DEPARTMENT OF THE INTERIOR

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EARLY MESOZOIC BASINS WORKSHOP

FIELDTRIP # 2

Base- and precious-metal occurrences in the Culpeper basin, northern Virginia

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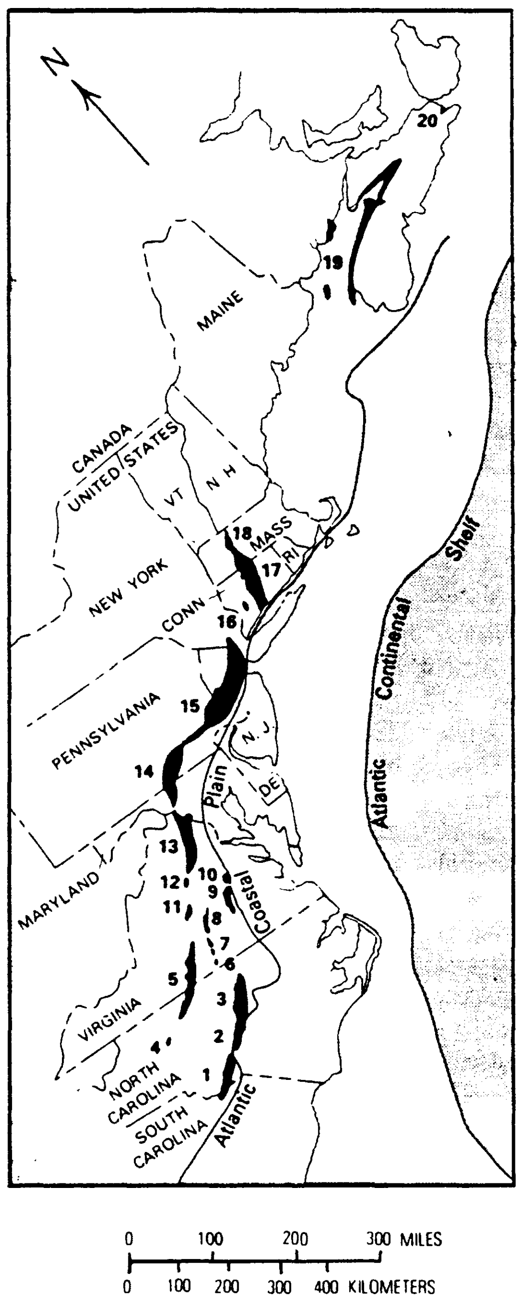
INTRODUCTION

During the 18th and 19th centuries, base and precious metals were actively prospected in, and locally produced from, "red beds" of the early Mesozoic basins in the eastern United States. Numerous small base- and precious-metal occurrences were discovered during this period (see table 1 for a list of occurrences in the Culpeper basin), and a few occurrences were developed into mines which produced significant amounts of ore, such as Cornwall, Pennsylvania, and Newgate and Bristol, Connecticut. The Culpeper basin in northern Virginia is typical of these early Mesozoic basins which occur near the east coast (figure 1) of the United States and contains a representative sampling of various types of base- and precious-metal occurrences.

Most of the large abandoned mine sites occurring in these early Mesozoic basins are not located in the Culpeper basin. Therefore, we will not be able to visit any of the large mine sites during this trip, but we will visit a few small occurrences that illustrate the nature and diversity of mineralization associated with these Mesozoic basins. In general, the base and precious metal occurrences tends to group into three broad deposit categories (with some overlap). The first category is deposits associated with igneous intrusions or the thermal aureole bordering igneous intrusions. Deposit types associated with this category include:

1. Magnetite skarn/replacement deposits in carbonate rocks bordering diabase sheets. These deposits, such as the Cornwall deposit in Pennsylvania, contain significant Fe and are enriched in Cu, Co, Ni, Au, and Ag.
2. Copper-rich hornfels bordering granophyre and ferrogabbro bodies. The hornfels is enriched in Cu or Cu and Fe and locally contains anomalous Au, Mo, and other trace metals.
3. Late-stage segregations and veins, enriched in Cu and locally in precious metals, associated with diabase bodies.

The second category is deposits associated with the migration of connate brines within the basin, apparently unrelated to



EXPLANATION

1. Wadesboro (N.C. - S.C.)
2. Sanford (N.C.)
3. Durham (N.C.)
4. Davie County (N.C.)
5. Dan River and Danville (N.C. - Va.)
6. Scottsburg (Va.)
7. Basins north of Scottsburg (Va.)
8. Farmville (Va.)
9. Richmond (Va.)
10. Taylorsville (Va.)
11. Scottsville (Va.)
12. Barboursville (Va.)
13. Culpeper (Va. - Md.)
14. Gettysburg (Md. - Pa.)
15. Newark (N.J. - Pa. - N.Y.)
16. Pomperaug (Conn.)
17. Hartford (Conn. - Mass.)
18. Deerfield (Mass.)
19. Fundy or Minas (Nova Scotia - Canada)
20. Chedabucto (Nova Scotia - Canada)

FIGURE 1. — Exposed early Mesozoic basins in Eastern North America.

Table 1. Inventory of mines, prospects, and mineral occurrences
in the Culpeper Basin, Virginia

name	county	state	quadrangle	latitude	longitude	occurrence type	deposit type	host rock lithology	host rock age	commodity principal	commodity accessory
Boyds barite	Montgomery	MD	Germantown	N39.10'59"	W77.19'37"	occurrence	vein	diabase	Jurassic	Ba	
Dawsonville 1	Montgomery	MD	Germantown	N39.07'54"	W77.20'06"	occurrence	placer	gravel	Quaternary	Au	
Dawsonville 2	Montgomery	MD	Germantown	N39.07'42"	W77.20'07"	occurrence	placer	gravel	Quaternary	Au	
Seneca Creek	Montgomery	MD	Seneca	N39.06'11"	N77.20'38"	occurrence	placer	gravel	Quaternary	Hg	
Sugarland	Montgomery	MD	Sterling	N39.05'58"	W77.23'52"	mine	stratabound/replacement	sandstone	Triassic	Cu	
Waterford gold	Loudoun	VA	Waterford	N39.07'57"	W77.33'05"	occurrence	placer	gravel	Quaternary	Au	
Goose Creek	Loudoun	VA	Leesburg	N39.05'53"	W77.30'01"	prospect	hornfels/replacement	siltstone	Triassic	Cu	
Sugarland Run	Loudoun	VA	Seneca	N39.02'22"	W77.21'46"	prospect	stratabound/replacement	sandstone	Triassic	Cu	Ag
Sterling	Loudoun	VA	Sterling	N39.00'20"	W77.26'05"	occurrence	stratabound/replacement	siltstone	Triassic	Cu	
Theodora	Fairfax	VA	Herndon	N38.56'59"	W77.25'23"	mine	hornfels	siltstone/sandstone	Triassic	Cu	
Spencer Farm	Fairfax	VA	Herndon	N38.54'17"	W77.28'35"	prospect	hornfels/replacement	sandstone	Triassic	Cu	
Chantilly prospect	Fairfax	VA	Herndon	N38.53'20"	W77.25'10"	prospect	hornfels/replacement	siltstone	Triassic	Cu	
Cub Run Copper	Fairfax	VA	Herndon	N38.52'54"	W77.28'15"	occurrence	hornfels/replacement	sandstone/siltstone	Triassic	Cu	
Chantilly	Fairfax	VA	Herndon	N38.52'50"	W77.25'08"	occurrence	stratabound/replacement	sandstone/shale	Triassic	Cu	
Fairfax Quarry	Fairfax	VA	Manassas	N38.49'33"	W77.29'19"	occurrence	diabase-host/vein	diabase	Jurassic	Cu	
Bull Run	Fairfax	VA	Manassas	N38.48'27"	W77.29'23"	occurrence	placer	gravel	Quaternary	Au	
Manassas	Prince William	VA	Independent Hill	N38.43'43"	W77.28'27"	occurrence	vein	siltstone/shale	Triassic	Ba	
Brentsville	Prince William	VA	Independent Hill	N38.41'21"	W77.29'56"	prospect	sediment-host	shale	Triassic	Cu	
St. Stephens	Fauquier	VA	Catlett	N38.40'49"	W77.40'08"	mine	vein	siltstone/diabase	Tr/J	Ba	
Calverton	Fauquier	VA	Catlett	N38.39'10"	W77.40'39"	occurrence	stratabound/replacement	black shale	Triassic	Zn	
Cedar Run	Prince William	VA	Nokesville	N38.37'32"	W77.34'41"	mine	vein/fault zone	siltstone	Triassic	Ba	
Botts barite	Fauquier	VA	Midland	N38.34'01"	W77.39'32"	occurrence	vein	shale	Triassic	Ba	
Elk Run mine	Fauquier	VA	Midland	N38.33'21"	W77.40'12"	prospect	fault zone/vein	siltstone/shale	Triassic	Cu	
Bealeton mine	Fauquier	VA	Midland	N38.33'15"	W77.43'54"	mine	hornfels/replacement	siltstone/shale	Triassic	Cu	
Gear Barite	Fauquier	VA	Midland	N38.32'45"	W77.43'32"	prospect	vein	siltstone/sandstone	Triassic	Ba	
Kemper	Fauquier	VA	Midland	N38.32'29"	W77.43'30"	prospect	vein	siltstone	Triassic	Ba	
Mountain Run	Culpeper	VA	Culpeper East	N38.27'09"	W77.54'09"	occurrence	hornfels/replacement	sandstone	Triassic	Cu	Fe U
Stevensburg	Culpeper	VA	Culpeper East	N38.26'20"	W77.54'56"	occurrence	stratabound/replacement	black shale	Triassic	Zn	Cu
Culpeper prospect	Culpeper	VA	Culperer East	N38.26'08"	W77.59'44"	occurrence	hornfels/skarn	lmst. conglomerate	Triassic	Cu	Fe
Batna	Culpeper	VA	Culpeper East	N38.23'50"	W77.53'29"	prospect	hornfels	siltstone	Triassic	Cu	
Somerset mine	Orange	VA	Gordonsville	N38.12'56"	W78.13'29"	mine	stratabound/replacement	sandstone/shale	Triassic	Cu	

