar-biotite-chlorite-sericite-carbonate rock. Phenocrysts and fragments of phenocrysts of blue quartz up to about ½ inch in diameter. Phenocrysts generally have embayed (resorbed) outlines. Strong lenticular dark and light-colored laminations to 221 feet and in the interval, 222-302 feet. Dark laminae are biotitic, chloritic;light-colored laminae are mixtures mainly of mosaic-textured quartz and (or) feldspar plus carbonate. Carbonate commonly is concentrated along middle of light colored laminae. Sample from 232½ feet contains feldspar phenocrysts in some layers. Laminae are somewhat crumpled in the interval, 232-236 feet. Chemically analyzed sample at 218½ feet contains 60.3% SiO_2, 14.5% Al_2O_3, 1.8% Fe_2O_3, 5.6% FeO, 5.3% MgO, 3.8% CaO, 2.5% Na_2O, 1.9% K_2O, 2.0% H_2O+, 0.37% TiO_2, 0.06% P_2O_5, 0.09% MnO, and 2.6% Co_2. Another chemically analyzed sample at 232½ feet contains 60.9% SiO_2, 13.7 Al_2O_3, 1.19% Fe_2O_3, 4.2% FeO, 3.19% MgO, 4.11% CaO, 4.59% Na_2O, 1.48% K_2O, 1.1% H_2O+, 0.74% TiO_2, 0.09% P_2O_5, 0.18% MnO, and

3.9% CO_2. Rock contains scattered magnetite grains and is slightly magnetic (small pieces are drawn to hand magnet).

302 Metafelsite or metapelite. Mottled light gray-green and yellow.

339 Mafic to intermediate metatuff, with some metafelsitic and possibly metasedimentary interbeds. Alternate green and light-colored layers. Green layers contain abundant chlorite; light-colored layers contain about 75% carbonate. Fine-grained mosaic-textured quartz and plagioclase form about 15% of the material in both dark and light layers. Actinolitic hornblende porphyroblasts overprint chloritic layers, and sprays of tremolite porphyroblasts are superimposed on the carbonate-rich layers.

Below 383 feet, patches of intermediate and felsitic metavolcanic rock contain feldspar phenocrysts.

Sample at 443 feet contains thin streaky dark laminae rich in biotite; laminations are at about 45^{o} angle to axis of drill core.

Some crumpling of laminae in intervals, 425-438 feet, 454-475 feet.

490 Interbedded metapelitic and intermediate metavolcanic rock. Layers contorted and disrupted. Pelitic rock is white to pale gray and consists mainly of fine-grained mosaic-textured quartz and scattered sericite flakes and with some laminae rich in staurolite (porphyroblasts). Metavolcanic layers are mottled gray-green and white and contain small aggregates of biotite and biotite-chlorite mixed with fine-grained mosaic-textured plagioclase and (minor) quartz. Metavolcanic rocks are at least partly pyroclastic, especially in interval, 559-565 feet.

568 White vein quartz.

471 Metapelite and (or) metafelsite. Crumpled in intervals, 579-581 feet and 619-620 feet.

Cut by vein quartz in intervals, 601-604 feet, 618-620 feet, and at 615½ feet.

620 Interbedded metapelitic and metavolcanic rock. Light gray to gray; parts mottled, parts with poorly defined laminations. Thin layers or lenses are rich in fine-grained mosaic-textured quartz and quartz-carbonate (pelitic), feldspar and feldspar-muscovite-biotite (volcanic). In volcanic layers, feldspar is elongate and strongly alined parallel to layers (trachytic texture?). Staurolite porphyroblasts are especially common along feldspathic (volcnaic) layers and at contacts of feldspathic and quartzose layers. Scattered garnets. Rock contains several thin crumpled zones in interval, 633-649 feet.

A sample from 647 feet consisting of alternate thin layers and lenses of quartz, quartz-carbonate, feldspar-muscovite-biotite, muscovite, and biotite-chlorite has a chemical composition of SiO_2 - 65.6%, Al_2O_3 - 13.7%, Fe_2O_3 - 0.95%, FeO - 3.8%, MgO - 3.2%, CaO - 3.9%, Na_2O - 2.5%, K_2O - 2.1%, H_2O+ - 1.0%, TiO_2 - 0.72%, P_2O_5 - 0.23%, MnO - 0.19%, and CO_2 - 2.7%.

665 Phyllitic metafelsite. Includes layers of quartz-sericite--possibly metapelite. Some zones contain scattered quartz phenocrysts in a groundmass consisting largely of fine-grained mosaic-textured quartz. Small amounts of feldspar are interstitial to mosaic patches of quartz. Irregular seams and laminae of sericite/muscovite, somewhat matted, could be pelitic metasediment, hydrothermally altered felsite along shears, or altered tuffaceous material such as flattened lapilli. Biotite scattered in some muscovite layers and in quartz-feldspar layers. Pyrite scattered (disseminated) in some layers with a slight concentration in biotitic zones, and several layers of massive pyrite, 1-2 inches thick, occur in interval, 747-777½ feet.

775-789 feet. Zone rich in biotite, which forms 1/2 to 3/4 of the rock near the bottom of this zone.

Foliation crosses axis of drill core at angle of 60°-70°.

Crumpled zones in following footage intervals: 684½-686, 689-690, 694-695, 699-702, 712-713, 720-723, and 725-727.

White vein quartz in interval 665-666 feet.

789 Vein quartz.

790½ Mafic metavolcanic rock (metabasalt?). Biotite-feldspar-chlorite-carbonate-quartz-magnetite rock. Streaky laminations of thin biotite seams between irregular lenticular areas of feldspar-biotite-rock. Relict basaltic or fine-medium grained diabasic texture. In such areas, wormy-textured feldspar aggregates have vague lath forms in a vague criss-cross pattern. Magnetite disseminated in tiny granules.

Rock crumpled in interval 792-795 feet.

795 Metafelsite. Light gray and blue gray. Partly porphyritic and partly tuffaceous.

800-804 feet. Zone of feldspar phenocrysts, 1-3 mm in diameter, seams and pods of matted sericite, scattered garnet porphyroblasts, and small amount of dusty magnetite.

809½-813 feet. Thinly laminated rock with scattered garnet porphyroblasts.

813-813½ feet. Probable crystal tuff.

813½ Mafic metavolcanic rock. Biotitic, laminated, with scattered pyrite and porphyroblasts of garnet.

819 Metafelsite. Feldspar-rich layers with scattered biotite, chlorite, sericite, and porphyroblasts of staurolite, and small phenocrysts of quartz. Interlayered lenticular structure might be flattened fragments. Some probable metapelite consists largely of fine-grained mosaic textured quartz.

828½ Mafic metavolcanic rock. Biotitic, garnetiferous.

829½ Metafelsite with probable interlaminated metapelite. Gray and light gray. Fragmental. Streaky lenticular laminations could be flattened fragments. Metavolcanic layers rich in sericite with some quartz, feldspar, and a few quartz phenocrysts alternate with lenses consisting mainly of quartz. Minor sericite and biotite in quartz-rich layers.

Dark, biotitic zones in footage intervals 829½-830, 840-841, 843-845½, and 858-860.

Garnetiferous, biotitic rock at 832 and 854½ feet, and in footage intervals, 841-842, 845½-848, and 853-854.

Numerous laminae and seams of pyrite in interval, 856½-863½ feet.

863½ Massive sulfide (Cofer orebody). Upper part mainly pyrite, chalcopyrite, and medium brown sphalerite; lower part is pyrite/chalcopyrite and brown to amber sphalerite. Galena in interval, 866½-867½ feet and at 870½ feet. Gangue is quartz, biotite, muscovite, and feldspar. A thin banded zone poor in sulfide within the ore body in the interval, 864-873½ feet, contains laminae rich in quartz, biotite, and feldspar. Feldspar-rich laminae, at least, are probably of volcanic derivation.

889	Phyllitic metafelsite. Down to 897 feet consists of interfoliated irregular light-gray and gray lenses and layers containing small phenocrysts of blue quartz. Groundmass mainly fine-grained mosaic-textured quartz and feldspar with intergrown sericite and scattered biotite flakes and carbonate crystals/aggregates. Biotite is somewhat concentrated in thin zones of quartz-feldspar that is slightly coarser grained than adjacent layers. Rock rather uniform in texture in interval, 897-929 feet. Phenocrysts of feldspar and quartz in sample from thin zone (2-3 mm thick) at 908 feet. Scattered garnet porphyroblasts.
929	Porphyritic felsic/intermediate laminated metavolcanic rock. Gray-green, fissile. Phenocrysts of feldspar and quartz in a groundmass of fine-grained quartz plus some feldspar and biotite. Small lenticules of blue quartz might be stretched phenocrysts. Thin,closely spaced subparallel biotite seams possibly represent original tuffaceous layers. Biotite makes up about 15% of rock.
935	Metafelsite and (or) metapelite. Gray. Garnetiferous. Irregular patches of vein quartz at 944 feet, 946 feet, and in interval, 947-948 feet.
958	Porphyritic felsic/intermediate metavolcanic rock. Laminated in interval, 958-982 feet. Rock similar to that in interval, 929-935 feet. Wavy (anastomosing) biotite seams reflect lenticular microstructure of intervening light-colored quartz-feldspar material. Phenocrysts of blue and colorless quartz are common, 1-3 mm in diameter. 982-990 feet. Massive non-laminated, non-foliated rock. Abundant muscovite and biotite. Scattered staurolite porphyoblasts and small aggregates of staurolite.
990	Metafelsite or intermediate metavolcanic rock with vein quartz and disseminated sulfides. Metavolcanic rock is mixture of muscovite, biotite, feldspar, quartz, and carbonate. Sulfides are sphalerite, galena, and yellow sulfide (pyrite, chalcopyrite?). Sulfides are especially associated with veinlets or lenses of coarse carbonate (recrystallized, possibly introduced into rock during or after metamorphism).
996½	Porphyritic metafelsite. Quartz phenocrysts in a groundmass of quartz, sericite, biotite, and minor feldspar. Matted sericite in thin zigzag layerlike zones that might be folded primary layers. Small pyrite grains disseminated in irregular areas. Few scattered porphyroblasts of carbonate and hornblende.

1025½ White vein quartz containing a few septa of gray-green schist.

1030 Metafelsite. Might include some interlayered metasedimentary rock. Phenocrysts of blue quartz in some layers that are made up largely of sericite and fine-grained quartz. Other layers have abundant fine-grained quartz and carbonate. Sporadic seams and patches rich in biotite, some with associated pyrite.

Some zones of crumpled layers as at 1038½ feet.

1075 Greenstone. Laminated, garnetiferous.

1077 Metafelsite with some pyritic pods and seams and with disseminated pyrite and sphalerite. Fine-grained mosaics of quartz plus small amounts of feldspar, carbonate, biotite, and sericite alternate with seams (layers ?) of matted sericite. Quartz phenocrysts in both the quartz-rich and sericite-rich parts of the rock. The sericite seams are contorted and branching and might be complexly folded (and metamorphosed) primary layers.

1077-1109 feet. Numerous irregular patches of vein quartz.

1115-1125 feet. Gray rock with streaky dark- and light-gray bands.

1131-1151 feet. Lenticular, vaguely fragmental structure. Scattered podlike pyrite aggregates.

1151 Mafic metavolcanic rock. Biotitic, possibly hornblendic. Garnetiferous.

1155 Metafelsite and (or) metapelite. Light gray and blue gray colors. Parts laminated especially in intervals, 1155-1164 feet, 1195-1199 feet, and below 1235 feet.

1250 Mafic metavolcanic rock. Biotitic, possibly hornblendic, Garnetiferous.

1251½ Felsic to intermediate porphyritic metavolcanic rock. Numerous small phenocrysts of feldspar.

1255 Metafelsite or metapelite and conspicuous streaky laminations.

1259 Mafic metavolcanic rock. Biotitic, possibly hornblendic.

1261 Metafelsite or metapelite. Light gray to gray. Streaky lenticular laminations.

1264 Intermediate or mafic metavolcanic rock. Biotitic, possibly hornblendic. Has some streaky laminations.

1267 Phyllitic metafelsite and (or) metapelite. Light gray to gray. Streaky laminations down to 1300 feet; conspicuous gray and dark-gray laminations below 1300 feet.

1320 Laminated greenstone. Alternate laminae are rich in biotite (and have chlorite, muscovite, and feldspar), feldspar-carbonate-biotite, and carbonate-quartz. Porphyroblasts of muscovite and chlorite tend to be localized in biotite-rich laminae. Magnetite disseminated throughout the rock but has a small degree of concentration in the biotitic laminae, sufficient to cause small pieces of the rock to be drawn to a hand magnet. Minor disseminated pyrite.

1325½-1326½ feet. Biotitic rock, possibly with some hornblende (not studied with microscope). Garnetiferous.

1326½-1339 feet. Laminated biotite-rich greenstone, similar to that in interval, 1320-1325½ feet. Garnetiferous.

1339 Banded intermediate metavolcanic rock. Might include laminae of pelitic rock. Alternate laminae of chlorite-feldspar overprinted by porphyroblasts of biotite or staurolite, laminae of feldspar-carbonate-quartz overprinted by porphyroblasts of tremolite, and laminae of feldspar-quartz with porphyroblasts of staurolite. Disseminated magnetite.

1345 End of drill hole.

Massive Sulfides of Virginia Field Trip

Piedmont Province

STOPS 3-8

By J.E. Gair

Sulfide Deposits and Related Geology, Southeast Limb of

Arvonia Syncline and Adjacent Folds

Slate, quartzite, various mica schists, and metagraywacke of Ordovician age constitute the Arvonia Slate in the core of the Arvonia syncline and overlie metavolcanic rock of probable Cambrian age on the limbs of the syncline (fig. 1). The metavolcanic rock is considered to be correlative with the Chopawamsic Formation (see discussion by Louis Pavlides). Porphyroblasts of garnet and biotite are common in the Arvonia Slate near the contact with the metavolcanic rock on the southeast limb of the syncline. The metavolcanic rock on the northwest limb of the syncline formerly was considered to be part of the Evington Group and that on the southeast limb was mapped both as hornblende gneiss of the Hatcher complex of Brown (1969) and as narrow lenses of uncertain correlation lying between the Arvonia Slate and the Hatcher.

Sulfide mineralization occurs in the metavolcanic rock on both limbs of the syncline, but as far as is known, is more highly concentrated in stratabound massive lenses on the southeast limb. Exposed metavolcanic rock on the southeast limb is principally amphibolite (or hornblende gneiss), but drilling also reveals considerable felsitic rock (which may include some metapelite).

In the northern part of the southeastern limb, the zone of metavolcanic rock between Arvonia Slate and granitic rock of Brown's Hatcher Complex is narrow, generally 1 km or less. Southward the zone of metavolcanic rock widens to several kilometers or more, partly because of its involvement in one or more folds southeast of the axis of the Arvonia syncline. The principal one of these folds is the Whispering Creek anticline (fig. 1; fig. 8--map for STOPS 4-8).

Sulfide deposits in the northern part of the southeastern limb of the Arvonia syncline occur in the vicinity of New Canton, Va. principally about 2 km south of that village (STOP 3--former Johnson mine and vicinity; fig. 7). Pyrite is the principal sulfide in these deposits; local concentrations, but averaging small amounts, of chalcopyrite, sphalerite, and pyrrhotite also occur. Early copper mining here recovered mainly supergene chalcocite. The deposits are very close to, if not right at, the contact of the metavolcanic rock (Chopawamsic Formation) with the overlying Arvonia Slate. The metavolcanic rock in this zone ranges from metafelsite schist (rhyolitic?) to amphibolite (metabasalt?). Most of the exposed metavolcanic rock in and close to the mineralized zone is garnetiferous chlorite schist and phyllite and more or less garnetiferous amphibolite. At STOP 3, near the adit just above Bear Garden Creek, thin quartzose layers (metachert?) are present in the amphibolite. Drilling in this area has shown a substantial amount of quartzose rock, which represents either original interbeds of chert in volcanic rock, or silicified layers of the volcanic rock.

Sulfide deposits in the southern part of the southeastern limb of the Arvonia syncline occur principally in several belts southeast of Andersonville (for example, at STOPS 5 and 8; fig. 8). As noted above, most of the exposed metavolcanic rock in the area is amphibolite, but drilling northeastward along the belt of gossan seen at STOP 5 and elsehwere in the area shows that a large part of the rock close to and in contact with sulfide bodies is intermediate and felsitic metavolcanic rock and perhaps includes some metapelite, all of which are similar in appearance to the rocks drilled in the Mineral district. Weathered exposures of interlayered felsic and mafic metavolcanic rock can be seen in the road cut at STOP 5.

The belts (or one belt repeated by folding) of metavolcanic rock containing stratabound sulfides southeast of Andersonville also contain occurrences of banded quartz-magnetite iron-formation, which clearly is interlayered with amphibolite (STOPS 4 and 6; fig. 8). Iron-formation occurs close to the sulfide at STOP 8, and at STOPS 4 and 6 probably is within a few hundred meters north of the northeastward projection of the sulfide zone of STOP 5(fig. 8). The occurrence of banded quartzose (cherty) iron-formation in a volcanic terrane can best be explained as a result of a volcanic exhalative process followed by chemical precipitation of silica and an iron mineral. The sulfide/iron-formation association in a volcanic terrane is strong evidence that the sulfide too was an exhalative precipitate related to volcanism.

Summary of features to be seen at STOPS 3-8

STOP 3. Old mine workings at contact of Arvonia Slate to west and underlying amphibolite to east. Nearby, felsitic or intermediate metavolcanic rock (Chopawamsic Formation). Quartzose (recrystallized chert) layers in amphibolite. Sulfides on dump across Bear Garden Creek. All of above on south side of ridge--Johnson mine site. On north side of ridge--site of McKenna mine--a shaft is at contact of Arvonia Slate (garnet-muscovite phyllite) to west and Chopawamsic Formation (chlorite-actinolite schist) to east. Pyrite in dump.

STOP 4. Outcrops along stream. Conglomeratic quartz-muscovite schist dips to northwest--basal unit of Arvonia Slate here--at northwest end of stream traverse. To southeast along stream, covered interval of about 175-200 meters followed by outcrops of banded amphibolite--Chopawamsic Formation. Quartz-magnetite iron-formation interbedded with amphibolite at southeast end of traverse.

STOP 5. Gossan representing massive sulfide zone in proximity to mafic and felsic metavolcanic rock, and a small amount of probable metapelite.

STOP 6. Banded quartz-magnetite iron-formation in proximity to mafic and felsic metavolcanic schist along road, and interlayered with amphibolite along stream (conformable layers of each rock type separated by small covered interval at latter location).

STOP 7. Abundant rubble and probable outcrops of banded quartz-magnetite iron-formation.

STOP 8. Rubble and float of banded quartz-magnetite iron-formation in proximity to gossan zone representing layer or lens of massive sulfide.

Reference cited

Brown, W.R., 1969, Geology of the Dillwyn quadrangle, Virginia: Virginia Division of Mineral Resources Report of Investigations 10, 77 p.

THE GREAT GOSSAN LEAD

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Introduction

The Great Gossan Lead is a northeasterly trending mineralized zone of pyrrhotitic pod- to vein-like massive sulfide bodies in Carroll and Grayson Counties of Southwestern Virginia. It is traceable in discontinuous outcrops, mines and exploration pits over a length of nearly 28 kilometers from a point about 5 kilometers north of Galax, Virginia to a point about 10 kilometers north of Hillsville, Virginia (fig. 9). A possible though poorly defined extension is traceable southwesterly for at least 11 kilometers into northern North Carolina.

The sulfide masses appear to range from small (<1m) discoid pods to tabular bodies, often closely spaced, forming a nearly continuous body several kilometers in length. Some drill cores reveal two or three separate sulfide masses. The sulfide masses are enclosed within the Precambrian Ashe formation of the Blue Ridge Province of Virginia.

Mining History of the Great Gossan Lead

Mining was active along The Great Gossan Lead from at least as early as 1789 until 1976 in a large number of different operations which variously extracted ores for iron, copper, sulfur and FeS. The identified operations and what is known of production as given by Currey (1880), Watson (1907) and Luttrell (1966) are listed in table 3 (see also figure 9).

The earliest mining activity in the region of the Great Gossan Lead occurred in 1789 (Currey, 1880) with the extraction of limonite gossan

Table 3. Mining operations of the Great Gossan Lead

Operation	Mining History	Reference
Betty Baker Segment		
Betty Baker	- opened 1854 by Meigs County, Tennessee and Virginia Mining Co. for supergene copper. - gossan iron and 1800 tons of pyrrhotite mined in late 1800's - 1905 Virginia Iron, Coal and Coke Co. opened pits >5600 ft along strike and mined underground from an 84 ft inclined shaft. - 595 tons of 16% Cu ore mined by 1880	Luttrell (1966) Currey (1880)
Anna Mary Ann Eliza	- supergene copper mined in 1855 by two short adits and a 1000 ft trench by Meigs County, Tennessee and Virginia Mining Co.	Luttrell (1966)
Galup	- similar to Betty Baker	Watson (1907)
Little Reed Island Segment		
Kincannon	- supergene copper extracted from three adits	Wright and Raman (1948)
Cranberry Segment		
Ben White	- similar to Cranberry	Weed (1911)
Brown and Stephenson	- under development in 1859	Currey (1880)
Fairmont (Fairmount)	- opened in 1855 for copper; 150 shaft.	Currey (1880)
Cranberry	- operated from 1854-1859 by Tennessee and Virginia Mining Co. and in 1893 by W.C. Moxham; 700 tons of 15% Cu mined by 1880	Luttrell (1966) Currey (1880)
Wildcat Segment		
Wildcat	- four adits and three tunnels opened in 1855 by Tennessee and Virginia Mining Co; 300 tons of 14% Cu ore mined by 1880	Currey (1880)
Wolfpit	- similar to Wildcat	Luttrell (1966)

Ann Phipps	- supergene copper mine opened in 1855 by Tennessee and Virginia Mining Co.; 300 tons of 15+% Cu ore mined by 1880	Luttrell (1966) Currey (1880)
Sarah Ellen Segment		
Kirkbride	- opened in 1859 for copper by Kirkbride Mining Co. 30 tons of 14% Cu ore mined by 1880	Currey (1880)
Sarah Ellen	- opened for copper in 1856 by Tennessee and Virginia Mining Co.; 300 tons of 14% Cu ore extracted by 1880	Currey (1880)
Vaughn	- worked for copper by Mr. Vaughn in late 1850's	Luttrell (1966)
Copperas Hill Segment		
Copperas Hill	- a 20 ft deep shaft sunk in 1857	Currey (1880)
Blair	- trenches, shaft and tunnel in 1857	Currey (1880)
Chestnut Creek Segment		
Lineberry (Limeberry)	- gossan iron mined in the 1780's from the "monkey grave"; 6 shafts sunk by 1880	Currey (1880)
Wilkerson	- opened for copper in 1857; 50 tons of 12% Cu ore extracted by 1880. Later mined for gossan iron	Currey (1880)
Yarnell	- 100 ft shaft sunk ~1857; 50 tons of 12% Cu ore extracted by 1880	Currey (1880)
Iron Ridge Segment		
Iron Ridge (Gossan, Monaret, Chestnut Yard, Great Outburst)	- Gossan iron mined in 1780's; supergene copper mined by Wistar Copper Mining Co. beginning in 1858. The Pulaski Mining Co. mined gossan iron in 1880's and pyrrhotite in 1985. The Virginia Mining Co. purchased the mine about 1915 and operated until about 1962.	Luttrell (1966)

Gossan Howard	- small open pit operated by Allied Chemical Corporation from 1962 until 1976 for production of commercial grade FeS	Henry *et al.* (1978)

Clifton Segment

Clifton (Leonard)	- small mine for supergene copper in quartz veins	Fontaine (1884)

which was smelted for iron. A blast furnace was built at the southern end of the district but the metal was of poor quality and after several years, operations were suspended. The 1847 discovery of the copper deposits at Ducktown, Tennessee, provoked interest along the Great Gossan Lead which culminated in the mining of supergene chalcocite and covellite beginning in 1850. The largest mines at that time included the Betty Baker, Cranberry, Kirkbride, Vaughn, Copperas Hill, and Iron Ridge. In the period January to July, 1855, eight operating mines shipped a total of 1,545,363 pounds of ore containing 25 percent copper which sold at the time for 26 cents per pound (Watson, 1907). The rich supergene ore was, however, soon exhausted and mining was halted in 1859 with the closing of the Cranberry mine. Currey (1880) lists a total copper ore production of 5,400,000 lbs.

Operations were resumed about 1880 when mining again was focussed primarily on iron from the gossan. The improved quality of metal and an extension of the railroads into the district helped support production at the Betty Baker, Lineberry, and Iron Ridge deposits. Gossan ranging from 35 to 45 percent iron continued to be mined until 1908 (Kline and Ballard 1949). Subsequently only the Iron Ridge continued to operate, but interest was centered on the primary pyrrhotite ore for its sulfur content which was used for the manufacture of sulfuric acid. From 1935 until closing in 1962, operations there were underground. From 1962 until 1976 Allied Chemical Corporation operated a small open pit mine, the Gossan Howard, for production of commercial grade FeS.

Grade and Tonnage

Grade, tonnage, and total production figures are not well known. The gossan iron ores, the materials for which the Great Gossan Lead was first exploited, contained as much as 57.8 weight percent iron (Currey 1880). Wright and Raman (1948) estimate remaining gossan iron ore reserves at 100,000 tons in the Cranberry Segment plus unknown appreciable quantities in the Wild Cat and Sarah Ellen segments. Intensive activity along the Great Gossan Lead in the mid- and late-1850's, led to the extraction of at least 2700 tons supergene copper ores which contained 12 to 20 weight percent copper (Currey 1880). Currey regarded "the mineral resources of the [copper] mines as inexhaustible," but Wright and Raman (1948) state that "probably no more than a total of several thousand tons of secondary copper ore, whose grade is doubtful, remain on the Gossan Lead."

The primary sulfide ores of the Great Gossan Lead are dominantly pyrrhotite but contain minor though significant amounts of sphalerite, chalcopyrite and galena; the average grade of the massive ores is near:

Fe	35 wt%
Zn	1.5
Cu	0.5
Pb	0.1
S	25
Gangue	37.9

Corriveau (1956) estimated a total mass of "possibly 180 to 200 million tons of sulfides and included gangue" of which the "mineable material ... is estimated to be 135 to 150 million tons." This estimate, which seems inordinately large, assumes that the entire Great Gossan Lead is like the Betty Baker Segment. A mass one-tenth to one-fifth that of Corriveau's estimate appears reasonable on the basis of the drill hole data given by Kline and Ballard (1949). Gair and Slack (1978) have recently estimated a combined mass of the Iron Ridge to 300 m. depth and the Betty Baker to 150 m. depth as 20 million tons.

General geology

The Great Gossan Lead district occurs within the Blue Ridge province in the Precambrian Ashe formation which in the vicinity of the ores is composed mainly of fine-grained sulfidic metagraywacke, gritty metagraywacke, and sulfidic to graphitic phyllite. Rankin et al. (1973) also reports minor greenstone, metagabbro, and more rarely, quartzite and marble. Staten (1976) found that near the northern end of the Great Gossan Lead the Ashe formation is dominantly quartz-muscovite schist and gneiss with minor amounts of hornblende gneiss, hornblendic amphibolite, biotite schist, chlorite schist, biotite-chlorite gneiss, biotite-chlorite schist, and calcareous rock. Cross cutting veins and boudins of quartz are also present.

Although quartz-muscovite schist is the dominant lithology in the Ashe formation near the Great Gossan Lead, the immediate wall rocks of the ore-bearing zones are commonly a biotite- and garnet-bearing chlorite schist. Significant amounts of sulfides (>5%) occur with the chlorite-schist which is interleaved with minor amounts of quartz-muscovite schist. Sulfides also occur within the quartz-muscovite schist, but are generally limited to small veins or disseminated grains of pyrrhotite.

The sulfide zone consists of mineralized pods which pinch and swell irregularly along strike and which are roughly concordant with the foliation of wall rocks. In the drill cores and in some outcrops multiple and parallel mineralized pods are present. The strike of the main sulfide zone approximates N45°E but varies locally from about N30°E to about N60°E. Dips are somewhat variable ranging from 30°-60° to the southeast. In the northeastern part of the Betty Baker segment, the strike becomes more easterly and is accompanied by a flattening in dip (Wright and Raman, 1948).

Contacts between the ore and its walls are generally rather sharp. Where such contacts are exposed between massive ore and the "hanging wall" at the Iron King mine the contact follows closely the foliation of the country rock.

Regional metamorphism has raised the rocks of the Ashe Formation in the vicinity of the Great Gossan Lead to the garnet zone of the lower amphibolite facies (Rankin et al. 1973). Staten (1976) has determined an upper thermal limit of the metamorphism at 415°-455° on the basis of the assemblages hornblende-plagioclase (An_{27}), muscovite-calcite-quartz-clinozoisite-plagioclase (An_{20}), muscovite-paragonite compositions, and temperature-sensitive distribution coefficients of iron and magnesium in garnet-biotite pairs. Staten's distribution coefficient data indicate that the ferromagnetisn silicates in the ore zones and the host rocks have equilibrated at the same temperature. These data, in addition to the well-developed metamorphic fabric and the intimate intercalation of sulfides with silicates, indicate that the sulfide minerals were emplaced prior to or during metamorphism.

The age of mineralization is not known with certainty, but an ore zone muscovite from the Iron Ridge mine was dated at 430 m.y. using K-Ar and 310 m.y. using Rb-Sr methods (Kinkel et al., 1965). These dates correspond closely with those of Ore Knob, N. C. and suggest that both deposits underwent a metamorphic event possibly correlative with the Acadian orogeny.

Sulfide mineralogy

The sulfide mass of the Great Gossan Lead is composed primarily of pyrrhotite with minor amounts of sphalerite and chalcopyrite. Megascopically chalcopyrite is usually the only visible sulfide other than the pyrrhotite, even though sphalerite is generally more abundant than chalcopyrite. Other ubiquitous sulfides--galena, arsenopyrite,--usually occur only as traces but locally may be in concentrations up to a few percent. Pyrite is rare to absent in most of the district but increases in abundance in the northeastern part of the district where local concentrations of up to about 25 percent occur in the Betty Baker mine. Additional minerals reported include trace amounts of cubanite, mackinawite, tetrahedrite, stannite, native bismuth, rutile, ilmenite, and graphite. Of these tetrahedrite, stannite, and bismuth have been found only at the Gossan Howard mine (Henry et al, 1978). Except for a localization of pyrite and a slight increase in arsenopyrite at the north end of the Great Gossan Lead, no mineral zoning has been observed. Gangue mineralogy in the massive sulfide zone is marked by an increase of chlorite, quartz, and calcite and a decrease of biotite and muscovite (Staten, 1976). Radiating bundles of actinolitic hornblende and actinolite-tremolite up to several centimeters long are also common in the sulfide zone. In general, the silicate minerals within and immediately adjacent to the massive sulfide zone are coarser grained than their equivalents in the wall rocks, and the ferromagnesian minerals within about 1-2 meters of the sulfide zone have significantly greater Mg/Fe ratios (Staten, 1976). Frequently, tiny radial aggregates of chlorite (approximately 0.1 mm) occur in the massive sulfide. They are unfractured and apparently formed as metamorphism waned and after deformation was completed.

Pyrrhotite ($Fe_{1-x}S$) - Pyrrhotite generally constitutes over 90 percent of the total sulfide mass within the ore zone. Although grain sizes (0.1 to 2 mm), and the degree to which the pyrrhotite has been recrystallized are variable, all pyrrhotite reported is the intermediate hexagonal variety with a composition, as determined by the $d_{(102)}$ spacing, of 47.5 $\pm$ 0.2 atomic percent iron. The remnant effects of deformation are evidenced by prevalent kinking and undulose extinction. Where deformation features are absent, re-equilibration through annealing is evidenced by the prevalent occurrence of pyrrhotite grains with triple junctions approximating 120°.

Pyrrhotite has also been observed as small, possibly exsolved, inclusions in chalcopyrite and sphalerite where it accompanies rows of oriented chalcopyrite grains. Where silicate minerals have been shattered, pyrrhotite commonly fills the fractures, apparently having been squeezed in during deformation.

Sphalerite [(Zn,Fe,Mn)S] - Sphalerite occurs throughout the massive sulfide both as single grains and polycrystalline aggregates but constitutes less than 6 percent of the mass. Individual grains are typically between 0.1 mm and 0.5 mm, but locally there are aggregates up to 5 mm in diameter. Sphalerite also occurs occasionally in aggregates up to a cubic centimeter in volume in glassy quartz pods associated within the ores. The sphalerite commonly contains apparently exsolved chalcopyrite blebs in parallel rows, which occasionally exhibit curvature indicating the effects of mild deformation. Observed in transmitted light, these blebs are actually rods extending through sphalerite grains but terminating 10-50 μm from the grain boundaries. No evidence of zoning was found. In reflected light, sphalerite is isotropic, dark grey in color, and normally has deep reddish-brown internal reflections. The unit cell dimensions of four sphalerite samples were found to lie between 5.415 and 5.419 $\pm$ 0.001 Å.

Sphalerite from the Great Gossan Lead contains significant amounts of manganese, cadmium, and copper in addition to the expected zinc and iron (table 4.). The cadmium and copper content of samples, analyzed so as to avoid inclusions, ranges respectively from 0.0 to 0.6 and 0.3 to 0.5 weight percent. The manganese content of the sphalerite which coexists with pyrrhotite and/or chalcopyrite varies between 0.5 and 1.2 weight percent but ranges between 1.5 and 2.3 weight percent when the sphalerite coexists with pyrite and pyrrhotite. The iron content of sphalerites coexisting with pyrrhotite ranges between 6.5 and 10.5 weight percent (corresponding to 11.3 to 18.2 mole percent FeS). The iron content of sphalerite coexisting with pyrite and pyrrhotite ranges between 4.5 and 8.1 weight percent (corresponding to 7.8 to 14.0 mole percent FeS).

Table 4

Representative microprobe analysis of minerals from the Great Gossan Lead. Analysis performed on an ARL-EMX microprobe operated at 15 kv and 0.15 μamp. sample current using synthetic sulfide and pure metals as standards. --Indicates not analyzed for that element.

		Composition, Wt %							Assoc.
		Fe	Zn	Cu	Mn	Cd	S	Total	Minerals
a.	Pyrrhotite								
	(Gossan Howard)	62.3	--	--	--	--	37.8	100.2	cpy, sph
		61.1	--	--	--	--	37.8	98.8	cpy, sph
b.	Sphalerite	7.0	58.3	--	0.39	0.51	33.6	99.2	po
	(FS-117-1398)	7.1	58.8	--	0.50	0.32	33.6	100.4	po
		6.8	60.0	0.04	0.36	0.09	32.4	99.7	po, cpy
c.	Sphalerite	8.9	58.1	--	0.65	0.27	32.7	100.6	po
	(Gossan Howard)	9.4	56.9	--	0.60	0.67	32.6	100.2	po
		8.5	57.9	--	0.59	0.25	32.9	100.1	po
		9.7	54.8	0.19	0.48	0.00	33.5	98.7	po, cpy
		7.4	57.3	0.55	1.13	0.05	33.8	100.2	po, cpy
		8.7	55.9	1.48	1.16	0.07	33.7	101.0	po, cpy
d.	Sphalerite	7.6	57.3	0.02	2.23	0.07	32.7	99.9	po, py, cpy
	(Betty Baker)	7.9	56.1	0.06	2.53	0.08	32.9	99.6	po, py
		7.3	57.8	0.05	2.32	0.07	32.4	99.9	po, py
		8.1	55.5	0.12	2.29	0.08	32.9	98.8	po, py, cpy
e.	Pyrite								
	(Betty Baker)	46.0	0.0	0.0	0.0	0.0	52.0	98.0	po, sph
f.	Chalcopyrite	31.7	--	34.5	--	--	34.5	100.7	po, sph
	(Gossan Howard)	31.9	--	35.2	--	--	33.1	100.1	po, sph
		31.0	--	35.2	--	--	34.1	100.2	po, sph
g.	Stannite	Fe	Zn	Cu	Sn	--	S	Total	
	(Gossan Howard)	14.6	1.55	30.0	23.9	--	30.1	100.1	po, cpy
h.	Arsenopyrite*	Fe	As	--	--	--	S	Total	
	(Betty Baker)	34.38	44.18				20.83	99.39	po, py, cpy
		34.21	45.89	--	--	--	19.41	99.51	po, py, cpy

*The probe standard used for the arsenopyrite analysis was Asp-200 of Kretschmar and Scott (1976).