igneous intrusion. Deposit types in this category include:

1. Sandstone-hosted copper-rich occurrences, commonly associated with organic debris. These deposits contain significant Cu, are commonly enriched in Ag, and are enriched in U in some places.
2. Black mudstone-hosted disseminated sulfide occurrences. This deposit type appears restricted to a particular sedimentological facies of mudstone, with enrichment in Zn, Cu, and locally Pb and Mo.
3. Base-metal barite vein/replacement bodies, locally enriched in Pb, Zn, Cu, and Ag as well as barite.

The third category is syngenetic deposits associated with basin sedimentation, such as placer gold deposits derived from detritus of pre-Mesozoic igneous and metamorphic rocks bordering the basins. The setting of most of these deposit types in a typical early Mesozoic basin is shown schematically in figure 2.

We will visit mineralized occurrences representative of the sandstone-hosted copper mineralization (STOP 1, type 2.1), black-mudstone-hosted disseminated sulfides (STOP 3, type 2.2), and base-metal barite veins (STOP 5, type 2.3). In addition, we will visit rock types associated with some of the other deposit types, such as skarn/hornfels (STOP 2) which is related to magnetite skarn/replacement bodies (type 1.1) and granophyre/ferrogabbro (STOP 4) which, in some cases, is associated with copper-rich hornfels (type 1.2) and segregation and vein occurrences in diabase (type 1.3). The locations of field trip stops 1 through 5 are shown in figure 3.

We have planned approximately 30 minutes at each stop. Logistics on this trip are tightly constrained. The trip runs 8 hours as planned, so please help keep us on schedule. We plan to eat lunch on the bus between stops 2 and 3, and we must be at stop 3, the Culpeper Crushed Stone Quarry, at noon! In addition, all participants who wish to enter the Culpeper Quarry must have hard hats and sturdy shoes (preferably field boots), and sign liability releases.

OVERVIEW OF THE GEOLOGY OF THE CULPEPER BASIN

The Culpeper basin of northern Virginia and adjacent Maryland is an elongate, north-northeast trending, fault-bounded trough containing a thick sequence of Upper Triassic to Lower Jurassic non-marine sedimentary rocks. The basin is centrally located in a belt of related lower Mesozoic troughs (figure 1) extending discontinuously from South Carolina to Canada. These basins formed during the initial stages of continental fragmentation which ultimately developed the framework of the modern western Atlantic margin.

The term Culpeper Group is herein used for the lower Mesozoic strata and intercalated basalt flows in the Culpeper basin, following the usage of Lee and Froelich (in press)

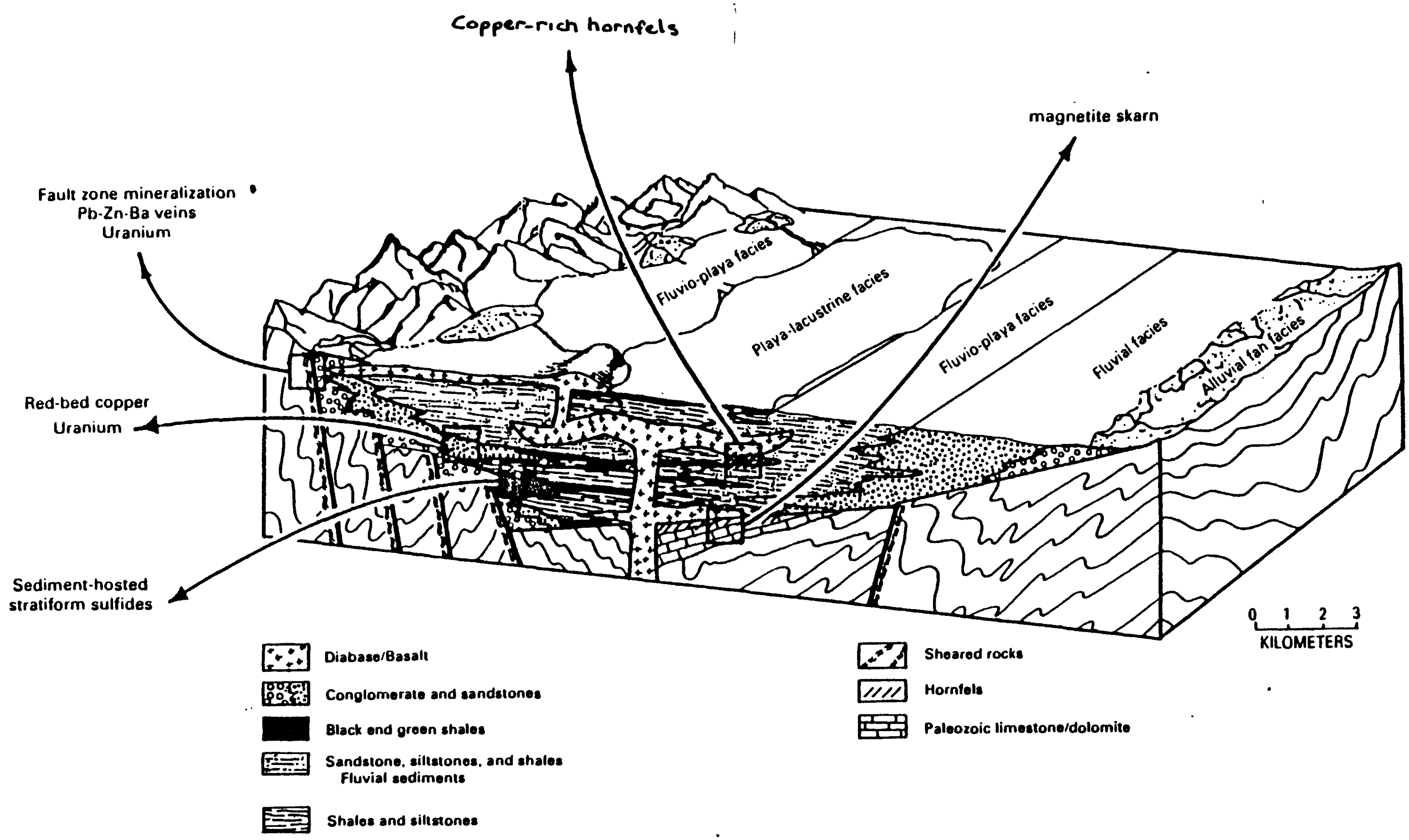


FIGURE 2 —Schematic distribution of facies in the early Mesozoic basins in the Eastern United States, showing some potential mineral resources. (Modified from Turner-Peterson, C.E., 1980, Short Course Notes, Rocky Mountain Section of Society of Economic Paleontologists and Mineralogists, p. 149–175.)