Chalcopyrite ($CuFeS_2$) - Chalcopyrite constitutes as much as 4 percent of the sulfide and occurs primarily as polycrystalline aggregates up to several millimeters in diameter. The mobility of chalcopyrite under pressure is evidenced by its common presence within pressure shadows of silicate fragments and its injection into fractures and along cleavages of gangue minerals. Chalcopyrite commonly contains scattered anhedral inclusions of pyrrhotite, sphalerite, galena, and rarely, corroded grains of pyrite. Chalcopyrite is also present as aligned crystallographically oriented blebs within sphalerite and as thin rims adjacent to chalcopyrite free or depleted sphalerite. Cubanite occurs as rare local exsolved lamallae in the chalcopyrite and mackinawite is present as irregular but crystallographically oriented worm-like grains, 5-20 μm in length.

Galena (PbS) - Galena is common as 10-500 μm anhedral inclusions in pyrrhotite, chalcopyrite, and sphalerite. It is present in almost all samples in trace amounts but may be present locally in excess of 3 percent, particularly in the presence of greater-than-average concentrations of sphalerite. Locally galena contains inclusions of chalcopyrite and rarely, of native bismuth or tetrahedrite.

Arsenopyrite (FeAsS) - Arsenopyrite occurs as disseminated euhedral crystals 0.01 to 0.1 mm across throughout the massive sulfides and as inclusions in silicates or carbonates such as calcite, dolomite and rhodochrosite. The euhedral crystals appear to be primary. The occasional fracturing evident in areas of intense deformation, particularly in samples from the Betty Baker segment, indicates that crystals were present prior to the close of deformation. Microprobe analysis of the composition of arsenopyrite (table 4), in equilibrium with pyrite and pyrrhotite, indicate equilibration temperatures above 420°C (Kretschmar and Scott, 1976).

Pyrite (FeS_2) - Pyrite is absent to very rare in all parts of the Gossan Lead examined except at the Betty Baker Mine and in some core samples nearby. In the central and southern parts of the district pyrite occurs only as a few residual highly corroded grains within larger grains of chalcopyrite; pyrrhotite is not in contact with the pyrite. In contrast, samples from the Betty Baker Mine and environs contain porphyroblastic pyrite euhedra up to one centimeter across in a matrix of pyrrhotite.

Cubanite ($CuFe_2S_3$) - Cubanite is present in places as exsolution lamellae approximately 20 microns wide and 1 mm in length within large grains of chalcopyrite.

Mackinawite ($Fe_{1+x}S$) - Mackinawite commonly occurs as worm-like bodies less than 10 microns wide in or directly associated with chalcopyrite. It may also form borders of approximately 5 μm in width between chalcopyrite and pyrrhotite.

Stannite (Cu_2FeSnS_4) - Stannite has been found only in specimens from the Gossan Howard mine. It occurs as rounded inclusions generally less than 20 μm in diameter within pyrrhotite, chalcopyrite, and sphalerite. One grain was of sufficient size to obtain the analysis given in table 4.

Bismuth (Bi) - Native bismuth occurs as rare rounded grains, generally less than 20 μm across, within galena in the same samples that contain stannite.

Tetrahedrite ($(Cu,Fe,Zn)_{12}(Sb,As)_4S_{13}$) - Tetrahedrite occurs as very rare inclusions in galena. The small size of the grains (≤ 10 µm) precluded quantitative analysis.

Rutile (TiO_2) - Rutile is a ubiquitous though minor component of the massive sulfides of the Great Gossan Lead. Grains are euhedral or rounded, are commonly twinned, and a few are sometimes deformed.

Ilmenite ($FeTiO_3$) - Ilmenite is associated in places with rutile in the wall rocks but only where in close proximity to massive sulfides. It occurs as euhedral laths about 0.01 mm to 0.1 mm long.

Graphite (C) - Graphite is common in all parts of sulfide masses and in wall rocks as radial aggregates and as isolated laths up to 0.1 mm in diameter. Deformed flakes are quite rare but occur in the more schistose units of the Ashe formation.

Textures of the Sulfide Zones and Their Interpretation

The massive sulfide zones of the Great Gossan Lead on both megascopic and microscopic scales bear textural evidence of the metamorphism to which they have been subjected. Exposures of massive sulfide in mine workings reveal intensively developed fragmental textures in which wall rock fragments ranging in size from millimeters to meters are dispersed randomly in the sulfide matrix. In some exposures foliation exists that is accentuated by the alignment of elongate and plate-like fragments whereas in others there appears to be total randomness in terms of shape and orientation of fragments. Generally foliation is much better developed where the proportion of sulfide in the rock is low. The intensity and size of fragmentation vary widely over short distances. In the Bumbarger pit of the Iron Ridge Mine the ore close to the hanging wall contains a myriad of centimeter sized fragments, whereas the ore in the central portion of the pit (∿50 m to the west) is characterized by larger (0.5-5 meter) blocks of schist, some of which are intensely folded. In the Gossan Howard Mine intense shearing and the development of 10-50 cm boudin-like gangue blocks are visible. In nearly all places, the contacts of chlorite and sericite schist fragments with sulfide are sharp. The only selvage observed is in the form of biotite and manganese garnet zones, 2 to 8 cm thick, which occur in the Gossan Howard Mine between quartzitic masses and the sulfide. Locally actinolite has developed in abundant radiating bundles of crystals, 2-3 cm long, which may occur at roughly 10 cm intervals. Along the margins of the sulfide zones the crystals may reach 10 to 20 cm in length.

At smaller scales the sulfide zones are typified by the intimate intercalation of sulfides with silicates, the presence of sulfides along cleavages and fractures in silicates concentration of sulfides in the hinges of folds, growth of some sulfides (e.g. chalcopyrite, galena) in pressure shadows, and kink banding in pyrrhotite. All of these features are interpreted as resulting from the flow of sulfides during dynamic metamorphism.

The presence of abundant kink bands but absence of twins in the Gossan Lead pyrrhotite suggests, on the basis of Clark and Kelly's (1973) experimental deformation studies, that the deformation preserved in the pyrrhotite occurred at less than about 300°C. Because this is considerably below the metamorphic thermal maximum (∿415-455°C) of the Great Gossan Lead rocks, deformation apparently continued after the peak of thermal metamorphism. The ductility of sulfides during the conditions of elevated temperature and pressure is evident in the injection of pyrrhotite, sphalerite, chalcopyrite, and galena into the silicates.

In some parts of the sulfide masses, pyrrhotite occurs as coarse granular (grains up to 5 mm across) aggregates in which triple junctions approximate 120° and thus appear to have equilibrated by recrystallization. Adjacent to deformed areas, in which folds may be outlined by sphalerite bands, coarsely granular zones may be bounded by narrow zones in which grain size is less than 100 microns but in which recrystallization has reestablished 120° grain junctions. Apparently, these finer grained zones represent regions of minor displacement and shearing.

All of the observations noted above are compatible with and support Kinkel's (1967) interpretation of the ores having been subject to a metamorphic event after their initial emplacement and clearly refute earlier suggestions of ore emplacement after the latest metamorphism.

Exsolution and diffusion, probably during and after metamorphism, appear to have been active mechanisms in small scale remobilization of some elements in the ores of Gossan Lead. Sphalerite grains, though most are less than 200 μm across, commonly contain oriented rows of chalcopyrite, and some pyrrhotite, inclusions that appear to have formed through exsolution. In some grains, the copper and iron, instead of being distributed as finely dispersed inclusions, have coalesced into coarser grains that have depleted zones around them.

Less conspicuous than the chalcopyrite inclusions in sphalerite but also believed to be of exsolution origin are the abundant, though small (<20 μm) worm-like inclusions of mackinawite in chalcopyrite. The maximum thermal stability of mackinawite is <170°C;thus the mackinawite must have formed after the peak of thermal metamorphism, possibly as a result of the intermediate solid solution breaking down to chalcopyrite and mackinawite.

Conditions of ore metamorphism and origin of the deposits

The mineralogy and textures of the massive sulfides and host rocks of the Great Gossan Lead permit some insight into the metamorphic conditions to which they have been subjected and to their origin. The sulfides are enclosed within a belt of schists rich in muscovite, sericite and chlorite, with some amphibolitic layers, the entire zone of which has undergone lower amphibolite grade metamorphism. The Fe/Mg distribution coefficients of coexisting biotite-garnet pairs in the massive sulfides and adjacent rocks reveal that both were subjected to a thermal maximum of 415-455°C, a value consistent with the total mineralogy of the host rocks (Staten 1976). Within and immediately adjacent to the sulfide zone chlorite, biotite, garnet, and amphibole have lower Fe/Mg ratios than do the same minerals distant from the ores (Staten 1976; Craig and Gilbert 1974). Application of the arsenopyrite geothermometer (Kretschmar and Scott, 1976) although not unequivocal, is supportive of 400°C+ metamorhpic thermal maximum. Analyses of arsenopyrite which is in apparent equilibrium with both pyrite and pyrrhotite at the Betty Baker Mine have yielded two populations (table 4). One population as represented by the first analysis (44.18 wt% = 31.8 at % As),corresponds to a temperature of about 420°C on the Kretschmar and Scott temperature - composition plot, whereas the second population, (second analysis, 45.89 wt% = 33.4 at % As) corresponds to a temperature of about 500°C.

The effects of metamorphism on these ores are typical of those for massive pyritic bodies subjected to lower-amphibolite-facies metamorphism (Vokes, 1969; Mookherjee, 1976). There has been breakdown of some pyrite to pyrrhotite, shearing and kinking of the pyrrhotite, and minor remobilization as evidenced by occurrence of chalcopyrite in pressure shadows of other minerals and by injection of sulfides into fractures and along partings and cleavages. Sulfur liberated in the conversion of pyrite to pyrrhotite may have reacted with iron-bearing silicates to form more pyrrhotite and to produce the zone of iron-poor silicates which exists around the ore zones. The ores are characterized by the presence of schist fragments "floating" in a sulfide matrix, although the degree to which these fragments were detached during a metamorphic stage rather than incorporated during initial sulfide formation is unclear. The foliation of the fragments varies from parallel to that of the wall rocks to random.

Assuming that the ore mineral assemblage now present, except for exsolved and inverted phases, represents the mineralogy of the ores at the time of maximum metamorphism, it is possible to estimate the activities of sulfur, oxygen, and arsenic at that time. Pyrrhotite that does not occur with pyrite in the sulfide masses contains 47.3-47.7 atomic percent Fe and reveals no evidence of having changed composition through oxidation or exsolution after metamorphism. The data of Toulmin and Barton (1964) indicate that at a temperature of approximately 425°C this pyrrhotite composition would be in equilibrium with a S_2 activity of about $10^{-8\pm1}$, which is consistent with that required for the presence of galena + bismuth and for the coexistence of arsenopyrite and pyrrhotite (Barton, 1969). The arsenopyrite euhedra are broadly dispersed in the ores and in places are fractured; thus they are interpreted as phases present during metamorphism. In contrast, the bismuth is rare, so it might not have been present during metamorphism. In the pyrite-bearing portions of the ores, the S_2 activity would have been buffered along the pyrite-pyrrhotite curve at about 10^{-7} at 425°C. The effect of pressure on these curves is not great. The activity of As required to have arsenopyrite stable with pyrrhotite is estimated to be approximately $10^{-0.5}$ to 10^{0} (Barton, 1969) which is apparently too low to permit formation of enargite. Oxygen activity during metamorphism was apparently less than about 10^{-25} as indicated by the absence of any iron oxide.

Sphalerites that occur with hexagonal pyrrhotite but not pyrite at the Gossan Howard mine contain 11 to 17 mole percent FeS and those of the same association in core 117 contain 12 to 13 mole percent FeS. The coexistence of sphalerite with pyrite and pyrrhotite in the sulfide masses of the Betty Baker mine at the northern of the Great Gossan Lead permits application of the sphalerite geobarometer described by Scott and Barnes (1971) and calibrated by Scott (1973). Microprobe analysis was carried out on several samples in which the sphalerite grains were in direct contact with both pyrite and pyrrhotite and did not contain chalcopyrite blebs. These sphalerites contain 11 to 14 mole percent FeS, less than 0.1 mole percent CuS and 3.2 to 6.0 mole percent MnS; for the purpose of these calculations, Cu and Mn are assumed to substitute for Zn in the sphalerite. It is likely that the highest FeS contents are most representative of equilibrium during metamorphism because reequilibration at lower temperatures would tend to reduce the amount of FeS in the sphalerite. At present neither the mechanism nor the cause of only partial reequilibration is understood. The maximum of 14 mole percent FeS in the sphalerite suggests that the pressure during metamorphism was approximately 5-5.5 kb, a value quite compatible with the Barrovian-type metamorphism that Rankin et al. (1973) recognized as present in the Ashe Formation.

The Great Gossan Lead is similar to many metamorphosed massive sulfide deposits, most notably those of the southern Appalachians such as at Ore Knob and Ducktown. The Great Gossan Lead, either on its own merits or as a result of similarity to other deposits has had its origin variously attributed to: hydrothermal vein filling (Weed and Watson 1906), hydrothermal replacement (Ross 1935; Stose and Stose 1957), unspecified syngenetic sedimentation (Kinkel 1967; Addy and Ypma, 1977), volcanogenic processes (Gilmour and Still 1968), and submarine Red Sea-type sedimentation (Mauger 1972). Vokes (1969) summarizes the nature of the problem in noting "it is difficult, at times practically impossible, to be certain of the true origin of a metamorphosed deposit."

The lithologies of the enclosing country rocks of the Great Gossan Lead (Staten, 1976) like those of Ore Knob (Kinkel, 1967) and Ducktown (Addy and Ypma, 1977) indicate that they are dominantly metasedimentary rocks, possibly with minor amounts of interlayered volcanics. The bulk chemistry of the ores is consistent with those of many other pyrite or pyrite-pyrrhotite ores which have been attributed to volcanic activity. Admittedly there are no unequivocal volcanic rocks in close proximity to the ores, but thin amphibolitic layers observed in drill core and intriguing blocks of meta-diorite in the waste from the underground workings of the Iron Ridge Mine may have had a volcanic origin. The host rocks certainly have as much volcanic character as those described in the well known Rammelsberg and Sullivan deposits (Gilmour, 1976; Sangster and Scott, 1976). In the drill cores and at the Gossan Howard mine chlorite schist serves locally as the principal immediate host rock for the massive sulfide zones. This schist could be a remnant of a magnesium-rich, perhaps dolomitic, mud or it could be a remnant of an original zone of alteration as is commonly present in the vicinity of submarine volcanogenic ores (Matsukuma and Horikoshi, 1970). Anderson (1969) notes, however, that "alteration zones adjacent to massive sulfide deposits in metamorphic rocks are commonly difficult to distinguish from regionally metamorphosed country rocks, particularly in the greenschist facies."

The mineralogy and textural features of the Gossan Lead sulfides are consistent with an interpretation that an original pyritic (or at least pyrite bearing) accumulation was converted mostly to pyrrhotite during regional metamorphism. The resulting loss of sulfur from the ore zone could well be responsible for the zone of low Fe/Mg ratios in biotite, garnet, and amphibole immediately adjacent to the massive sulfides and some of the sulfides dispersed in the adjacent schists. The width of this zone would likely be related to the width of the ore zone as it would depend on the amount of sulfur liberated during metamorphism; it would also, of course, depend on the iron content of the wall rock silicates. In the cores examined in the present study, Staten (1976) observed an iron depletion zone of 1-2 meters adjacent to ore zones up to 6 m thick. In contrast, at Ore Knob Fullagar _et al_. (1967)

reported iron depleted wall rocks up to 50 m adjacent to an ore zone of 7 m thick and at Ducktown, Brown (1961) and Harvey (1975) have observed that biotites within 15 to 20 m of the ore zones are iron depleted.

The presence of shearing in the ores is not believed to indicate emplacement of the ores along a fault as suggested by Weed (1911), and Ross (1935), but rather is interpreted to be the result of sulfide strain during metamorphism. Clark and Kelly (1973) have shown that the strength of pyrrhotite decreases dramatically with increasing temperature. Accordingly, during stress deformation by shearing would develop more readily in the pyrrhotite-rich pods than in the surrounding schists and gneisses.

In summary, the Great Gossan Lead sulfides are believed to have had their origin as massive pyritic bodies deposited contemporaneously with clastic sediments possibly as a submarine precipitate from a volcanic vent. This is similar to the origin recently suggested for the Ducktown deposits by Addy and Ypma (1977). Later metamorphism to the lower amphibolite facies caused conversion of the pyrite to pyrrhotite; the resulting release of sulfur produced more iron sulfide and left a zone of iron-depleted silicates now observed as a 1-2 m thick layer responsible for the development of shearing in the sulfide zones during the metamorphism.

Acknowledgements

The authors are indebted to Allied Chemical Company and Freeport Sulfur Company for access to their property and permission to publish data derived from their samples. Much of this description has been taken from Henry, Craig and Gilbert (1978); the research represented by this work was supported by NSF grant DES 72-01587 A01.