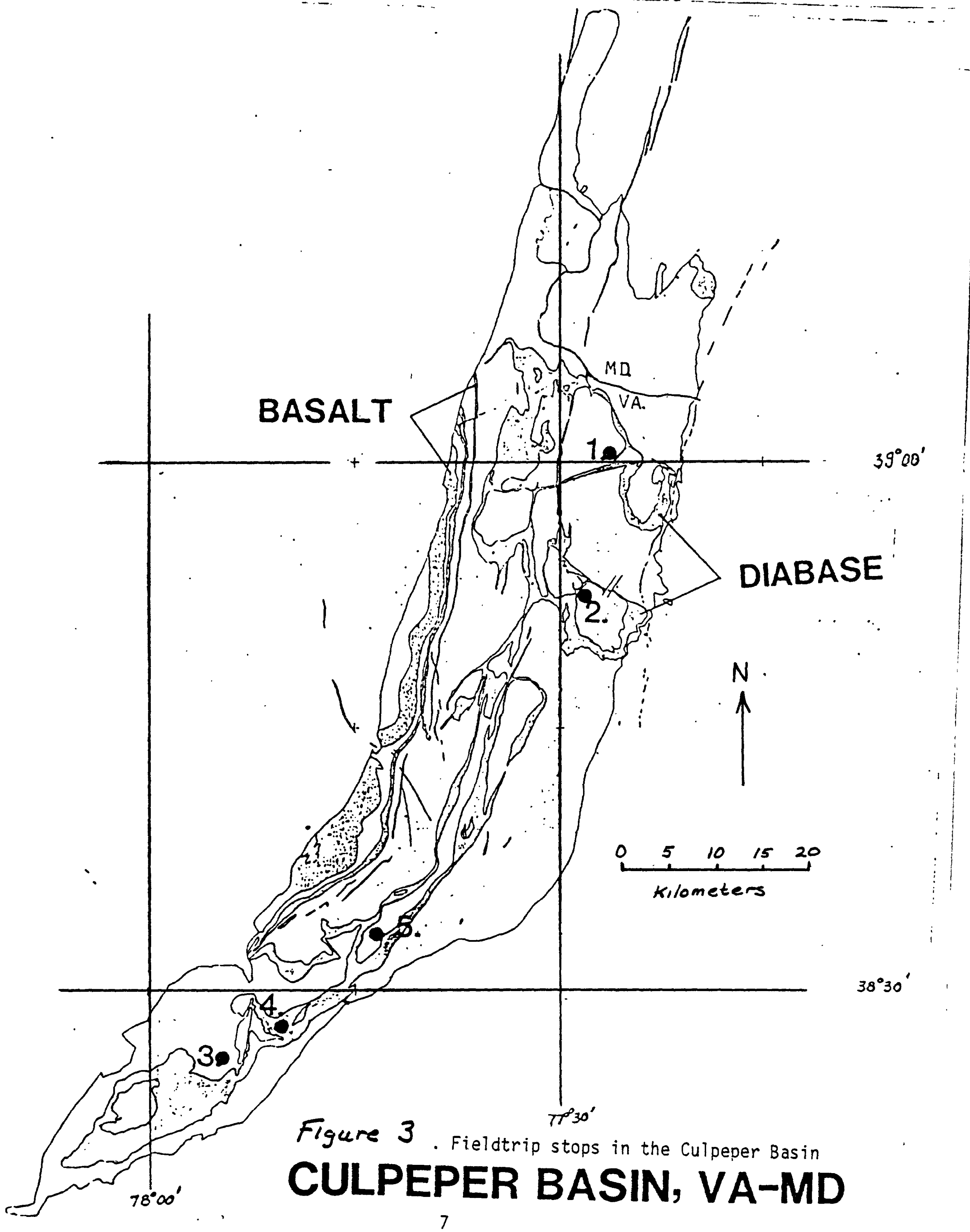


Figure 3. Fieldtrip stops in the Culpeper Basin

CULPEPER BASIN, VA-MD

(figure 4). The lower Culpeper Group, mostly of Late Triassic age, is subdivided into four formations: the Manassas Sandstone, the Balls Bluff Siltstone, the Tibbstown Formation, and the Catharpin Creek Formation. The Manassas Sandstone contains three conglomerate members that lie at the base of the Culpeper Group in different areas along the eastern margin of the basin. These members all grade upward and laterally into the main arkosic red sandstone (Poolesville Member) of the Manassas. The Balls Bluff Siltstone conformably overlies, grades into, and intertongues with sandstone of the Manassas. It occupies the medial part of the basin and is predominately red-brown siltstone and sandstone intercalated with green-gray fossiliferous mudstone. The Balls Bluff Siltstone is conformably overlain by sandstones and conglomerates of the Tibbstown Formation in the southern Culpeper basin and the Catharpin Creek Formation in the central Culpeper basin. The conglomerates occur as lenses at the top of these formations, and are the youngest sedimentary rocks in the southern Culpeper basin.

The upper Culpeper Group of Early Jurassic age consists of a series of intercalated basalt flows and sedimentary rocks. The lowermost unit, the Mount Zion Church Basalt, consists of two or more individual basalt flows. The Mount Zion Church Basalt is overlain by red-brown sandstone, siltstone, and gray mudstone of the Midland Formation, which in turn is succeeded by the Hickory Grove Basalt. The Hickory Grove consists of at least two or more flows that locally are separated by lenticular sandstone and siltstone bodies. The Hickory Grove Basalt is overlain by sandstone and interbedded with red-brown and gray-green siltstone of the Turkey Run Formation, which is capped by the Sander Basalt. The Sander Basalt comprises the thickest series of flows, and contains the most extensive lenticular sandstone and siltstone intercalations. The overlying Waterfall Formation consists of interbedded sandstone, siltstone, conglomerate, and several thin calcareous shale zones.

Fossil flora and fauna are present but generally sparse in the "red beds" typical of the Culpeper basin; however, conchostracans, ostracods, fish scales, insect parts, and diagnostic spores and pollen are present and locally abundant in some of the dark gray shales and siltstones of the Culpeper Group. The presence of diagnostic Late Triassic and Early Jurassic spores and pollen distributed throughout the stratigraphic section has enabled the systematic palynofloral zonation of the entire Culpeper Group to be determined. This zonation is supported in places by diagnostic fish fossil zones. Strata of the Culpeper Group range in age from at least the late Carnian stage of the Late Triassic (about 225 m.a.) to the late Sinemurian or possibly early Pliensbachian stage of the Early Jurassic (about 193 m.a.) with the Triassic-Jurassic boundary (about 208 m.a.) a short distance below the Mount Zion Church Basalt.