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Massive Sulfides of Virginia Field Trip

Blue Ridge Province

Great Gossan Lead

STOPS 9-13, 13A, 15A

by J.E. Gair

Metasedimentary and metavolcanic rocks of the Ashe Formation

The late Precambrian[1/] Ashe Formation contains the large stratabound sulfide deposits of the Great Gossan Lead, which occur in eight major segments along virtually a single zone, northeastward from a point about 6 km north of Galax, Virginia for a distance of about 20 km (fig. 9). The Ashe also contains the Ore Knob deposit of modest size about 50 km southwest of Galax in North Carolina, the small Elk Knob deposit still farther southwest, north of the Grandfather Mountain window, and two small deposits about 60 km northeast of Galax in Floyd County, Va. The Ashe Formation northeast of the Grandfather Mountain window occurs in an area of about 3,000 km^2 along the east flank of the Blue Ridge uplift; it is continuous into and is considered to be largely equivalent to the Lynchburg Formation to the northeast (fig. 10). The Lynchburg in turn extends northeastward as a narrow belt along the east flank of the Blue Ridge uplift for about 250 km from the vicinity of Floyd County to northern Virginia. No significant stratabound sulfide deposits are known in the Lynchburg Formation.

1/ About 700 million years old.

The Ashe Formation consists of interbedded metasedimentary and mafic metavolcanic rocks (amphibolite and hornblende gneiss). The southwest end of this belt of the Ashe (north and northeast of Grandfather Mountain window (fig. 10), North Carolina) consists predominantly of mafic metavolcanic rock (Rankin and others, 1972). Northeastward into Virginia, metasedimentary rocks increase in abundance, and stratigraphically above and below the zone of the Great Gossan Lead most of the formation is metasedimentary. East and southeast of the east end of the Great Gossan Lead, the upper half or so of the Ashe Formation contains a substantial amount of mafic metavolcanic rock interbedded with the metasedimentary rock (Espenshade and others, 1975).

The metasedimentary rocks of the Ashe Formation are largely altered (metamorphosed) graywacke, impure quartzite, and shale, now biotite-muscovite-quartz gneiss, quartz-muscovite schist and phyllite, and conglomeratic gneiss containing granules and pebbles of quartz and feldspar detritus. In places, the formation also contains graphitic schist/phyllite, layers of impure marble, and calc-silicate minerals of metamorphic origin. Porphyroblasts of biotite, garnet, and staurolite are commonly present in the metasedimentary rocks of appropriate composition. Blocks of massive gneiss consisting of assemblages of sodic plagioclase-quartz-biotite-garnet plus minor muscovite occur in the sulfide ore in the Iron Ridge part of the Great Gossan Lead about 6 km north of Galax (see descriptions of STOPS 14 And 15), and somewhat similar feldspar-rich gneiss and schistose gneiss occur in place at STOP 15A, on the projection of the ore zone about 1 km northeast of the Iron Ridge deposits. An analyzed sample of such rocks from the ore zone contains about 4% Na_2O. The fabric of these rocks has a strong preferred orientation parallel to foliation. Alined biotite can be readily seen in the field, and under the microscope elongate and alined quartz and feldspar grains are also evident, as well as alined lensoid aggregates of feldspar and quartz. These rocks are probably meta-arkose, but some zones unusually rich in sodic plagioclase might have been affected by soda metasomatism, either during metamorphism or premetamorphic mineralization. The Ashe Formation is believed to have been deposited in a rift at the east edge of the North Amerian crustal plate (see Introduction). There is a possible parallel between the deposits of the Great Gossan Lead formed in such a setting, and the Sullivan massive sulfide deposit in British Columbia, which has an albitized zone adjacent to the ore body (Swanson and Gunning, 1945) and is in late Precambrian (Y) metasedimentary host rocks deposited in a basin that might be a fault-bounded aulocogen at the (west) edge of the North American crustal plate (Harrison and others, 1974).

STOPS 9-13 and Optional STOPS 13A and 15A provide numerous exposures of metasedimentary rocks and several of amphibolite of the Ashe Formation (figs. 10, 11). STOPS 9-11 are in the city of Galax; STOPS 12, 13, and 13A are about 5 km northwest to west of Galax, a few kilometers southwest of significant mineralization in the district; and STOP 15A is 1 km northeast of the Iron Ridge mine, near the boundary between the Iron Ridge and Chesnut Creek segments of the Great Gossan Lead.

Summary of features to be seen at STOPS 9-13, 13A, and 15A

STOP 9 Staurolite schist[1/]. The surface of the outcrop is essentially a dip surface, N. 60°E. - 50°S. Note the down dip lineation caused by alinement of micas. The rusty weathering reflects a relatively high sulfide content. Note the small pink garnet and large black biotite porphyroblasts. Staurolite porphyroblasts may not be easy to see because their distribution is irregular and they are larger than one expects--as much as 8 x 2.5 x 1.5 cm. Other minerals present in the schist include quartz, plagioclase, muscovite, chlorite, apatite, and tourmaline.

1/ Condensed from Rankin, 1971.

STOP 10 Quartz-biotite-muscovite gneiss and schist. Well-layered rock strikes northeastward and dips steeply southeastward. Thin amphibolite interbedded with the metasedimentary rock in this vicinity. Schist and gneiss reflect greater or lesser content of micas (initially deposited as clay).

STOP 11 Biotite-muscovite gneiss with thin interlayers of schist[1/]. Well layered. Foliation is parallel to compositional banding. A gritty layer, 8 cm thick, is present near the south end of the exposure. Beds strike northeast and dip moderately steeply to the southeast. An amphibolite layer, 6 m thick, is exposed in the first outcrop north of the main exposure, along the road (to the left, facing outcrops). Within a few centimeters of its boundaries, the amphibolite is altered to biotite schist. Some white lenticles in structurally upper (to right) 5 cm of amphibolite layer might be flattened amygdules. Arkosic zone present in metasedimentary rock at structural upper contact of amphibolite.

STOP 12 Interbedded quartz-mica gneiss, schist, and phyllite--metasedimentary rocks. Numerous outcrops along road. These exposures provide a good indication of the recurrence and variability of lithologies in the Ashe Formation.

STOP 13 Successively along road, outcrops of muscovite-rich phyllite, muscovite-quartz schist, and amphibolite (plagioclase-chlorite-amphibole rock). Although the different types of rock cannot be seen in contact with one another, they are considered to be interbedded because of similar strikes and dips.

[1/]Condensed and modified slightly from Rankin, 1971.

STOP 13A (Optional). Successively along road, outcrops of muscovite phyllite and amphibolite (amphibole-rich schist).

STOP 15A (Optional). Arkosic gneiss and thin interbeds of biotite-chlorite schist. Sandy zones more or less garnetiferous; some biotitic layers contain coarse garnets. Also interbedded along this nearly continuous outcrop are a chloritic meta-arkose (schist) with scattered large actinolite porphyroblasts and smaller garnet porphyroblasts, and an actinolite schist.

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Massive Sulfides of Virginia Field Trip

Blue Ridge Province

Great Gossan Lead

STOP 14

By J.E. Gair

The Huey Pit

The Huey pit is located in the Iron Ridge segment (Great Outburst area) of the Great Gossan Lead (fig. 11). Mining began in the district in the 1780's for gossan iron, and in the Iron Ridge segment about 1850, for supergene copper. Gossan iron was mined in this segment from about 1880 to 1905, and iron sulfides, principally pyrrhotite, were mined for sulfur (sulfuric acid) after 1905. The Huey was probably the first large open pit sulfide mine in the district, opened sometime after 1905. The mine, now inactive, is presently owned by Allied Chemical Company. We owe the Company a "thank you" for granting us permission to visit this pit, as well as the Bumbarger pit (STOP 15).

The geology at the Huey pit can perhaps be described most simply as layers and coarsely fragmental zones of wall rock lying between and adjacent to several steeply dipping bedlike and veinlike tabular, lensoid, and branching bodies of massive sulfide. The sulfide bodies seen in the walls of the pit range from about 1 to 5 meters in thickness, but might have been thicker or have coalesced into a thicker mass in the mined-out center of the pit. The immediate wall rock is mainly rather massive micaceous quartzite or meta-arkose. Some of the quartzitic rock contains coarse biotite porphyroblasts. In places, a thin selvage rich in biotite/chlorite or in pale amber garnet lies between sulfide bodies and the quartzitic or arkosic wall rock. Although the sulfide bodies are generally layerlike, the branching of such bodies in places indicates either veinlike injections of the sulfide, or movement of sulfides around and between very large blocks of wall rock, possibly slide blocks or slumped masses formed either during tectonism of the region, or earlier, shortly after sedimentation. Some sulfide layers appear to be internally brecciated, which could be either a tectonic feature or the result of slumping after partial hardening of the original sulfidic material. The good definition of sulfide and rock layers at this stop contrasts with the more intimate mixing of sulfide and fragmented wallrock to be seen at STOP 15. Possibly the features here represent an earlier stage and those at STOP 15, a later stage in the deformation of syngenetic sulfide which in the beginning was simply interlayered with beds of clastic sediment.

The sulfide mineralization in the Huey pit consists almost entirely of pyrrhotite. Here and there may be seen small grains of chalcopyrite. The pyrrhotite evidently is a reflection of the amphibolite (garnet-staurolite) metamorphic grade of the surrounding rocks; presumably it was pyrite before regional metamorphism took place. Inclusions of muscovite phyllite and of tremolite are abundant in some of the sulfide layers. The presence of tremolite suggests the possibility that carbonate was present in these layers prior to regional metamorphism. The origin of the biotite/chlorite selvage in contact with sulfide bodies in places is not known. We can speculate that the selvage might represent a reaction that took place during metamorphism between sulfide and wall rock, or between sulfur-bearing solutions and fragments of iron-bearing argillaceous or volcanic wall rock in which iron was extracted from the wall rock minerals and combined with sulfur to make additional sulfide. If the sulfide bodies are accumulations brought to their present locations by submarine slumping or turbidity currents after initial deposition elsewhere, the dark biotite/chlorite selvage might represent mafic volcanic rock initially interlayered with the sulfide, or picked up along the way during transport of the sulfide.

Massive Sulfides of Virginia Field Trip

Blue Ridge Province

Great Gossan Lead

STOP 15

The Bumbarger Pit

By John Slack

The Bumbarger pit was developed during the earliest phases of mining along the Iron Ridge (Great Outburst) part of the Great Gossan Lead. It is located 0.2 km south of State Route 607 and approximately 1 km southwest of Chestnut Creek (fig. 11). The Gossan Howard and Huey pits are, respectively, 0.9 and 0.6 km southwest of the Bumbarger. Open-pit mining in this part of the district began about 1915, when the Virginia Mining Company, a subsidiary of General Chemical Company, mined sulfide ore first at the Huey and then at the Bumbarger pits; all mining was by underground methods after 1935 (Luttrell, 1966).

The Bumbarger pit is elongate in plan, its long axis oriented slightly north of east. The main part of the pit is 130-150 m long and 55-80 m wide (fig. 12). The deepest parts are nearly 40 m below adjacent hilltops. Three deep areas within the pit provided access for underground mining on the eastern and southern sides. Just south of the southern edge of the pit, a shaft extends underground to the lower levels (Stose and Stose, 1957, fig. 51).

The sulfide ore body and enclosing country rocks commonly dip gently (15-30°) to the southeast (fig. 12). Some exceptions are noted, however, such as on the northwest side of the pit where the hanging wall contact dips 10° northwest, and on the southeast side where it dips locally 60°. Foliation or schistosity within the ore zone, as defined by planar lenses of country rock, is approximately parallel to the bedding of the enclosing wall rocks. The hanging wall is well exposed on the southern and eastern sides of the pit. Its presence on the northwest side is accounted for by downfaulting. At the extreme western end of the pit, the hanging wall and footwall appear to merge, without an intervening mass of sulfide; this strongly suggests a lenticular form for the orebody. On the north wall of the pit, mining terminated in an area (partly cliff) containing little sulfide and abundant fragments of country rock. If this is at or near the footwall, then the orebody may narrow there into a dumbbell shape. Alternatively, the footwall there could be deeper (i.e., north of present north wall of pit) if sulfide is beneath the north side of the cliff. However, although no undisturbed (non-fragmental) footwall is seen in the pit, there is no evidence for the presence of sulfides north of the north side of the pit--the mining footwall. The deeper workings near the south-central part of the pit also apparently do not expose the footwall of the ore zone.

The sulfide ore body is enclosed in staurolite-grade metasedimentary rocks of the late Precambrian (Z) Ashe Formation (Rankin and others, 1973). On the southern side of the pit, the wall rocks are thinly interbedded quartz-mica schist and dark gray slate or phyllite (locally graphitic) and slaty metasiltstone. The down-faulted segment of the hanging wall north of the pit is made up mainly of foliated micaceous phyllite. With the exception of a few minor faults, the country rocks do not show evidence of localized deformation, such as tight folds. Loose blocks of "pseudodiorite" within the pit probably originated as premetamorphic calcareous concretions (Emmons and Laney, 1926). Loose blocks of metagabbro have been seen northeast of the pit near highway 607 and a block of metadiabase was found on a mine dump between highway 607 and the pit. These rocks are of igneous origin and probably are intrusive; an unusually high content of titanite in each shows that they may have come from the same body. The unweathered appearance of these rocks indicates they came from underground workings. No outcrops of mafic intrusive rock have been found in the vicinity of the pit. Amphibolite, believed to be metamorphosed mafic volcanic rock, occurs 2 km southwest of Iron Ridge.

The ore zone consists of massive sulfide mixed with lenses of various sized blocks of country rock. Fragmental textures are present on all scales. Pyrrhotite, the chief sulfide, occurs with accessory fine-grained sphalerite and chalcopyrite between and surrounding fragments of quartzose mica schist, micaceous quartzite, an unusual possibly arkosic or metasomatized rock rich in sodic plagioclase, all referred to here as "metagraywacke," plus fragments of micaceous phyllite and barren quartz. Rare inclusions of biotite- and chlorite-rich schist also have been found. Inclusions of micaceous phyllite commonly form elongate lenses less than 1 m long and give the ore a distinct foliation. Fragments of quartz and "metagraywacke" are angular to well-rounded; some blocks of the "metagraywacke" are as much as 20-30 m in length. In many places, these blocks appear to be floating in a matrix of massive sulfide. Locally, "metagraywacke" fragments show internal folding of micaceous (mainly biotite) layers and are foliated. The folds typically are tight isoclinal or chevron structures. The foliation within the fragments may be either conformable or randomly oriented with respect to that of the ore zone and the wall rocks. Some parts of the ore body, especially in the northeastern section of the pit, contain sulfides intergrown with coarse clots of bladed actinolite and chlorite (see Ross, 1935, pls. 12, 35B).

The origin of the fragmental structures found within the main ore zone is unclear. Many of these features could have developed by postore regional deformation and metamorphism of stratiform, and presumably synsedimentary, mineralization. Greater ductility of the sulfides than of the wall rocks during metamorphism might have localized deformation and caused preferential fragmentation of the wall rocks near the ore zone. The generally random pattern of foliation in wall-rock fragments relative to foliation in the ore body and hanging wall rocks could have formed by rotation and reorientation of (already-foliated) blocks during the metamorphic flowage of sulfides.

An alternative explanation for these structures involves premetamorphic sedimentary slumping on a steep depositional slope. The lithology of the country rocks, especially the interbedded "metagraywacke" and slate, suggests a high-energy turbidite environment that could have caused slumping. Some of the large blocks of "metagraywacke" within the orebody apparently were derived from a source that was some distance from the pit, as their lithology is different from that of the directly adjacent wall rocks. Folds, such as those found locally in the "metagraywacke" blocks, could have formed during preconsolidation slumping, which would explain their presence in the blocks, but their absence in the wall rocks. Clots of mafic silicate minerals (chlorite-actinolite) such as occur in the ore zone are unknown in any nearby country rocks. The clots might have been derived by slumping from mafic volcanic rocks exposed 2-5 km along strike southwest of the pit, or from other closer, unknown volcanic rocks. Shortly after sulfide deposition (syngenetic model), turbidity currents or slumping could have removed the sulfides from their original vent and from possible host volcanic rocks, and mixed them with approximately coeval sediments. The clots of coarse chlorite and actinolite might be greatly modified relict fragments of mafic volcanic rocks that remained attached to the sulfides as they were transported downslope. Recrystallization of the mafic inclusions under high fluid pressures in the ore zone during regional metamorphism might then account for the large crystals of mafic silicates in the ore, even though similar coarse minerals are lacking in the amphibolite of the Ashe Formation. This model provides a more direct link between the sulfide deposits and volcanism, and eliminates problems inherent in a strictly sedimentary origin for the deposits.

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Massive Sulfides of Virginia Field Trip

Blue Ridge Province

Great Gossan Lead

STOP 16

By J. E. Gair

Open pit, northeast end of Betty Baker mine

The Betty Baker segment is about 5 km long at the northeast end of the Great Gossan Lead (figs. 10, 13). Mining began there early in the history of the district. Between 1850 and 1859, as elsewhere in the district, supergene copper was recovered. In one 6-month period, the average Cu grade of supergene ore mined in the district was 25 percent (Stose and Stose, 1957).

The Betty Baker segment of the Great Gossan Lead is now a property of the Freeport Sulphur Company. We are indebted to the Company for permission to visit this segment. The pit at STOP 16 was cleaned out as recently as 1965 or 1966 during an exploration drilling program of Freeport Sulphur. The pit contains virtually the only remaining exposure of sulfide ore in the Betty Baker mine (because the others have been covered by slumping of the walls and growth of vegetation). In the pit, a lens of massive pyrrhotite, perhaps 10 meters thick, contains numerous pebble-size and cobble-size fragments of muscovite phyllite and quartzite or metaarkose wall rock and vein quartz. Coarse crystals or aggregates of pyrite, possibly clasts, several centimeters in diameter, are present here and there in the massive pyrrhotite. The sulfide body is overlain by weathered schist and gossan along the northwest wall of the pit. The immediate wall rock northwest and southwest of the pit is largely muscovite-rich phyllite, but to the northeast the wall rock also consists of some fine- and even-grained quartzite, possibly metachert containing interleaved sericite and irregular masses of vein quartz.

As at the Bumbarger pit (STOP 15), the significance of the abundant wall-rock fragments in the sulfide body is not clear. The fragments could fit a model of soft-sediment or semi-soft-sediment slumping involving both detrital sediments (with or without some volcanic material) and sulfide, or a model involving tectonic deformation in which the sulfide flowed around and between diverse wall-rock fragments. An explanation proposed during early studies of the Great Gossan Lead, that the Lead is a fault zone into which sulfides were carried by hydrothermal solutions is less likely to be valid than the modified syngenetic concepts because of the difficulty in accounting for hydrothermal mineralization through a distance of 20-30 km or more in the absence of an evident source of the hydrothermal solutions and a lack of evidence for the action of such solutions in the immediate wall rocks of the deposits and in the Ashe Formation in general.

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Massive Sulfides of Virginia Field Trip

ROAD LOG

By J.E. Gair and J.R. Craig

Mileage

Point to Point	CUM	
0	0	Holiday Inn, Rte. 28 1/, Herndon, Va. Drive south on Rte. 28.
.35	.35	Intersection, Rte. 606 (left) to Herndon.
1.15	1.5	Cross Dulles Highway.
4.8	6.3	Rte. U.S. 50.
4.5	10.8	Turn right to U.S. 29.
.95	11.75	Turn left onto ramp to Rte. I-66. Continue west on I-66.
4.75	16.5	Cross Rte. 234 (Manassas exit).
4.4	20.9	Intersection, I-66 and U.S. 29 South/U.S. 211 West at Gainesville, Va. (end of I-66). Continue straight ahead (west) on U.S. 29/211.
.3	21.2	Intersection U.S. 29/211 and Rte. 55 (to right) in Gainesville. Continue straight ahead on U.S. 29/211.
3.25	24.45	U.S. 15 to right and straight ahead with U.S. 29/211.
8.65	33.1	U.S. 17 to right and straight ahead with U.S. 29/211/15 By-Pass in Warrenton, Va.
.9	34.0	U.S. 211 West to right. Continue straight ahead on U.S. 29/15 By-Pass/17
7.35	41.35	Turn left to U.S. 17 East at Opal, Va..
3.25	44.6	Rte. 28. Continue straight ahead on U.S. 17 East.
17.45	62.05	Turn right onto Rte. 752.
2.5	64.55	STOP 1. Walk northwestward to powerline. Turn left (south) and follow powerline to edge of bluff on north side of Rappahannock River. Exposures of metavolcanic and metasedimentary rocks of the Chopawamsic Formation. Return to bus. BOX LUNCH.
2.5	67.05	Return to U.S. 17. Turn left and continue west on U.S. 17.
17.45	84.5	Turn left (south) onto Rte. 28.

1/ All routes (Rte) are Virginia state highways unless otherwise indicated as U.S. or Interstate (I-) highways.

2.4	86.9	Intersection, U.S. 15/29 South. Continue south on U.S. 15/29.
9.4	96.3	Intersection U.S. 15/29 Business (to Culpeper) and U.S. 15/29 By-Pass. Keep to left on By-Pass.
3.7	100.0	Exit right to U.S. 522 and Rte. 3 (Mineral exit).
.2	100.2	Turn left to U.S. 522/Rt. 3.
.5	100.7	Turn right onto U.S. 522 South.
14.1	114.8	Rte. 20. Continue straight ahead on U.S. 522 South.
10.8	125.6	North Anna River.
2.1	127.7	Christopher Creek.
1.6	129.3	Rte. 208 to left and straight ahead with U.S. 522. Continue straight ahead.
1.2	130.5	Contrary Creek. <u>Optional STOP 1A</u>. Exposures of Chopawamsic Formation along the creek. Site of former Sulphur Mine is a short distance southwest of the bridge, where exposures of the Chopawamsic Formation and gossan may be seen.
1.4	131.9	Road to left (northeast) to Cofer Mine.
1.5	133.4	Turn sharply to right (northwest) onto one-lane graveled road.
.55	133.95	<u>STOP 2</u>. Arminius Mine area and drill core storage buildings of New Jersey Zinc Company and Callahan Mining Corporation. Cores from three diamond drill holes will be laid out for examination. The cores provide examples of lithologies of the Chopawamsic Formation in the immediate vicinity of sulfide bodies and examples of sulfide mineralization in the Chopawamsic.
.55	134.5	Return to U.S. 522/Rte. 208. Turn right and continue south.
.4	134.9	Intersection, Rte. 618 to left in Mineral, Va. Turn right, remaining on 522/208.
.1	135.0	Intersection, Rte. 22 in Mineral. Turn right (north and then west) onto Rte. 208/22.
5.2	140.2	Intersection, U.S. 33 in Louisa, Va. Continue straight ahead on Rte. 208/22/U.S. 33 West.
.75	140.95	Turn left (south), following Rte. 208 (toward Ferncliff, Va.).
4.2	145.15	South Anna River.

4.6	149.75	Turn right onto ramp to I-64 West.
18.5	168.25	Exit to right, ramp to U.S. 250 (Shadwell exit).
.3	168.55	Turn left (south) to U.S. 250 East.
.2	168.75	Turn left at driveway to Sheraton Motor Inn. End of first day.
		SECOND DAY
		Return to U.S. 250
.35	169.1	Turn right onto U.S. 250 West.
.05	169.15	Turn right, ramp to I-64 East.
5.15	174.3	Exit right, ramp to Rte. 616. Turn right to Rte. 616 South.
.8	175.1	Cross U.S. 250.
7.8	182.9	Turn right onto U.S. 15 South.
4.9	187.8	Rivanna River.
6.4	194.2	Intersection, Rte. 6 in Dixie, Va. Turn right, following U.S. 15 South/Rte. 6 West.
2.1	196.3	Rte. 6 to right in Fork Union, Va. Keep to left on U.S. 15 South.
4.8	201.1	James River.
.35	201.45	Turn left onto Rte. 688 (to New Canton).
.2	201.65	Turn right onto Rte. 670.
.35	202.0	Turn left onto Rte. 770.
.25	202.25	STOP 3. End of maintained road. Walk southeastward on extension of Rte. 770 (road/trail) to site of former Johnson Mine near northwest bank of Bear Garden Creek (formerly Phelps Creek). No mineralization seen in place, but position of mine openings suggest that mineralized zone is close to contact between metasedimentary rocks of the Arvonia Slate above (to west) and amphibolite of the Chopawamsic Formation below (to east). These formations are well exposed in the vicinity of the mine openings.
.25	202.5	Return to intersection of Rtes. 770 and 670. Turn left (south) onto Rte. 670.

.2	202.7	U.S. 15. Turn left onto U.S. 15 South.
1.8	204.5	Rte. 675 at Arvonia, Va. Continue on U.S. 15 South.
12.3	216.8	Railroad crossing, Dillwyn, Va.
1.0	217.8	Rte. 20. Continue on U.S. 15 South.
1.4	219.2	Sprouse's Corner. Intersection, U.S. 15 and U.S. 60. Continue on U.S. 15 South.
.65	219.85	Turn right (southwestward) on Rte. 640.
2.1	221.95	Rte. 633 at Enonville, Va. Continue straight ahead on Rte. 640.
3.7	225.65	Y-intersection, Rtes. 640 and 638 at Andersonville, Va. Keep to left (south) on Rte. 638.
.55	226.2	Y-intersection, Rtes. 638 and 637. Keep to right (south) on Rte. 638.
.95	227.15	STOP 4. Gate and driveway to left into field. Walk irregular course along farm road, fenceline, and pipeline, about 1/2 mile to tributary of Willis River located about 1/4 mile east of Rte. 638. Exposures of basal conglomerate of Arvonia Slate and underlying amphibolite of Chopawamsic Formation. Thin layer of quartz-magnetite iron-formation interbedded with the amphibolite. A layer or zone of massive sulfide occurs in the Chopawamsic a short distance southeast of these exposures, as will be seen at the next stop where gossan representative of the sulfide mineralization will be seen adjacent to exposures of mafic and felsic metavolcanic rock. Return to bus on Rte. 638. BOX LUNCH.
.95	228.1	STOP 5. One-lane unimproved road angling uphill to left (southeastward) away from Rte. 638. Walk along road away from the paved highway. Gossan is exposed along the road and loose pieces of gossan are present in the cleared area at the end of the road (top of knob, a few hundred feet from paved highway). Downhill (north) along Rte. 638 from the unimproved road are exposures of felsic and mafic metavolcanic rock and quartz-muscovite schist--probably metapelite--all part of the Chopawamsic Formation. These features show an association of sulfide mineralization and units of the Chopawamsic Formation. Continue south on Rte. 638.
1.35	229.45	Turn left (east) onto Rte. 636.
1.05	230.5	Turn left (northeast) onto Rte. 609.

.75	231.25	Y-intersection, Rtes. 609 and 635. Keep to left on Rte. 609.
1.5	232.75	Rte. 637 to left. Continue on Rte. 609.
1.35	234.1	Turn left (north-northwest) onto Rte. 633.
.65	234.75	Willis River.
.75	235.5	STOP 6. Top of knob. Interbedded northeast-trending quartz-magnetite iron-formation, amphibolite, and cherty quartzite. Outcrops and loose rock along road northwestward from top of knob, and along creek about 1/4 mile northeast of road. Note that the zone of quartz-magnetite iron-formation seen at this stop is very nearly on-strike with the gossan (sulfide) zone seen at STOP 5.
.35	235.85	Continue northwestward on Rte. 633 to turn around point and return to STOP 6.
1.4	237.25	Return to Rte. 609, turn left and continue northeastward on Rte. 609.
2.95	240.2	Turn right (south) onto U.S. 15.
1.5	241.7	Turn right (southwest) onto Rte. 775 (Rte. 621 to left, east of U.S. 15).
.85	242.55	STOP 7. Excellent exposures and abundant rubble of banded quartz-magnetite iron-formation in woods to left (east) of road.
.1	242.65	Turn around.
.85	243.5	Return to U.S. 15. Turn right (south) on U.S. 15.
2.1	245.6	Turn right (west) onto Rte. 633 at Curdsville, Va.
1.15	246.75	Y-intersection, Rtes. 633 and 635. Keep to left on Rte. 635.
1.9	248.65	Rte. 608 to left (south). Continue straight ahead on Rte. 635.
.35	249.0	Turn right (north) into driveway to farmhouse. Drive .2 mile to vicinity of farmhouse.
		STOP 8. Walk about 1/4 mile northeastward from farmhouse. Massive sulfide zone represented by gossan is located approximately along the southeast edge of field. Abundant rubble of gossan and some rubble of quartz-magnetite iron-formation in vicinity of gossan rubble. Also near the gossan rubble is rubble of a quartz-tourmaline rock and of a quartz-biotite pegmatite.
3.6	252.6	Return to U.S. 15 (driveway to Rte 635; left onto Rte. 635, continuing onto Rte. 633). Turn right (south) onto U.S. 15.
7.9	260.5	Turn right (west) onto U.S. 460. Continue westward.

23.0	283.5	Rte. 727 to left (south) in Appomattox, Va. Continue straight ahead on U.S. 460 West.
18.7	302.2	U.S. 501. Continue straight ahead on U.S. 460 West.
2.75	304.95	(Mileage approximate). Turn right onto ramp to U.S. 29 North By-Pass (Lynchburg Expressway).
1.35	306.3	Turn right onto ramp to Oddfellows Road and Holiday Inn, Lynchburg.
.15	306.45	Holiday Inn. End of second day.
		THIRD DAY
.25	306.7	Holiday Inn to U.S. 29 South By-Pass (Lynchburg Expressway).
1.5	308.2	Ramp to the right to U.S. 460 East. Continue straight ahead on U.S. 29 South By-Pass/U.S. 460 West.
.35	308.55	Intersection, U.S. 29 South and U.S. 460 West. Keep to right on U.S. 460 West (Lynchburg Expressway).
1.15	309.7	Exit on ramp to right, continuing on U.S. 460 West.
48.5	358.2	(Mileage approximate) Exit right in Roanoke, ramp to I-581 North.
5.2	363.4	Exit left, ramp to I-81 South. Continue on I-81 South.
63.8	427.2	Exit right, ramp to U.S. 52 South (Fort Chiswell exit).
7.8	435.0	New River.
1.7	436.7	Turn right onto Rte. 69 (connecting to I-77 South).
.3	437.0	Turn left, ramp to I-77 South.
9.35	446.35	Turn right (west) onto U.S. 58/221.
9.6	455.95	Traffic light, Galax, Va. Intersection with Caldwell Street to left. Amoco station to the right. Continue straight ahead on U.S. 58 West/U.S. 221 West.
.2	456.15	STOP 9. U.S. 58/221 in Galax (1-story white cement block building on left; outcrop just ahead on the right). Park in front of white building. Examine outcrop (use extreme care because of heavy highway traffic). Garnet-staurolite-biotite-chlorite schist of the Ashe Formation. Schist is sulfidic. This outcrop and the rocks to be seen at stops 10 and 11 are probably far up in the hanging wall of the Great Gossan Lead sulfide deposits.
		Continue westward on U.S. 58/221.

0.1	456.25	Traffic light. Intersection, Rte. 89 By-Pass (to left). Continue straight ahead on U.S. 58/221.
.05	456.3	Chestnut Creek.
.25	456.55	Traffic light. Turn left (south) on Rte. 89 (North Main Street, Galax).
.1	456.65	Midtowner Motel on left.
1.05	457.7	STOP 10. Outcrops of Ashe Formation to right of road, behind buildings of Galax Car Wash and adjacent buildings. Outcrops consist largely of interbedded metagraywacke, sericitic quartzite, and phyllite. Continue south on Rte. 89.
.3	458.0	Chestnut Creek.
.05	458.05	Turn left (east and north) onto Lineberry Drive (Rte. 89 By-Pass North).
.15	458.2	STOP 11. Outcrops of Ashe Formation to right of road, behind aquamarine-colored building of Easter-Gilliam Associates (building materials). Outcrops of metagraywacke schist, fissile metasiltstone schist, and phyllite. About 100 feet ahead (north) along the road is an outcrop of schistose amphibolite. A characteristic feature of the Ashe Formation is amphibolite interbedded with the metasedimentary rocks. Continue straight ahead (north) on Rte. 89 By-Pass.
1.15	459.35	Traffic light. Oldtown Street. Continue straight ahead.
.5	459.85	Traffic light. Intersection, Rte. 89 By-Pass and U.S. 58/221. Keep to left onto U.S. 58 West/U.S. 221 West.
.3	460.15	Traffic light. Turn left onto Rte. 89 South (North Main Street, Galax).
.1	460.25	Midtowner Motel. Turn left into motel parking lot. CHECK-IN AND LUNCH.
.1	460.35	Return from motel to U.S. 58/221 (turn right onto North Main Street from motel). Turn left onto U.S. 58 West/U.S. 221 West.
.15	460.5	Turn right onto Fries Road (Rte. 606--opposite sign on left for Rose Lane Motel).
1.3	461.8	Intersection, Fries Road--Rte. 606--(to left) and Iron Ridge Road--Rte. 607--(straight ahead). Turn left, remaining on Fries Road--Rte. 606.
.75	462.55	Intersection, Rte. 606 (to right) and Rte. 634 (straight ahead). Turn right, remaining on Rte. 606.

1.05	463.6	Intersection (at top of hill), Rte. 606 (to left) and Rte. 809 (straight ahead). <u>STOP 12</u>. Bus will wait here. On foot, follow Rte. 606, 0.2 mile to intersection of Rtes. 606 and 642. Continue walking along Rte. 606 to the right, 0.65 mile to the intersection of Rtes. 606 and 732. Along this stretch of Rte. 606 are numerous exposures of metasedimentary rocks of the Ashe Formation--phyllite, sandy schist, and metagraywacke schist. By projection, the zone of the Great Gossan Lead sulfide deposits (northeast of here) should pass near the intersection of Rtes. 606 and 809 where the bus is parked, and the rocks seen at this stop, therefore, should be stratigraphically below the sulfide zone, in the footwall of the Great Gossan Lead.
1.05	464.65	Bus returns to intersection of Rtes. 606 and 634. Turn right onto Rte. 634.
.55	465.2	<u>STOP 13</u>. Intersection, Rte. 634 (to left) and Rte. 641 (to right--northwest from intersection). Walk about 0.2 mile along Rte. 641. Outcrops of the Ashe Formation are exposed in the bank along the northeast side of the road. Rocks to be seen here include quartz-muscovite schist, muscovite-rich phyllite, and amphibolite. By projection, the horizon of the Great Gossan Lead should pass northwest of this stop, and the exposures seen here should be a short distance stratigraphically above the zone of sulfide mineralization. Continue on Rte. 634, south from intersection.
.75 to .8	465.95 to 466.0	Outcrops of amphibolite on the right.
.4	466.4	<u>Optional STOP 13A</u>. Intersection, Rte. 640 at Oldtown. Turn right (west). Walk 0.7 to 0.95 mile, to abundant outcrops of Ashe Formation on right (north) side of road. <u>Note</u>: It is possible that bus may be able to be taken 0.7 mile along Rte. 640 from Oldtown to a potential turn-around location, in which case this optional stop will definitely be included. At this stop, exposures can be seen of phyllite and amphibolite. These rocks are probably a short distance stratigraphically above the horizon of the Great Gossan Lead. However, in this area northwest of Galax and southwest of the major deposits of the Great Gossan Lead, several thin gossans have been mapped in the past, evidently at several different stratigraphic levels. Which, if any, of these gossans is at the horizon of the Great Gossan Lead is uncertain. The rocks at this stop could be almost in the immediate hanging wall of the major sulfide horizon (projected to this area), or could be as much as several thousand feet higher.