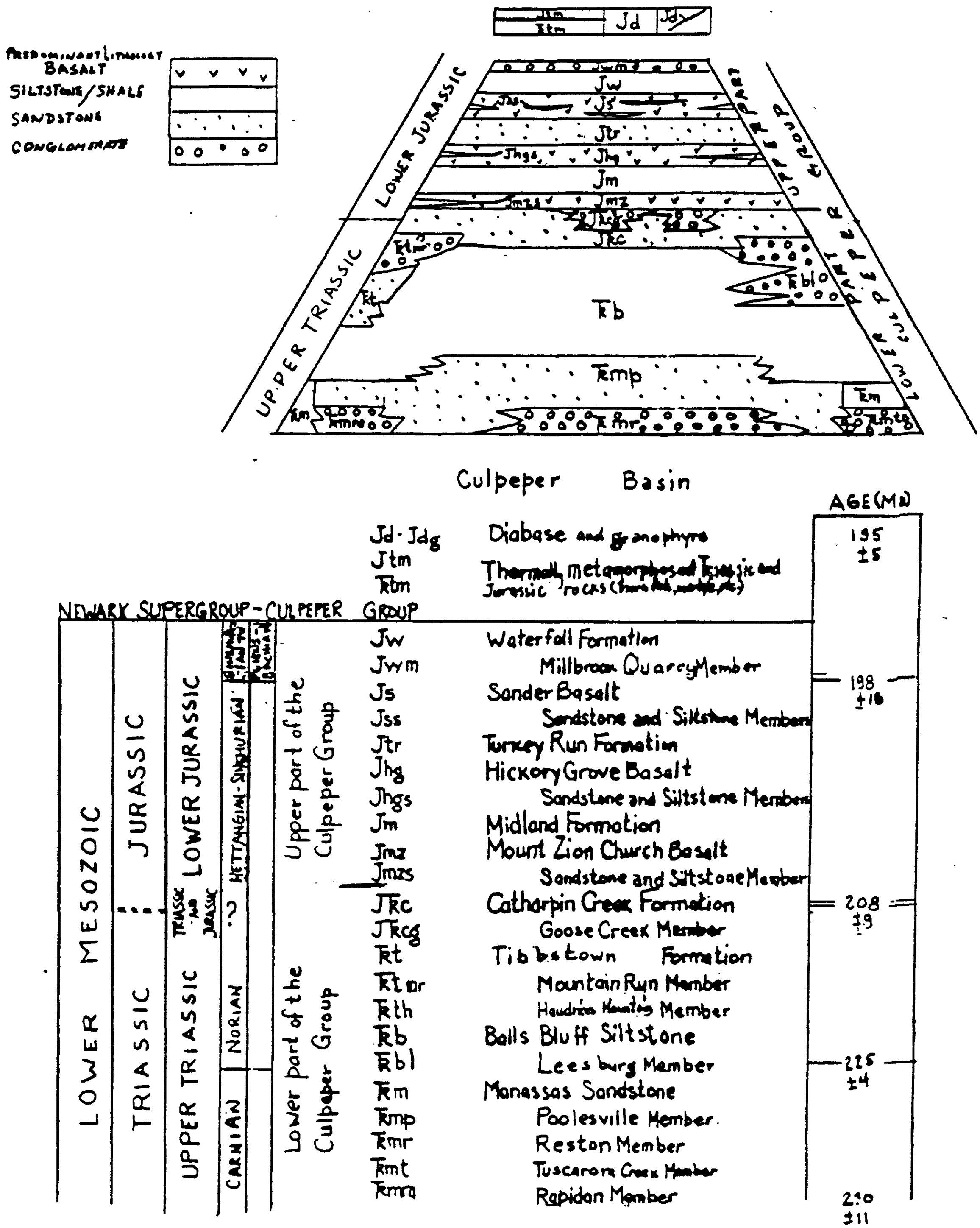


Figure 4. Simplified stratigraphic correlation diagram summarizing age and lithology of the Culpeper Group in the Culpeper basin, Virginia.

Most published depositional models of the Culpeper basin (for instance, Lindholm, 1979, Froelich and others, 1982, Gore, 1984) suggest a closed-basin setting and arid to semi-arid conditions. Conglomerates restricted to the basin margins contain structures indicative of debris flow and shallow, flash-flooding stream deposition and are interpreted as alluvial fan deposits. Poorly-sorted, pebbly sandstones dominated by horizontal lamination and numerous cut-and-fill structures are believed to represent the distal fan deposits. Many sandstone outcrops, however, are comprised of channel-form, 3-6 m thick, fining-upward sequences dominated by large-scale cross-bedding and ripple-scale cross-lamination. These are intercalated with lenses of thin, rippled sandstone and siltstones with abundant burrow and root structures. This type of sandstone is interpreted as the deposits of perennial meandering or anastomosing rivers which flowed over heavily vegetated flood plains. These rivers may represent basin-axial drainages coeval with the alluvial fans or they may reflect more pluvial periods with higher river discharges. The fine-grained sedimentary rocks of the Culpeper Group were deposited in both fluvial and lacustrine environments. The fine-grained fluvial deposits are dominated by red siltstones with abundant burrow and root structures and carbonate nodules indicative of vegetated flood plains with soil development. The siltstones are cut by 2-4 m thick fining-upward sandstone sequences that are interpreted as deposits of small, flash-flooding, meandering streams. The lacustrine deposits typically form 3-10 m thick cycles consisting of gray to black laminated shale grading upward into red siltstone or finegrained sandstone. The shales commonly contain aquatic fossils, including conchostracans and fish, and are interpreted as the deposits of shallow to deep lakes. The red siltstones have desiccation and root structures indicating subaerial conditions. The lacustrine cycles are interpreted as the transgression and regression of closed-basin lakes in response to long-term climatic changes.

During the early stages of Jurassic deposition (about 200 m.a.), tholeiitic diabase stocks, sills, and dikes extensively intruded and metamorphosed the sedimentary rocks and generated local areas of basalt flows. The strata were regionally tilted to the west, particularly along the active western border faults.

STOP 1 - Sandstone-hosted copper mineralization, Rt. 28 Sterling, Virginia.

INTRODUCTION

The small copper occurrence in weathered sandstones at stop 1 is representative of the class of sandstone-hosted copper deposits. The geologic setting and genesis of this deposit type is discussed by Rose (1976). The copper occurrence at Stop 1 illustrates the association of copper mineralization with local reducing areas in an otherwise "oxidized" sedimentary sequence. Copper mineralization is commonly associated with organic material, often plant fragments, root zones, hydrocarbons, and, less often, black shale lenses, in permeable sandstone units deposited in tectonically-active intracratonic basins. In some areas of pervasive mineralization, the association with organic material is not readily apparent because of reaction with mineralizing fluids and flushing of organic constituents. In other areas, basalt and hornfels (magnetite) act as reductants, as, for as example, in the numerous occurrences of copper mineralization located at the base of the Orange Mountain Basalt in the Newark basin of New Jersey.

Most of the known copper deposits of this type are relatively small, although some larger and more significant deposits occur, such as the White Pine district, Michigan (White, 1971), and Corocoro, Bolivia (Ljunggren and Meyer, 1964). Some of the Zambian copper belt deposits may belong in this category as well (particularly Chibuluma). Unweathered sandstone-hosted copper deposits are characterized by copper sulfide minerals replacing and coating organic material and also precipitating as a cement in the sandstone. Mineralization commonly follows a copper enrichment sequence, with early diagenetic pyrite replaced or followed by chalcopyrite, then bornite, chalcocite, and locally native copper (in some localities with native silver). The copper mineralization is commonly enriched in precious metals, such as Ag and Au. A grab sample from the dump of the abandoned Schuyler mine in the Newark basin in New Jersey, running approximately 1.5% copper, contained 65 ppm Ag and 0.4 ppm Au. Similar samples from other Newark Supergroup occurrences, such as Newgate and Meriden, in the Hartford basin in Connecticut, run from <1% to 7% copper, and contained 60 to 140 ppm Ag. Pb and Zn are typically low in these mineralized areas, with concentrations in the range of 30-80 ppm. Ba and Sr are typically enriched, with values in the range of 1000-20,000 ppm Ba and 100-1000 ppm Sr.

Copper mineralization in red-bed deposits apparently formed relatively early in the diagenetic history of the enclosing sediments from fluids (brines?) derived from within the basin. The information summarized in Rose (1976) indicates that the copper occurrences of this type probably formed from cool (<150°C) sulfate-rich brines migrating updip along preferentially permeable zones to reducing sites of deposition. The mineralizing fluids are apparently equilibrated with quartz, feldspar, illites, and carbonates. The fluids are in the hematite stability field, but are often undersaturated with respect to hematite. As a result, many of the mineralized sandstones appear "bleached" and have lost much of their hematite/goethite pigmentation. The fluids were not in equilibrium with gypsum, anhydrite, or barite, although some of the mineralized rocks are enriched in barium. Redox interfaces appear to control copper mineralization, with deposits occurring at sites where sulfate is reduced.

DESCRIPTION

This exposure of the Balls Bluff Siltstone is part of the fluvial facies transitional to the underlying Manassas Sandstone. The gray sandstone exposed in a trench in the hill contains a typical example of strata-bound copper mineralization in the Culpeper Group. The sandstone is about 2 m thick with a sharp basal contact that dips more steeply (40^{o}) than the underlying strata ($25-30^{o}$), suggesting a channel scour. The sandstone is comprised of 20-30 cm thick lenses which are interpreted as trough cross-bedding. Each crossbed set consists of punky-weathering carbonate granules grading into mediumto coarse-grained arkosic sandstone with a lenticular silty shale parting at the base. Abundant plant debris mixed with the carbonate granules in the silty shale localized most of the copper, as surficial coatings of malachite and chrysocolla. Coarse-grained cross-beds immediately above the basal contact of the sandstone do not show any evidence of copper. They also lack the silty shale partings and have only poorly-preserved wood fragments. A ripple cross-laminated, fine-grained sandstone overlies the gray sandstone in a small exposure north of the trenches. Across Rte 28 to the west the overlying red siltstone exhibits little internal bedding and contains burrow and root structures and weathered carbonate nodules. Beneath the scour contact of the gray sandstone, a sequence of four 20-50 cm thick beds of gray to buff sandstone each grade upward into red shaly siltstone. The sandstone beds contain ripple cross-lamination and the siltstones exhibit flat lamination or ripple crosslamination. Both the sandstone and siltstone layers are disrupted by root and burrow structures. The lowest sandstone layer exposed at this outcrop contains mudclasts and plant debris and shows some copper mineralization in silty partings, presumably analogous to those in the upper gray sandstone.