1.4	467.8	Driving distance to potential turn-around location for bus west of Oldtown (Optional Stop 13A) and return to intersection of Rtes 640 and 634 at Oldtown. Continue straight ahead (eastward) on Rte 640 (Oldtown Road).
1.05	468.85	Turn left (east) onto U.S. 58/221.
1.25	470.1	Traffic light. Turn right (south) onto Rte. 89 (North Main Street, Galax).
.1	470.2	Turn left into parking area of Midtowner Motel. End of third day.
		FOURTH DAY
		Turn right (north) from motel parking area onto Rte. 89 (North Main Street).
.1	470.3	Turn left (west) onto U.S. 58/221.
.15	470.45	Turn right onto Fries Road (Rte. 606).
1.3	471.75	Intersection, Rte. 606 (to left) and Rte. 607--Iron Ridge Road (straight ahead). Continue straight ahead on Rte. 607--Iron Ridge Road.
1.7	473.45	Church on left.
.15	473.6	Stop sign. Intersection, Rte. 721 to right and straight ahead with Rte. 607. Continue straight ahead on Rte. 607/721.
.25	473.85	Rte. 721 turns off to left. Continue straight ahead on Rte. 607.
.55	474.4	Site of former Gossan-Howard mine on left.
.3	474.7	Church on left.
.15	474.85	Y-intersection, Rtes 607 and 602. Keep to right on Rte. 607.
.3	475.15	STOP 14. One-lane dirt road to right (south). Walk along dirt road about 0.6 mile to large open pit mine. In this pit will be seen massive sulfide ore, mainly pyrrhotite, and some pyrite and chalcopyrite, and wall rocks that are mainly micaceous quartzite and phyllite. Wall rocks commonly are fragmented, some in large blocks. Sulfide bodies are in the form of layers, isolated lenses, some of which may be large fragmented masses, and branching layers or lenses which may have been formed by pre-consolidation slumping of sulfide and wall rocks or by the tectonic mobilization of sulfide.
		Return to bus and continue northeastward on Rte. 607.

0 .5 475.65 STOP 15. BOX LUNCH. Entrance road to Iron Ridge mine and Bumbarger pit. Walk southwestward and then northwestward to the large open pit. The massive sulfide body mined in this pit is bounded by metasedimentary rocks--principally micaceous quartzite and phyllite. In places, thin lenses of biotite-rich schist bound the sulfide. A variety of wall rocks plus vein quartz are found as tiny to very large fragments in the sulfide body. Room-size blocks of wall rock can be seen at a number of places in the pit. Foliation is common in the sulfide and in places bends around pieces of wall rock enclosed in the sulfide. The observed features whether unconsolidated sulfide and partly consolidated wall rock material slumped early in the history of these rocks and sulfides, whether disruption was principally a tectonic-metamorphic phenomenon, or whether wall rocks were disrupted tectonically and then invaded by sulfide along the zones of disruption.

Return to bus and continue northeastward on Rte. 607.

.55 476.2 Optional STOP 15A. Outcrops in right bank of road. Metasedimentary schists (micaceous quartzite, metagraywacke). Outcrops continue (north) along road almost to the bottom of the hill, about 0.2 mile. Most of these rocks are in the immediate hanging wall of the main sulfide zone. The horizon of the sulfide zone crosses the road near the bottom of the hill, but the sulfide is very thin here or has lensed out and is not evident at the road.

Continue north and northeast on Rte. 607.

.25 476.45 Chestnut Creek. (If optional Stop 15A is made, bus will wait just before bridge).

.05 476.5 Railroad crossing.

1.5 478.0 Turn right (southeastward) onto Rte. 635.

3.9 481.9 Turn right (southwestward) onto Rte. 887 (Glendale Road).

2.95 484.85 Y-intersection, Rte. 887 (Glendale Road) and U.S. 58/221. Continue straight ahead (west) on U.S. 58/221.

.6 485.45 Turn left (south) onto Rte. 89 (North Main Street, Galax).

.1 485.55 Turn left into parking area, Midtowner Motel. End of fourth day.

FIFTH DAY

Turn right from motel parking area onto Rte. 89 North (North Main St.).

.1 485.65 Turn right (east) onto U.S. 58/221.

7.0	492.65	Rte. 620. Continue straight ahead on U.S. 58/221.
3.4	496.05	Rte. I-77. Continue straight ahead on U.S. 58/221.
2.5	498.55	Traffic light, Rte. U.S. 52 in Hillsville, Va. Continue straight ahead on U.S. 58/221.
.3	498.85	Intersection, U.S. 221 and U.S. 58. U.S. 221 and Va. Rte. 100 to the left. Turn left onto U.S. 221/Va. 100.
1.4	500.25	Intersection U.S. 221 (straight ahead) and Rte. 100 (to the left). Turn left, remaining on Rte. 100 North.
3.8	504.05	Turn right onto Rte. 783.
.75	504.8	Turn right onto Rte. 752.
.5	505.3	STOP 16. One-lane dirt road to left (northwest). Walk along road and trail, along ridge and down into valley, about 0.25 mile to open pit near east end of Betty Baker mine. Massive sulfide, largely pyrrhotite. Coarse pyrite crystals or aggregates are scattered in the pyrrhotite. Fragments of wall rock and vein quartz are abundant in the massive sulfide. Note schist overlying the sulfide in places and the gossan cap over some of the sulfide and above some selvages of schist at the top of the sulfide body. Last field trip stop. Return to bus.
.5	505.8	Return to Rte. 783. Turn right (north onto Rte. 783).
.55	506.35	Turn right onto Rte. 100 North.
2.45	508.8	Rock Creek in Sylvatus, Va.
1.6	510.4	Little Reed Island Creek.
3.85	514.25	New River.
5.7	519.95	Turn right onto ramp to I-81 North.
24.35	544.3	Rte. 8 (Exit 36 to Christiansburg, Blacksburg, and Virginia Polytechnic Institute). Continue on I-81.
3.9	548.2	Rtes. U.S. 11/460 (Exit 37 for Christiansburg, Blacksburg, and VPI). Continue on I-81.
47.05	595.25	James River.
10.8	606.05	Rte. U.S. 11 North (Natural Bridge exit to right). Optional exit and detour to view Natural Bridge. If this detour not taken, cumulative mileage should be reduced by 1.05 miles from this point to end of field trip. LUNCH STOP NEAR HERE.

6.0	612.05	(Approximate mileage). Continue on U.S. 11 North and and return to I-81 north of Natural Bridge.
40.75	652.8	Turn right to I-64 East.
12.9	665.7	Crest of Blue Ridge.
18.2	683.9	Turn right onto ramp to U.S. 29 North (exit for Charlottesville and Culpeper).
.75	684.65	Intersection, U.S. 29 North By-Pass and U.S. 29 Business to Charlottesville, Va. Continue straight ahead on U.S. 29 North By-Pass.
1.45	686.1	Intersection, U.S. 29 North By-Pass/U.S. 250 East By-Pass and U.S. 250 Business/U.S. 250 West. Continue straight ahead on U.S. 29 North By-Pass/U.S. 250 East By-Pass.
2.1	688.2	Turn right onto ramp to U.S. 29 North in Charlottesville (Washington, Culpeper exit). Continue on U.S. 29 North.
14.2	702.4	U.S. 33. Continue on U.S. 29 North.
26.8	729.2	Intersection, U.S. 29 North By-Pass and U.S. 29 North Business to Culpeper. Continue straight ahead on U.S. 29 North By-Pass.
2.3	731.5	Exit for U.S. 522 and Rte. 3. Continue on U.S. 29 North By-Pass.
11.05	742.55	Rappahannock River.
2.6	745.15	Y-intersection, U.S. 29 North and Rte. 28 (to the right). Continue on U.S. 29 North.
4.2	749.35	U.S. 17 to right (east) and straight ahead with U.S. 29 North. Continue on U.S. 29 North/U.S. 17 North.
5.55	754.9	Intersection, U.S. 29 North/U.S. 17 North/U.S. 15 North By-Pass and U.S. 15 North Business to Warrenton. Keep to left on U.S. 29 North/U.S. 15 North By-Pass.
1.8	756.7	Traffic light. U.S. 211 to left (west) and straight ahead with U.S. 29 North. Continue straight ahead.
.9	757.6	U.S. 17 North to left. Continue straight ahead on U.S. 29 North/ U.S. 211 East/U.S. 15 North By-Pass.
8.65	766.25	U.S. 15 North to the left. Continue straight ahead on U.S. 29 North/U.S. 211 East.
3.25	769.5	Rte. 55 to the left in Gainesville, Va. Continue straight ahead on U.S. 29 North/U.S. 211 East.

.3	769.8	Turn right onto I-66 East.
4.4	774.2	Rte. 234 (Manassas exit). Continue straight ahead on I-66 East.
4.75	778.95	Exit to the right (U.S. 29/U.S. 211, Centreville, Dulles Airport), continuing straight ahead on U.S. 29 North/U.S. 211 East.
.95	779.9	Turn left onto Rte. 28 North.
.4	780.3	Ramp to right to I-66. Continue straight ahead on Rte. 28 North.
4.0	784.3	U.S. 50. Continue on Rte. 28 North.
4.8	789.1	Cross Dulles Highway.
1.15	790.25	Rte. 606 to the right to Herndon. Continue straight ahead on Rte. 28 North.
.35	790.6	Holiday Inn, Herndon. END OF FIELD TRIP.

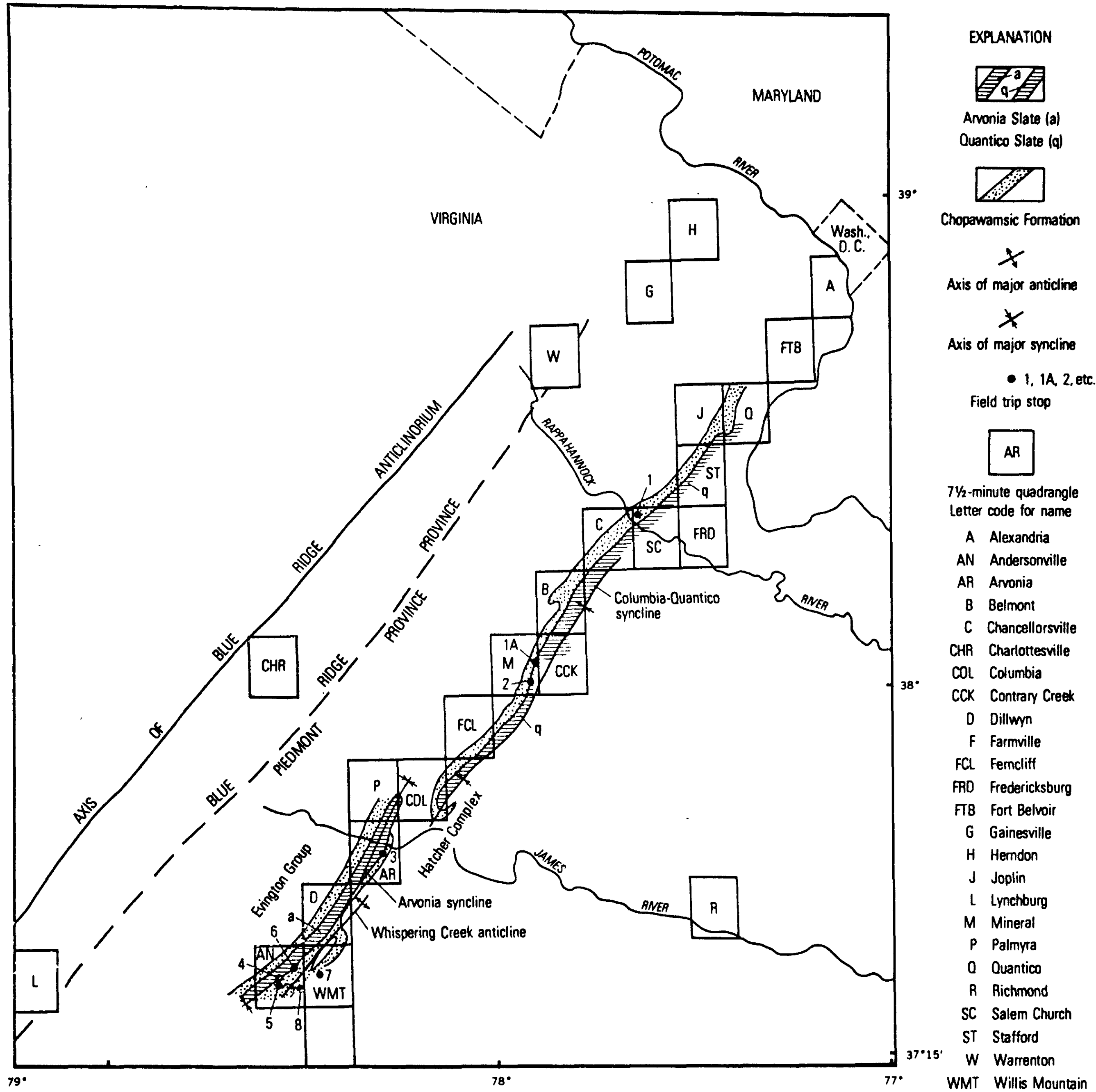


FIGURE 1. INDEX MAP FOR FIRST TWO DAYS OF FIELD TRIP. STOPS 1–8

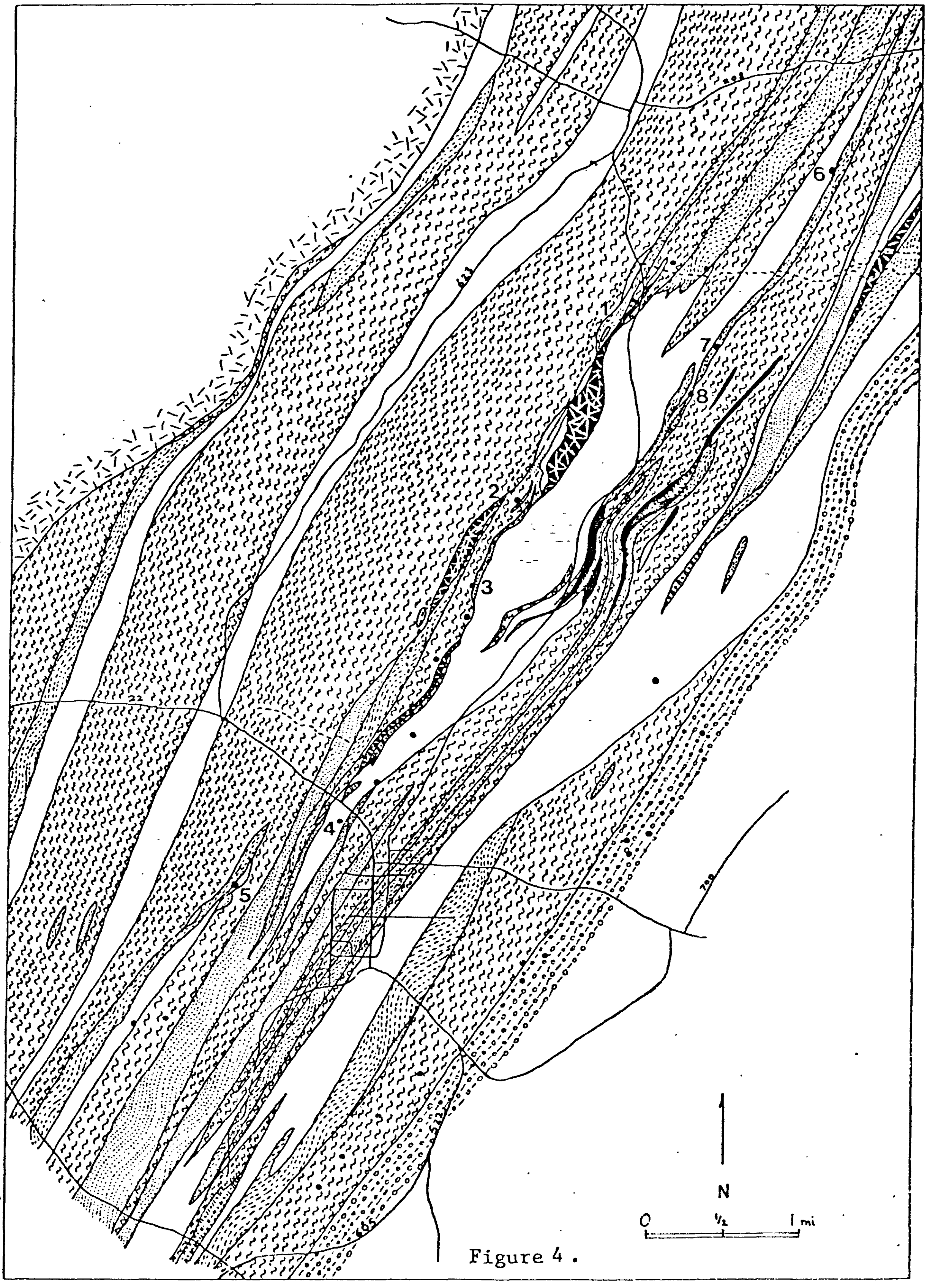


Figure 4.