Figure 5 shows a reconstruction of the sedimentary relationships at Stop 1 by comparison to more complete exposures in the Culpeper and other Newark Supergroup basins. This reconstruction is interpreted as the deposits of a small meandering river on a heavily vegetated flood plain. The gray sandstone at Stop 1 represents channel thalweg deposits while the interbedded sandstone and shaly siltstone represent lateral accretion sets of a point bar or a concave bench. The trough cross-beds are the deposits of sinuous-crested dunes that migrated during floods, trapping wood, silt, and other debris on the lee sides,

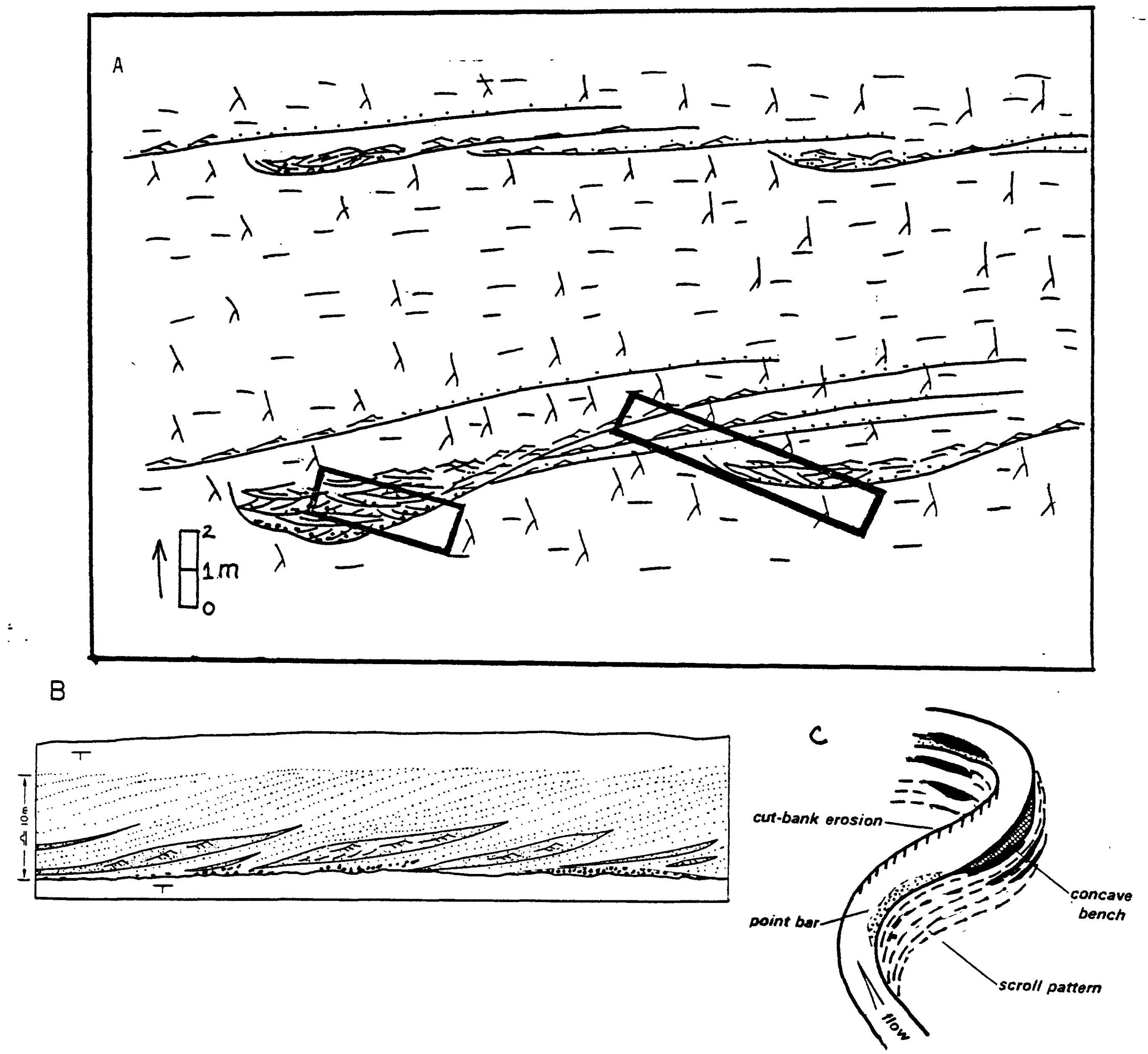


Figure 5. A: Schematic crossection illustrating the lithologic setting of stops 1 and 2. Heavy boxes show sections at stop 1. The sequence in the upper portion of the figure is more like the section at stop 2. B: Cretaceous sandstone in England, Wealdon Group, showing lateral accretion sets in a setting similar to stops 1 and 2. C: Plan view of a meandering river that would produce deposits similar to figures 5 a and 5 b. Dark areas show the distribution of best deposits for copper mineralization

and that were draped with mud and silt during intervening slack water. Most of the mud was eroded off during subsequent floods except for the mud trapped in the deepest troughs in front of the dunes. High energy dunes near the cut bank of the channel apparently eroded all of the mud drapes, reworking them as mudclasts. Low velocity ripples migrated across the upper portions of point bars during floods and were draped with mud during the waning stages of the floods. During slack water this portion of the point bar was subaerially exposed and colonized by vegetation. The flood plain surrounding the meandering rivers was probably inundated with water only during floods. The carbonate nodules are interpreted to have originated as soil features. They provided the carbonate granules in the trough cross-beds when soils were eroded during floods.

Modern examples of small, muddy, sinuous rivers with analogous suites of sedimentary structures have been described in the literature, such as the Barwon River in New South Wales, Australia (Taylor and Woodyer, 1978; Woodyer and others, 1979). The Barwon River is part of a fluvial system that drains into the sea. The Balls Bluff example may represent part of an internal drainage, such as a distal facies of a large fluvial system that drains into a large lake. The Balls Bluff deposits at this stop should be laterally equivalent to lake deposits, if the Culpeper basin was a closed basin. The cyclic lake deposits that crop out south of this locality may be related to these fluvial deposits. Lake transgressions may be due to increased flooding of the rivers, producing point-bar sandstones, and the lake regressions may be equivalent to long periods of low channel activity, producing intense soil carbonate development.

The copper mineralization at this outcrop is clearly related to the occurrences of well-preserved woody material. The localization of this mineralization in the trough cross-beds may be the result of preservation of organic material in the reducing environment created locally by mud drapes over trapped woody debris. The mud drapes on the upper portions of the point bars did not preserve organic material because they were subaerially exposed following deposition, while the lower point bars were continuously subaqueous. Diagenetic fluids that carried copper probably reached the woody debris because of the permeability of the sandstone. Woody material is preserved only in the thick channel deposits because woody material in thinner deposits would have been oxidized by subsequent burrowing and root penetration. The resulting patterns of mineralized deposits would be expected to be lenticular in shape as shown in figure 6 b,c. The mineralized sandstone units should be elongate in the direction of net flow and form broad areas of narrow lenses perpendicular to that direction.

STOP 2 - Hornfels, Rt. 661, Chantilly, Virginia.

INTRODUCTION

Stop 2 is a hornfels of lithologies nearly identical to those at stop 1, and illustrates the style of textural and mineralogical changes associated with the thermally-altered zone surrounding diabase sheets. In what were once calcareous sandstones, this hornfels shows some slight enrichment in iron and copper. However, other areas show extreme enrichment in iron with accessory copper, cobalt, gold, and nickel associated with magnetite-rich skarns developed in calcareous rocks bordering diabase sheets.

Magnetite-rich skarns, such as those at Cornwall and Morgantown, Pennsylvania, are enriched in base and precious metals (other than iron) carried in associated sulfides. The sulfide contents of these ores averaged less than 5 weight percent; however, mining operations at that time were designed to minimize the sulfide content of the magnetite ore. Sulfide-rich areas may occur in the skarn mineralization, often at the periphery of the skarn along the marble contact. Sulfide concentrates (approximately 63% pyrite and 37% chalcopyrite) from the Cornwall deposit contain approximately 9.9% Cu, 0.11% Ni, 0.87% Co and about 1 ppm Au and 9 ppm Ag (Lapham, 1968, Table II; Smith and others, in press). Byproduct recovery of cobalt from these sulfide concentrates was a major domestic source of cobalt for a number of years. Sulfide concentrates (approximately 92% pyrite, 4.5% chalcopyrite, and 3.5% pyrrhotite) from the Grace mine at Morgantown contain approximately 1.4% Cu, 0.26% Ni, and 0.68% Co (Sims, 1968). Although the magnetite skarn ores are now considered uneconomic as iron ores, the enrichments in Co, Ni, Cu, Au, and Ag associated with local segregations of sulfides probably warrant further investigation.

DESCRIPTION

This sequence of thermally metamorphosed Triassic rocks is roughly at the same stratigraphic level in the Balls Bluff Siltstone as that at stop 1. Here a 30 cm thick layer of medium-to-coarse-grained meta-arkose, in part recrystallized and replaced with medium-grained pink feldspar and minor quartz, is impregnated with abundant specular hematite, minor malachite, and epidote. This porous coarse-grained layer is sandwiched between beds of dense spotted hornfels. Tholeiitic Early Jurassic diabase with granophyre crops out in the ridge approximately 250 meters to the northwest. The mineralized sandstone layer appears to be a lens that can be traced for about 75 feet. A series of lenses at about the same stratigraphic level can be traced for about 500 feet to the west.

The coarse-textured "meta-arkose" probably once contained abundant carbonate granules and woody debris, analogous to the coarse-grained sandstone beds at Stop 1. The meta-arkose is cross-bedded with a paleocurrent orientation to the west, so the roadcut exposure is normal to flow. It overlies a hornfels of silty mudstone with a distinctive nodular texture. Similar hornfels elsewhere in the basin contain nodules of metamorphic minerals, such as epidote, chlorite, and biotite, which have replaced synsedimentary carbonate nodules that followed roots or that were scattered in the sediment. Overlying the meta-arkose is a metasiltstone with ripple cross-lamination. The ripples show a paleocurrent direction of N40W. The meta-arkose thins northward and becomes finer-grained. A rippled metasiltstone directly overlies the hornfels of silty mudstone lateral to the meta-arkose.

These deposits are interpreted as meandering river deposits similar to those of Stop 1, but smaller in scale. The meta-arkose was deposited as a channel thalweg, while the rippled meta-siltstone beds are the upper point bar deposits. The hornfels of silty mudstones are the floodplain deposits and the epidote nodules are altered carbonate nodules. The smaller channels may be laterally equivalent to the larger channels or they could have been formed by downflow bifurcation of larger channels.

The thermal alteration of this outcrop has recrystallized and possibly introduced hematite and feldspar, and flushed carbonate from the unit. The minor copper mineralization here postdates the intrusion and was introduced by supergene fluids.

STOP 3 - Culpeper Crushed Stone Quarry, Stevensburg, Virginia.

INTRODUCTION

Sediment-hosted stratabound base-metal occurrences, enriched in Cu, Zn, or Pb, sometimes occur in black mudstone sequences. Within the cyclic sequence of lacustrine-siltstone hornfels exposed in the Culpeper Crushed Stone Quarry are a few black calcareous siltstone layers enriched in base and precious metals. The anomalous zinc, copper, and lead enrichment appears restricted to a particular sedimentological unit in the cyclic sequences. In this unit, sphalerite and chalcopyrite replace diagenetic pyrite which occurs within root casts in the siltstone. In fresh samples, the mineralized siltstones typically run from 1000-7000 ppm Zn, 200-28,000 ppm Cu, and up to 200 ppm Mo, 1000 ppm Pb, and 17000 ppm Mn. The mineral-rich zones are found laterally for 3.5 km north of the quarry and 3 km south of it. One unusual feature of the lacustrine section exposed at the quarry is that it appears to lack fossils, in contrast to many other fossiliferous lacustrine sections in the early Mesozoic basins. One possible explanation is that here the lake waters were toxic due to high sulfate content or salinity.

DESCRIPTION

Stop 3 is a quarry exposure of about 80 m of slightly thermally-altered mudstone and siltstone. These deposits are divided into nine lithologic types, which are shown in the stratigraphic column (Figure 6): 1) Dark gray to black, laminated shaley mudstone without mudcracks. This lithology is interpreted as the deposits of a deep, perennial lake. 2) Dark gray or purplish red, platy mudstone with internal pinch-and-swell layering, reflecting oscillatory ripples, and large sinuous mudcracks. This lithology is interpreted as shallow lake deposits that were intermittently subaerially exposed. 3) Gray or purplish red mudstone with layering similar to lithology 2, but broken into breccia-like blocks by numerous polygonal mudcracks. This lithology is interpreted as a subaerially-exposed lake deposit which was wetted then dryed repeatedly without net sediment accumulation. 4) Thin beds of tan-weathering siltstone with mudstone partings that are disrupted into polygonal, concave-upward curls. This lithology is interpreted as shallow lake or sheetflood deposits which are desiccated causing the coarser material to curl away from the finer-grained sediments. The silt layers may have been bound by algal mats. 5) Massive, red or gray mudstone with abundant narrow, jagged mudcracks and spheroidal to flattened, dolomite- or calcite-filled vugs. This lithology is interpreted as the deposits of an aggrading playa-like mudflat. The vugs are interpreted as vesicles formed from air trapped during flooding events which brought in the sediments. 6) Massive, red or gray mudstone similar to lithology 5 but also containing abundant cement-filled tubes (root structures). This lithology is interpreted as playa-like mudflat deposits disrupted by roots. The plants may be growing on the playa, preferentially following crack patterns for more moisture, or the rooting may be much younger and following cracks rather than penetrating the hard, dry playa mud. 7) Massive, red or gray mudstone with abundant mm-scale to cm-scale, dolomite- or mud-filled tubes (root structures) and deep, narrow, sinuous mudcracks. This lithology is interpreted as the deposits of a vegetated mudflat. The deeper cracks suggest that the surface was wetter than that of lithogies 5 and 6, although the cracks may be narrow due to the roots binding the surface. 8) Massive, gray to black sandy mudstone or siltstone with abundant dolomite- and calcite-filled tubes (root structures), some deep, narrow, sinuous mudcracks, large dolomite or epidote nodules, and sulfide mineralization. This lithology is interpreted as a vegetated shallow water shoreline deposit that was intermittently subaerially exposed. 9) Undifferentiated massive red or gray mudstone, because of inaccessibility for examination except by binoculars. The mudstones are mostly combinations of lithologies 5, 6, and 7. Another important lithologic type is marked "c" on the stratigraphic column. It is a lenticular oolitic limestone with stromatolitic micrite lamination and abundant sulfide minerals. This is interpreted as a shoreline tufa deposit. probably related to spring activity.