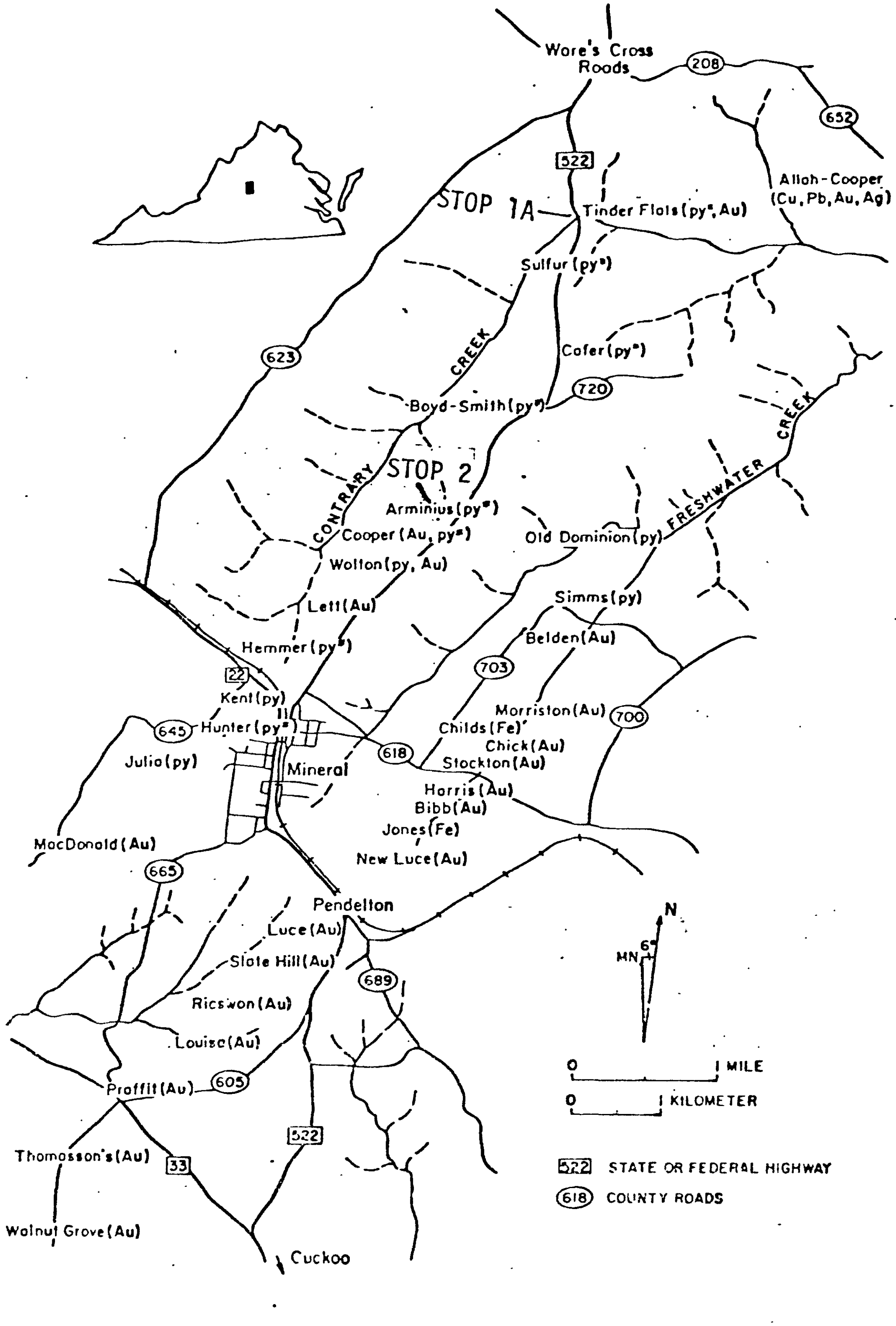


Figure 3. General setting of the mines of the Mineral District, Louisa County, Virginia. The designations after the mine names are: (Au)-gold deposit, (py)-massive pyritic deposit, (py*)-massive pyritic deposit with base metals, (Fe)-gossan iron deposit. STOP 1A and STOP 2 shown.

Figure 4. Geologic map of the Mineral District, Louisa County, Virginia. After W. J. Feuer, 1977, courtesy of Callahan Mining Corporation.

granodiorite

garnet muscovite chlorite schist

quartz sericite schist and gneiss

sericitic quartzite, biotite sericite quartzite

chloritic quartzite

sulfides, gossan

transitional amphibolite

amphibolite

quartz sericite biotite schist and gneiss

biotite sericite fragmental schist

1. Sulphur
2. Boyd-Smith
3. Arminius
5. Julia
6. Allah Cooper
7. East Sulphur
8. Cofer

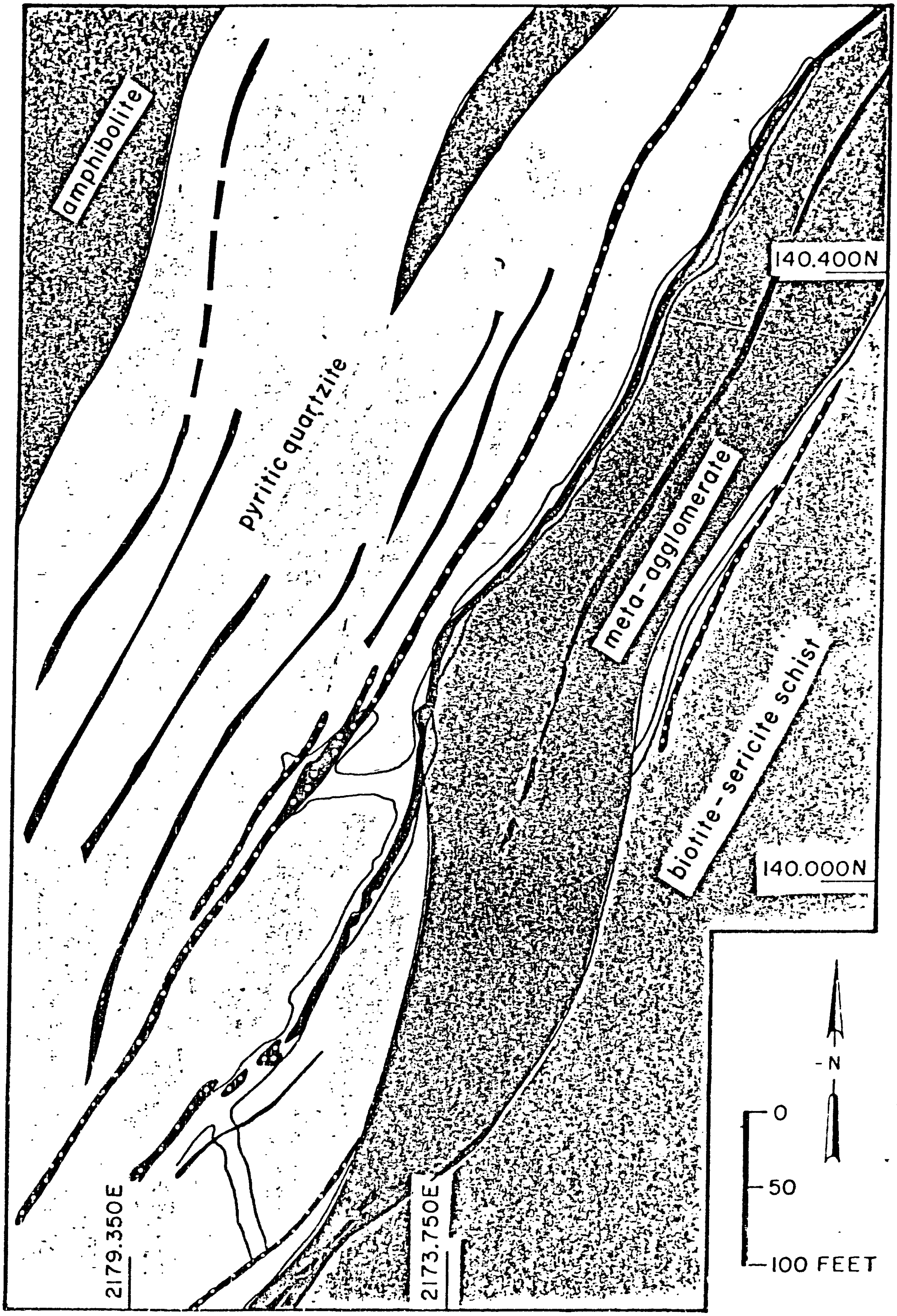


Figure 5. Geology of the Cofer Deposit, Plan View (after Hodder, et al. 1977).

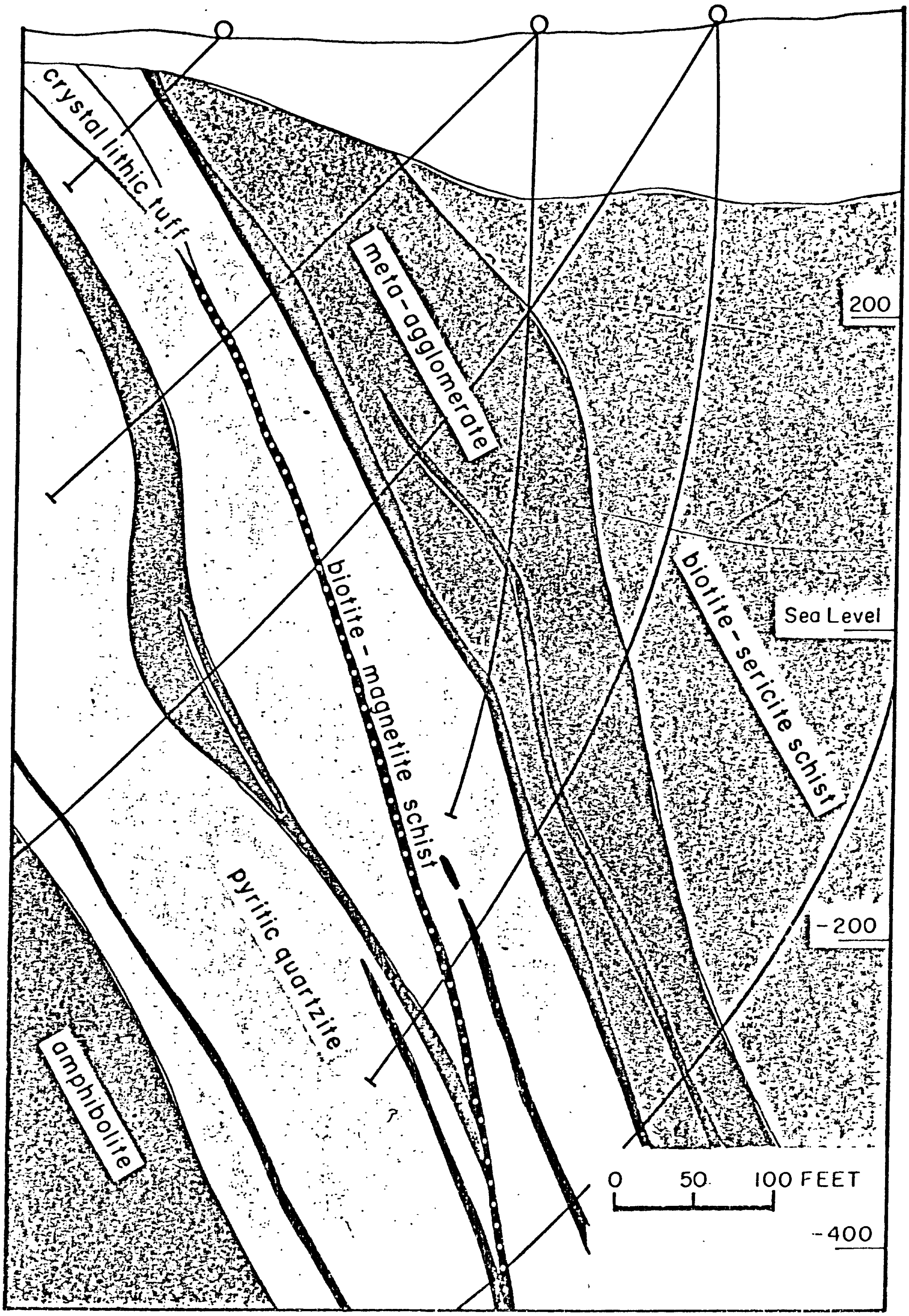


Figure 6. Geology of the Cofer Deposit, Cross-section (after Hodder, et al. 1977).

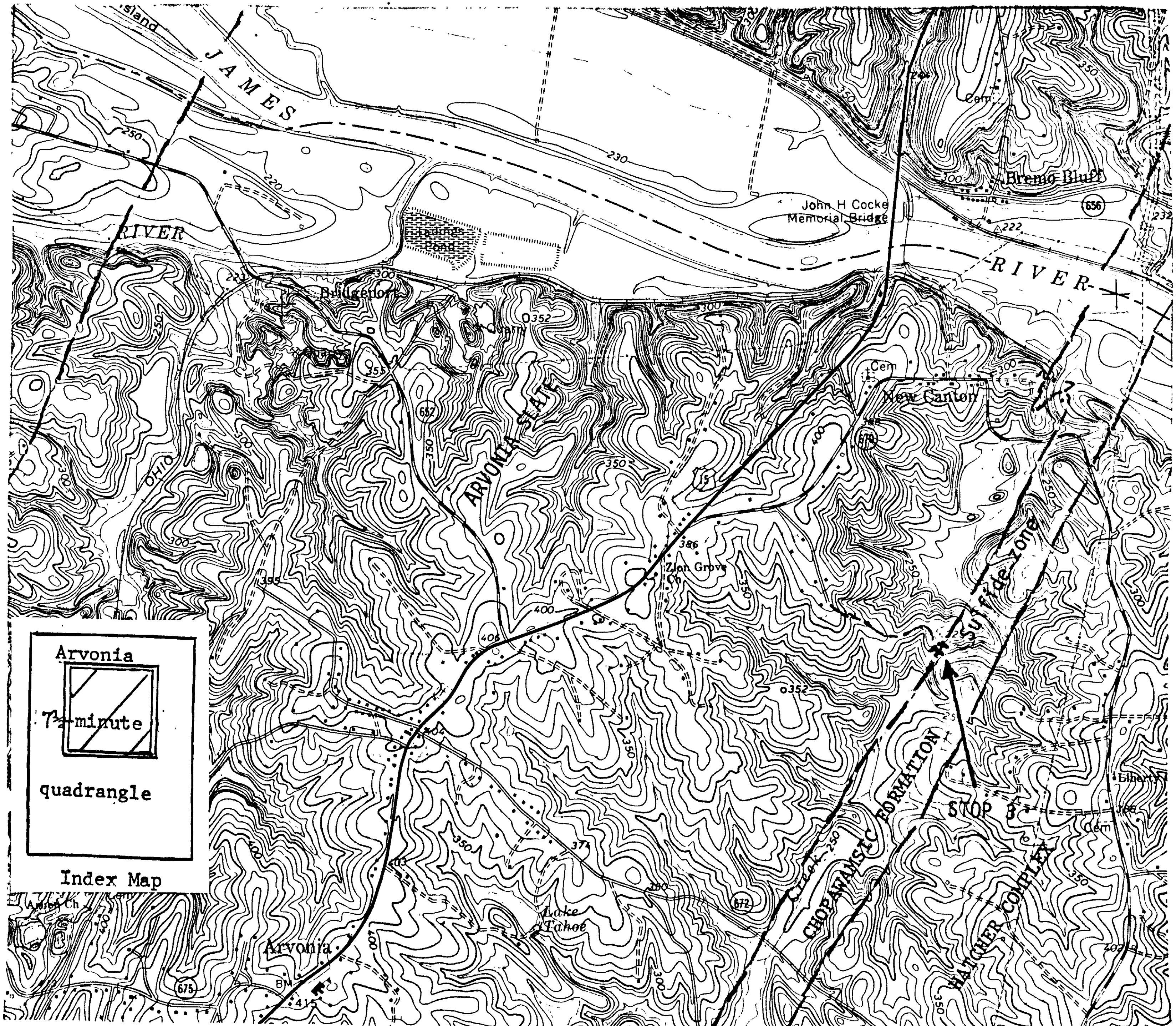
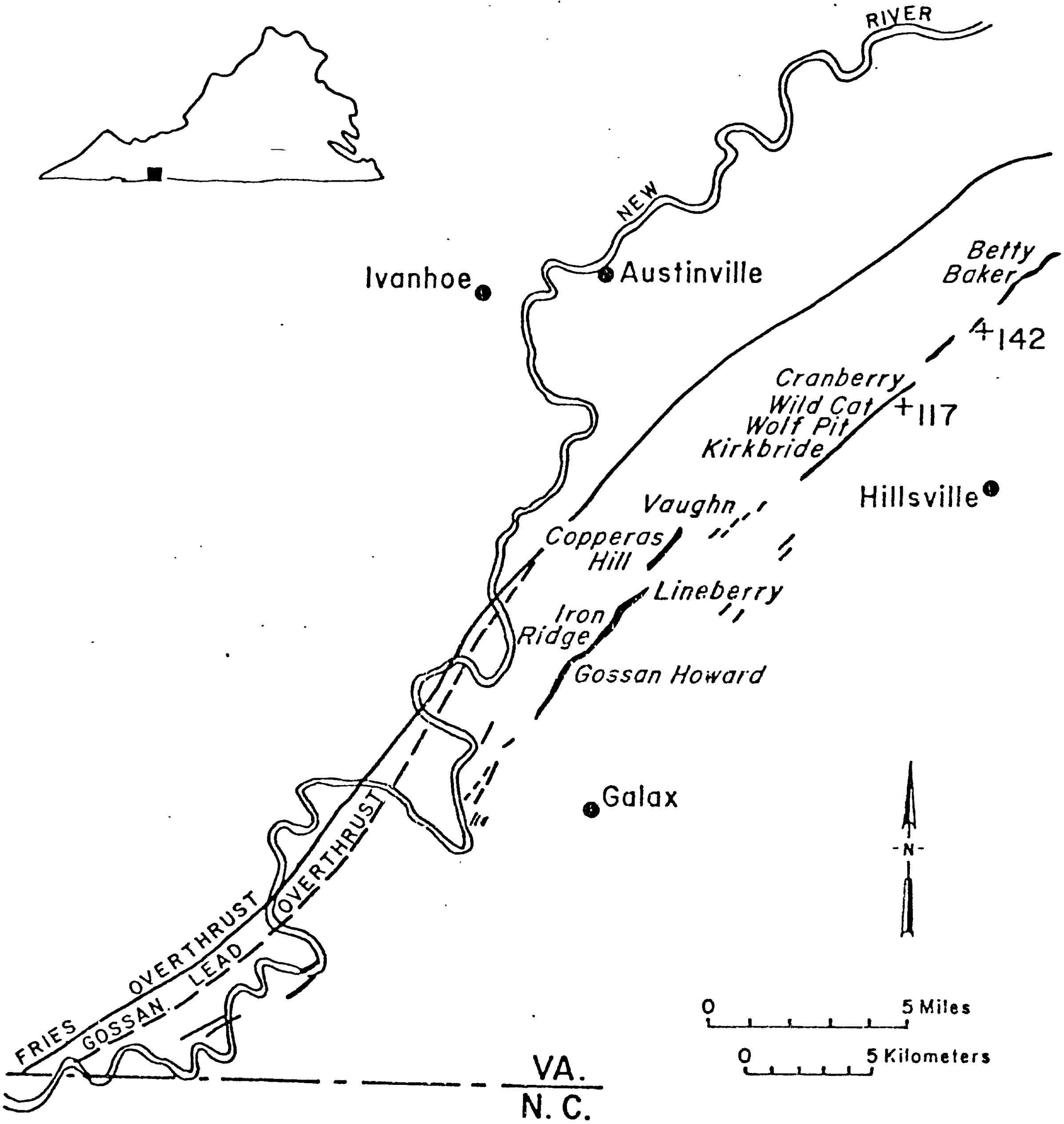


FIGURE 7.--LOCATION MAP FOR STOP 3.