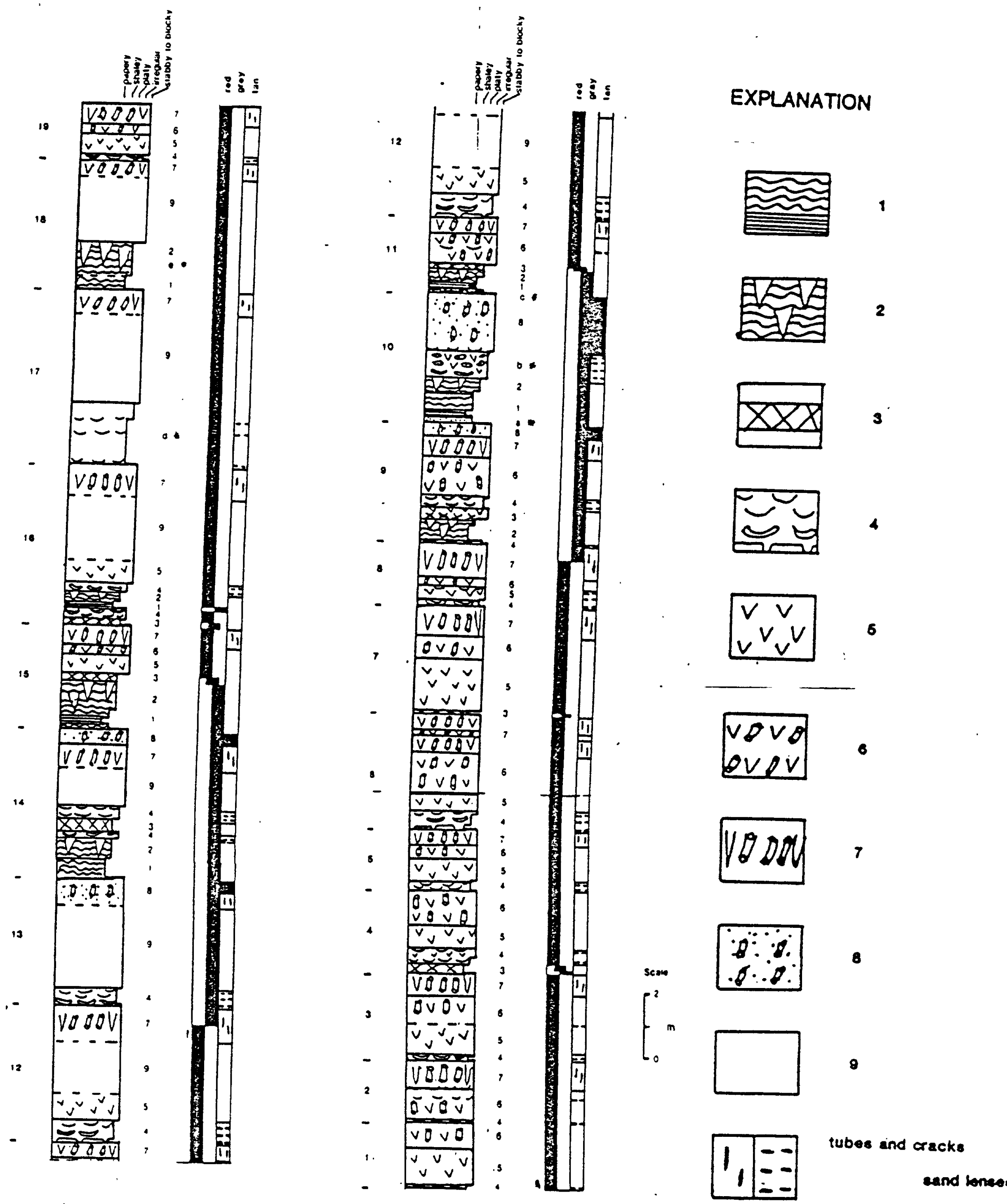


Figure 6. Stratigraphic column illustrating lithologic types at the Culpeper Crushed Stone Quarry, Stevensburg, Virginia. Zinc and copper mineralization is associated with the gray siltstones of lithology 8.

The lithologies are organized into cyclic patterns of rocks with layering that grades into massive rocks. Nineteen cycles are shown on the stratigraphic column with two end member types: 2-1-2-3-4-6-7-8 and 4-5-6-7. The contacts between cycles are abrupt while the boundaries between lithologic types within cycles are gradational. The cycles are interpreted as representing the transgression and regression of a lake, probably because of climatic changes (see Olsen, 1986). The shorter red cycles represent dryer conditions and a shallower lake than the longer gray cycles. This type of cyclic sedimentary rocks in the Balls Bluff Siltstone appears restricted to the southern part of the Culpeper basin. The cycles seen here are generally thinner and have much more evidence of prolonged desiccation than the deposits to the north. The lacustrine deposits at Stop 3 may represent the sediment-starved margin of the lakes forming cycles to the north or they may represent a different climatic setting in a sub-basin of the Culpeper. These lake deposits are older than any exposed to the north in the Culpeper basin and the style of sedimentation is similar to Upper Carnian and lower Norian mudstones in the Newark basin of Pennsylvania, New Jersey, and New York.

Zinc and copper mineralization as sphalerite and chalcopyrite, respectively, is restricted to lithology 8 at this exposure. This lithology was mineralized probably because it contained woody material in the roots, the water-saturated conditions of accumulation and the burial beneath organic-matter-rich lake deposits were conducive to preservation of the wood (in a similar deposit, carbonized remnants of tree stumps project up into the overlying laminite), and the sandy mudstone is slightly more porous than the overlying and underlying rocks, allowing diagenetic fluids to pass through. The copper and zinc sulfides appear to be replacing pyrite that grew around the roots during their decay. It is not clear what role, if any, the thermal alteration of the mudstone had on the mineralization.

STOP 4 - Granophyre and ferrogabbro, Berry Hill, Germanna Bridge, Virginia.

INTRODUCTION

Hornfels enriched in copper and other metals (Au, Ag, Mo, Bi, Sn), examples of which occur at the Stone Jug mine and Huntertown prospect in Pennsylvania (Smith and others, in press) appear to be associated with and overlie late-stage diabase differentiates (ferrogabbro and granophyre) enriched in volatiles, copper, and other trace metals. Stop 4 illustrates representative granophyre and ferrogabbro differentiates which are similar to those hosting copper-rich hornfels elsewhere.

Robert Smith in his Ph.D. thesis at the Pennsylvania State University (Smith, 1973) analyzed a late-stage ferrogabbro differentiate from Reesers Summit, Pennsylvania, which is similar to the differentiates that result in copper and gold mineralization in hornfels. This ferrogabbro contains 2800 ppm Cl, 242 ppm Cu, 170 ppm S, and 7.2 ppb Au. It also contains magnetite and trace amounts of chalcopyrite, bornite, and covellite. Associated quartz contains vapor-liquid fluid inclusions that indicate the presence of a separate fluid phase and which contains some of the Cl reported in the analysis. Using compositions of coexisting phases in the sample, he calculated a solidus temperature of 780°C and a fugacity of H_2O of 1900 bars. Therefore, at total pressures slightly less than 2 kilobars, a chlorine-rich hydrothermal fluid capable of transporting copper, gold, and other trace metals could have been liberated.

The copper mineralization in hornfels occurs as small veins and replacements in dark-gray fine-grained hornfels, similar in appearance to that in Stop 2. Primary sulfide and oxide minerals are chalcopyrite, bornite, and, at places, magnetite, hematite, and chalcocite. Malachite and chrysocolla, formed by supergene alteration of the copper sulfides, commonly occur on fracture and weathered surfaces. At the Stone Jug mine, Pennsylvania, trace amounts of molybdenum are present in the minerals molybdenite and powellite. Analysis of copper-bearing ore from the Stone Jug mine shows 6% Cu, 100 ppm Ag, 1.6 ppm Au, and 180 ppm Mo. Analysis of material from a dump at the Hunterstown prospect, Pennsylvania shows 0.1% Cu, 4.5 ppm Au, 50 ppm Mo, 150 ppm Sn, and 30 ppm Bi (J. P. Minard, 1984, personal communication, based on unpublished U. S. Geological Survey field notes for Pennsylvania, 1968-1969).

DESCRIPTION

The ridge trending N20°E is underlain by syenitic granophyre with abundant pink feldspar intergrown with large bladed hornblende crystals. The granophyre is in contact with gray, medium-grained ferrogabbro, locally pegmatitic, with coarse plagioclase, pyroxene, and magnetite. The granophyre-ferrogabbro suite is enclosed within an orthopyroxene-bearing (sparse) diabase sheet indistinguishable from the upper leucocratic part of the large Rapidan sheet of high-TiO_2 quartz-normative diabase to the south with voluminous orthopyroxene cumulates. From this area, the granophyre-ferrogabbro ridges can be traced for more than 15 miles. The association of bronzite-norite cumulate zones and ferrogabbro differentiates is similar to that in other sheets, notably the York Haven Sheet and the Reesers Summit ferrogabbro section in the Gettysburg basin studied by Robert Smith in 1973. Major and trace element chemistry and field relationships suggest that for both sheets, the ferrogabbro bodies are complementary fractions to the orthopyroxene cumulates. These large bodies of differentiated rocks apparently are segregated by lateral flow processes, which contrasts with the style of vertical gravitational differentiation seen in the Palisades sill.

STOP 5 - Kemper barite mine (abandoned), Midland, Va. (Figure 11)

INTRODUCTION

Epithermal veins containing quartz and commonly barite, galena, sphalerite, and/or chalcopyrite occur in or near the margins of the early Mesozoic Culpeper, Gettysburg, Newark, Hartford, and Fundy basins. Individual veins range from a few cm to 10 m in width, and base-metal mineralization is known to occur over an interval of up to 500 meters in depth. The barite and sulfide mineralization occurs as open-vein filling within high-angle fault or fracture zones exhibiting multiple periods of brecciation. Mineral textures and sulfur isotope analyses indicate that multiple pulses of fluids with differing chemistry passed through the vein systems. The veins are sometimes zoned, with barite-rich caps and margins overlying and surrounding sulfide-rich cores. Where crosscutting relationships are present, the veins are younger than Early Jurassic diabase dikes and basalt flows. There is no obvious association with igneous activity, although the veins are occasionally sited at the flanks of diabase sheets and dikes. Fluid migration responsible for the vein formation may have been caused by the changing stress regime developed during the Middle Jurassic during the separation of North America from Africa.

Barite veins were mined extensively in the mid-nineteenth century when Virginia was the largest barite producer in the U.S. (Edmundson, 1938). At that time the Culpeper basin had three or more large active mines. The large barite vein deposits in the Culpeper basin appear to be generally devoid of sulfides; however, minor chalcopyrite, galena, and pyrite have been reported from the Cedar Run barite mine. Similar vein systems in Pennsylvania, Connecticut, and Massachusetts were worked as lead and zinc mines during the nineteenth century. Sulfide mineralization in the vein systems is silver-rich, with galena carrying approximately 300 ppm Ag, chalcocite 1000 ppm Ag, and bornite 500 ppm Ag. In addition, the copper-rich sulfides carry up to 20 ppm Bi. Some of the vein deposits are zoned, with barite-rich and sulfide-poor zones surrounding central sulfide-rich portions of the veins. The zoning of barite and sulfides is particularly evident at the Magnet Cove mine bordering the Fundy basin in Nova Scotia where a silver-rich base-metal sulfide deposit was discovered accidentally during routine drilling to expand a barite quarry operation.