Figure 9. Map of the Great Gossan Lead showing the locations of many of the prominent deposits. (from Henry et al. 1978).



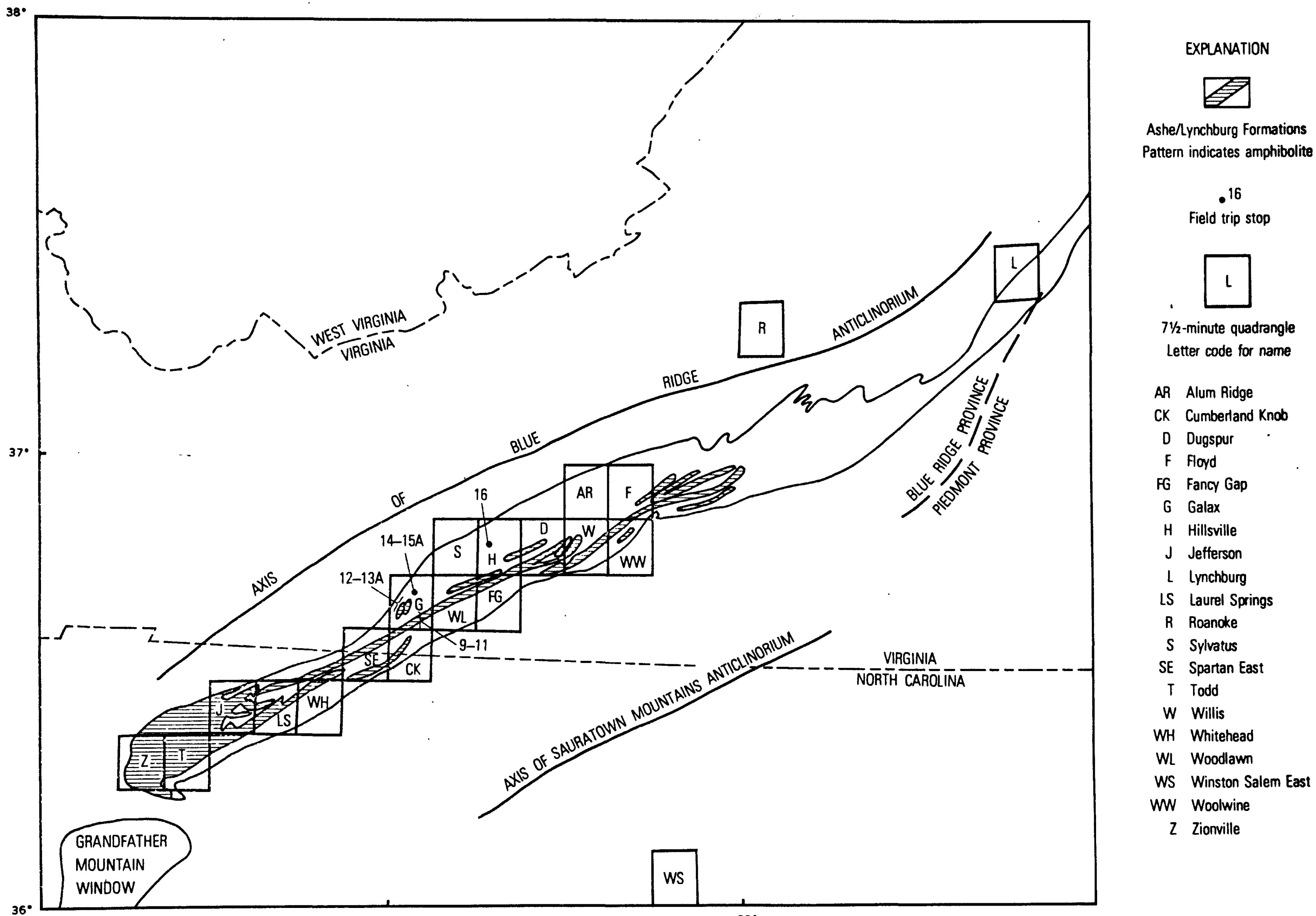


FIGURE 10. INDEX MAP FOR LAST THREE DAYS OF FIELD TRIP. STOPS 9–16

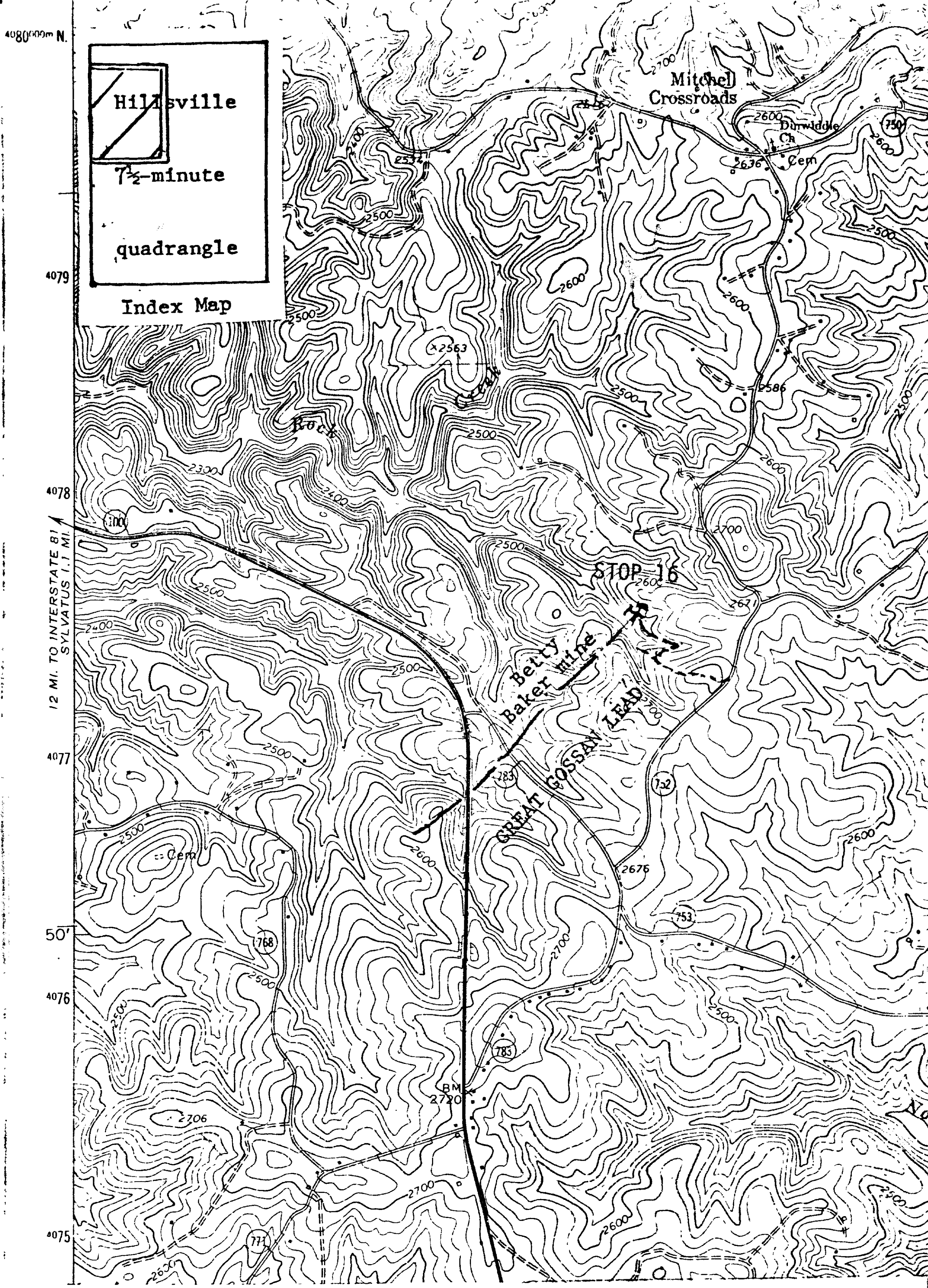


FIGURE 13--LOCATION MAP FOR STOP 16.

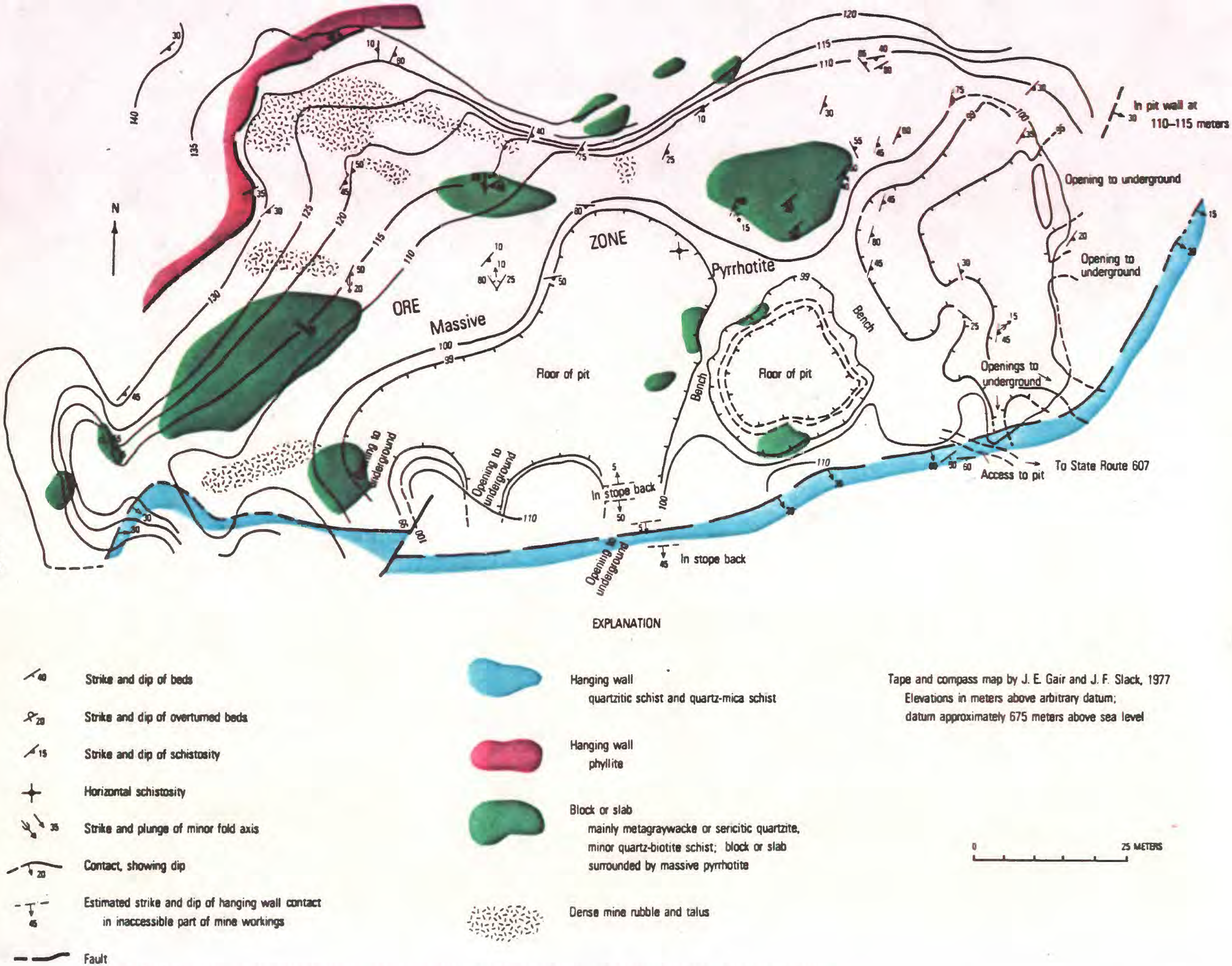


FIGURE 12. BUMBARGER PIT--IRON RIDGE SEGMENT, GREAT GOSSAN LEAD, VIRGINIA

X301 75

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

COMMONWEALTH OF VIRGINIA
DIVISION OF MINERAL RESOURCES
JAMES L. CALVER, STATE GEOLOGIST

Open file 78-1068

GALAX QUADRANGLE
VIRGINIA
7.5 MINUTE SERIES (TOPOGRAPHIC)
NW/4 GALAX 15' QUADRANGLE

Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Topography by photogrammetric methods from aerial photographs taken 1963. Field checked 1965
Polyconic projection. 1927 North American datum
10,000-foot grid based on Virginia coordinate system, south zone
1000-meter Universal Transverse Mercator grid ticks, zone 17, shown in blue
Fine red dashed lines indicate selected fence and field lines where generally visible on aerial photographs. This information is unchecked
Revisions shown in purple compiled in cooperation with Commonwealth of Virginia agencies from aerial photographs taken 1970
This information not field checked

UTM GRID AND MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION
Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
U.S. Route — State Route

QUADRANGLE LOCATION

FIGURE 11.-LOCATIOIMAP FOR STOPS 9-15A.

GALAX, VA.
NW/4 GALAX 15' QUADRANGLE
N3637.5—W8052.5/7.5

1965
PHOTOREVISED 1970
AMS 4857 III NW—SERIES V834

open file 78-1068

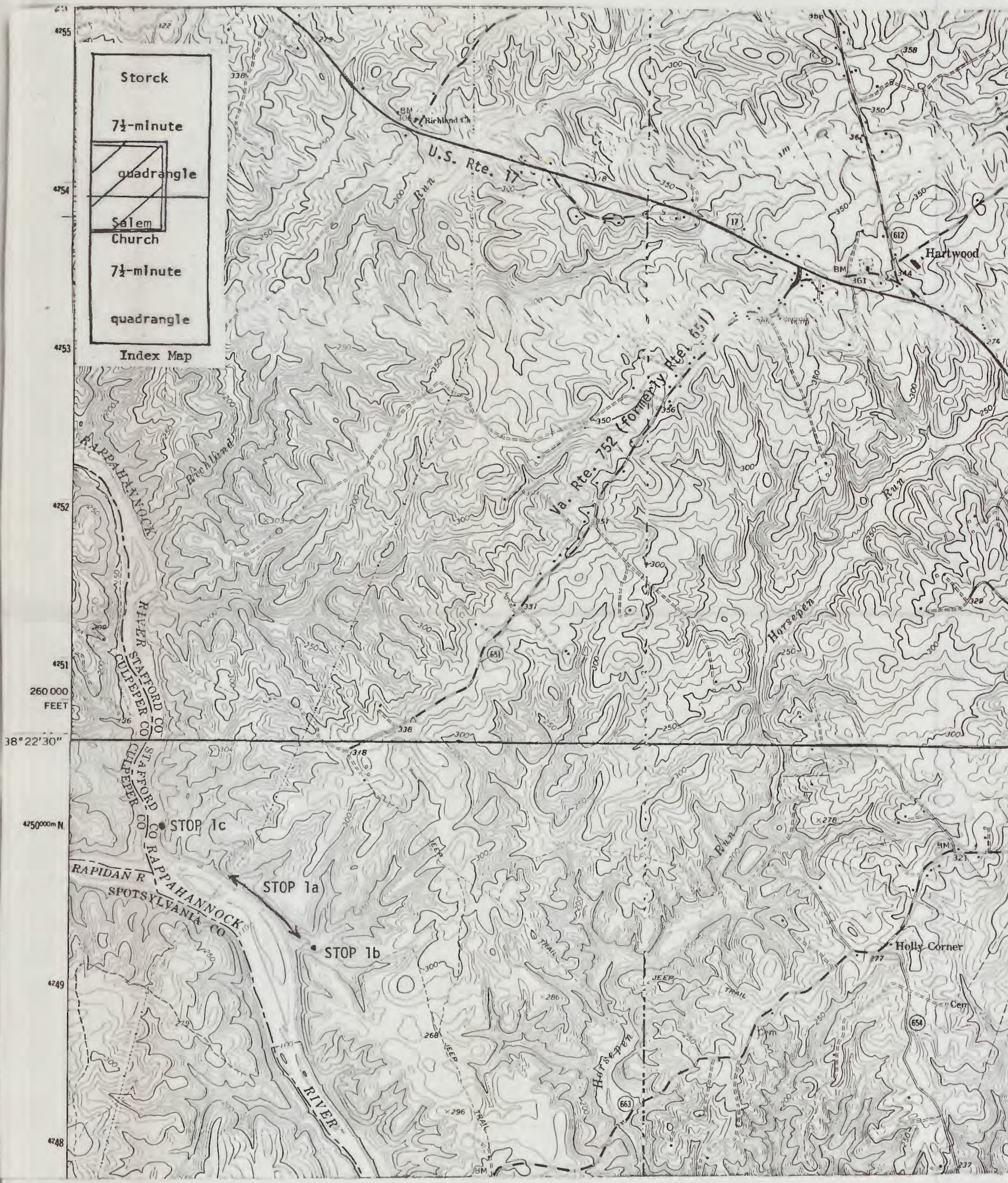


FIGURE 2.--LOCATION MAP FOR STOP 1.

Open file 78-1068

FIGURE 8.--LOCATION MAP FOR STOPS 4-8.