Studies on fluid inclusions in quartz and sphalerite from some of the vein systems gives filling temperatures of 150-225°C. The fluids are sodium-rich with moderate salinity (11 to 14 equivalent weight percent NaCl). The sulfur isotopic signature of sulfides and sulfates is variable. Temperatures of equilibration calculated from sulfur isotopic fractionation between coexisting sulfides generally agree with the fluid inclusion filling temperatures, indicating equilibrium fractionation. However, sulfate-sulfide isotopic fractionation is not in equilibrium.

DESCRIPTION

Veins containing barite and quartz at the site of the abandoned Kemper barite mine occur in thermally-altered purple to gray fractured siltstones and sandstones of the Balls Bluff Siltstone. Relict bedding in the hornfels has a northeast strike and dips approximately 15° west. Diabase is exposed in the drainage a few hundred meters northeast of the barite pits. The barite prospect pits trend roughly north-northeast. The large barite veins in the Culpeper basin are sited in or near fault zones. The Kemper, Gear, and Cedar Run barite mines are roughly aligned along the projected subsurface trend of the Mountain Run fault zone, near the eastern border of the Culpeper basin. This fault zone may have provided a conduit for the fluids responsible for mineralization.

Mineral paragenesis in the veins typically indicates multiple periods of vein opening, brecciation, and mineralization. A generalized paragenesis for mineralization at the Kemper mine is as follows (from oldest to youngest):

1. fracturing of siltstone hornfels
2. local silicification and oxidation of hornfels
3. barite filling open space in fractures and veins
4. drusy quartz filling open vug spaces in the veins
5. ferroan dolomite (mostly altered to yellow ochre)
6. clear barite crystals in open vug spaces.

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ROAD LOG

7 1/2 minute quadrangles traversed:

Vienna, Sterling (STOP 1), Herndon (STOP 2), Arcola, Thoroughfare Gap, Warrenton, Remington, Culpeper East (STOP 3), Germanna Bridge (STOP 4), Midland (STOP 5), Gainesville, Manassas.

MILAEGE	TIME HR MIN	
0.0	8:00	Assemble at USGS parking lot; Departure time 8:30 AM. Exit lot to left (east) to Reston Ave.
0.1		Jct. Reston Ave. (Rt. 602). Turn left on 602
0.6		Jct. 602 overpass over Rt. 267 (Dulles Access Road); Turn left (west) on Rt. 267 heading toward Dulles Airport. Stay on Rt. 267, avoiding the Dulles Airport only exits. -- $0.25 toll on this road --. The entrance to Rt. 267 is the approximate boundary between the Piedmont crystalline terrain and the Triassic lowland at the eastern margin of the Culpeper basin.
1.1		Gray soil marks a zone of thermally metamorphosed Triassic rocks adjacent to a large Jurassic diabase body. Scattered rounded core-stone boulders mark the east end of a large semi-circular spoon-shaped diabase sheet that surrounds the town of Herndon to the south.
4.7		Jct. Rt 267/Rt. 28 (Sully Road); Exit on Rt. 28 North (right)
5.7		Jct. Rt. 28/606 (to Herndon and diabase quarry)
6.4		Jct. Rt.28/846 (Sterling Blvd.)
7.4		Jct. Rt. 28/625
7.6		Jct Rt. 28/845; Park on right (east) side.
	8:30	<u>STOP 1</u> - Sandstone-hosted copper mineralization in the Balls Bluff Siltstone, Sterling Quad, Loudoun Co. On E side of Rt. 28. -- 30 MINUTES --
	9:00	Turn around and proceed south on Rt. 28
7.8		Jct. Rt. 28/625

8.8		Jct. Rt. 28/846 (Sterling Blvd)
9.5		Jct. Rt. 28/606 (to Herndon and diabase quarry) Continue south on Rt. 28.
10.5		Overpass, Dulles Access Road and Rt. 267
14.7		Sully Plantation
15.3		Jct. Rt. 28/Rt. 50; Right on Rt. 50
15.7		Jct. Rt. 50/661; Left on 661 (Lee Road)
16.6		Cub Run -- Park in driveway on right
	9:25	STOP 2 - Thermally metamorphosed rocks in the Triassic Balls Bluff Siltstone, Herndon quadrangle, Loudoun Co. On W side of 661. -- 30 MINUTES --
	9:55	Return to jct. with Rt. 50.
17.5		Jct. 661/Rt. 50; Turn left (west) on Rt. 50. For the next ten miles the route traverses west-dipping Triassic siltstone, sandstone, and conglomerate intruded and thermally metamorphosed by two Jurassic diabase sheets. For the last mile on Rt. 50, the Triassic-Jurassic contact is crossed, marked by two Jurassic basalt flows (Mount Zion Church and Hickory Grove Basalts).
28.5		Jct. Rt. 50/Rt. 15 (Gilbert's Corner); Turn left (south) on Rt. 15. For the next 13 miles the route mostly parallels the low linear strike ridges formed by west-dipping basalt and interbedded Jurassic strata. The Bull Run Mountains are visible two to four miles to the west, and are separated from the Culpeper basin by a major east-dipping normal fault.
		LUNCH ON BUS
41.8		Jct. Rt. 15/Rt. 29-211; Turn right (west). For the next 2.8 miles the road passes through alternating strike ridges of west-dipping basalt (Sander Basalt) and intervening swales in Lower Jurassic siltstone, shale, and sandstone.

44.6		New Baltimore; location of the western border fault of the Culpeper basin. For the next 5.2 miles the road traverses rolling Piedmont topography formed mostly on deeply weathered Catoctin Greenstone.
50.1		Warrenton
56.6		Jct. Rt 15-29/Rt. 17 (Opal). We reentered the Culpeper basin about 1.5 miles back; however, the western border fault does not form a prominent scarp here.
74.6		Jct. Rt. 15-29/Rt. 3 (Culpeper); Exit to right, Turn left (east) on Rt. 3. The prominent hill is Mt. Pony, the upturned northern margin of the Rapidan diabase sheet which contains abundant orthopyroxene.
80.2	12:00	<u>STOP 3</u> - Sediment-hosted stratabound sulfide mineralization, Culpeper Crushed Stone Quarry, Stevensburg, Culpeper East quadrangle, Culpeper Co. -- 70 MINUTES --
	1:15p	Turn right (east) on Rt. 3 when leaving quarry
81.3		Topographic ridge is a basement inlier of Catoctin Greenstone and Chilhowee Quartzite.
82.3		Diabase boulders from an offshoot that connects the main mass of the Rapidan sheet to the Berry Hill granophyre-ferrogabbro differentiates which are enclosed by opx-bearing diabase to the north.
83.7		Jct. Rt. 3/Rt. 669; Turn left (north)
85.4		Jct. 669/672: Elkwood
86.1		Jct. 669/farm road; Enter farm road on right.
86.2	1:30p	<u>STOP 4</u> - Ferrogabbro and granophyre diabase differentiates at the Moorman farm, Germanna Bridge quadrangle, Culpeper Co. -- 30 MINUTES --
86.3	2:00p	Turn right (south) on 669 from farm road.
89.8		Cross RR tracks, Brandy Station; Turn right on 663 to Rt. 15-29
89.9		Jct Rt. 663/Rt. 15-29; Turn right (north) on 15-29.
96.9		Jct. Rt. 15-29/Rt. 28; Turn right (north) on 28

99.2		Jct. Rt 28/Rt.17; Turn right (east) on 17
103.1		Jct. Rt. 17/ farm road on left; turn left (east) on farm road
103.5	2:35p	<u>STOP 5</u> - Kemper barite mine (abandoned), Midland quadrangle, Fauquier Co. Pits are north of the road in pasture land. -- 30 MINUTES --
103.9	3:05p	Return to Rt. 17; Turn right (west) on 17.
111.2		Jct. Rt.17/Rt. 15-29 (Opal); Turn right (north) on 15-29.
117.7		Warrenton
129.3		Jct. Rt. 15-29/I-66; enter I-66 on right heading east.
144.3		Jct I-66/Rt. 50; Exit I-66 on right, make loop, and enter Rt. 50 heading west.
145.5		Jct. Rt. 50/Rt.602 (West Ox Rd.); Turn right (north) on 602.
153.0	4:35p	Arrive USGS parking lot.