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GEOLOGICAL SURVEY

Preliminary Geology of the Blacktail Mountain Drilling Site, Flathead County, Montana

By

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1979

This report is preliminary and has not
been edited or reviewed for conformity
with U.S. Geological Survey standards
and nomenclature.

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Abstract

Five argillitic green beds that alternate with six argillitic purple beds in the upper part of the Spokane Formation of the Belt Supergroup of Proterozoic Y age were sampled by 22 shallow core holes. The holes were drilled on a hexagonal pattern over an area about 50 m wide and 150 m long to obtain detailed information on environment of deposition and distribution of anomalous amounts of copper sulfides visible in outcrop, as well as to obtain samples for study of the geochemistry, isotope geology, mineralogy, and physical properties of the rocks and sulfide occurrences. Preliminary megascopic examination of the cores suggests that the purple and green colors represent original oxidizing and reducing environments of deposition on a relatively stable tidal flat and shallow shelf. Two of the five green beds contain zones of copper sulfides, largely bornite and chalcocite with trace amounts of chalcopyrite and covellite. The zones vary somewhat in thickness and stratigraphic position within the mineralized green beds.

This report covers only the preliminary results of the ongoing multiple intensive studies of the drilling site and cores. These studies are part of an attempt to develop a model for green-bed copper-silver occurrences in Belt rocks of Proterozoic age. The model is needed to aid appraisal of the mineral potential of these mineral occurrences that are common in much of the 120,000 km^2 of Belt terrane.

Introduction

Stratabound copper-silver ores and potential resources are widespread in rocks of the Belt Supergroup of the northwestern United States (Harrison, 1972, 1974). Exposure of these Proterozoic Y rocks are found in an area of at least 120,000 km^2, and much of the area contains at least one rock layer that exhibits anomalous amounts of copper sulfides.

A simplified classification of the stratabound deposits includes two types: 1) deposits in strata that are dominantly quartzite, and 2) occurrences in argillitic green beds that are interlayered in red-bed sequences. Exploration by industry has focused largely on the quartzite-type of deposits, primarily those in the Revett Formation. Several mineralized zones within the Revett have been drilled in northwestern Montana, and at least one ore deposit is currently being planned for development by the American Smelting and Refining Company. Continued exploration by industry should eventually produce sufficient data to evaluate the mineral resource potential of the quartzite-type of occurrence as well as to provide further insights into the genesis of the ore deposits, which is still controversial.

Green-bed occurrences have received much less attention, even though they are by far the most common type of occurrence of anomalous copper and silver in Belt rocks. The apparent size and grade of green-bed occurrences appear to be significantly less that those in quartzite, and green-bed occurrences may not be ore deposits in a 1979 economy. On the other hand, geochemical data collected by the U.S. Geological Survey and the widespread distribution of the occurrences now known from Survey mapping in the past decade suggests that the tonnage of copper-silver in the green-bed occurrences is many times that in the quartzite-type. The resource potential of the abundant occurrences, which are predominantly on Federally managed land, needs to be critically evaluated for incorporation in land-use planning as well as inventoried as part of future United States mineral resources. In addition, the general lack of data and understanding related to the genesis of the green-bed occurrences permits the possibility that somewhere a set of geologic processes, as yet not defined, may have formed green-bed deposits that are economic even by 1979 standards.

The Blacktail Mountain drilling project is a first step in development of a model to help evaluate green-bed copper occurrences in terms of their copper-silver resource potential. The site (fig. 1) was selected for the following reasons:

1. Anomalous amounts of copper sulfide were visible in bulldozed outcrops of the site.
2. The rock formation (upper part of the Spokane) is one of the most persistent within the Belt basin to contain anomalous amounts of copper-silver in green beds.
3. Structure of the rocks was reasonably simple, and no intrusive rocks that could have complicated the sulfide occurrences crop out in the area or are indicated by geophysical data.
4. Five green-beds, two of which showed anomalous copper in outcrop, could be tested for copper distribution at minimal cost.
5. The probability of significant variation in copper-silver content of units was high, whereas the probability of discovering a sulfide ore body (by tradition, the prerogative of industry rather than the U.S. Geological Survey) was negligible. In fact, numerous unsuccessful attempts were made to convince several mineral exploration companies to drill the area for scientific information.
6. Environmental impact would be minimal, as the area has been bulldozed previously for construction materials.
7. The area was part of the Flathead National Forest and was without mining claims.

The purpose of this report is to present preliminary geologic data that can serve as a basis for general interpretation of geochemical and geophysical data collected during studies at the site, from the bore holes, and from examination of the cores. The report should also serve as a geologic guide to those who wish to examine the quarter of the slabbed core stored in the Denver Core Library of the U.S. Geological Survey.

We are grateful to several of our colleagues for help in collecting the data presented in this report. Jon J. Connor helped in preparation of the planetable geologic map of the drilling site as well as the original drilling plan. J. William Hasler supervised the drilling contract and consulted with the driller on problems of core recovery. Richard E. Van Loenen cheerfully aided for two weeks with menial tasks of core collection and slabbing. Robert G. Schmidt supervised core collection and made preliminary field logs for the final four holes drilled. We are particularly indebted to our driller, David Billmayer, whose interest in our job, understanding of our need, and cooperative procedures allowed us to obtain an average 98 percent core recovery with minimal loss for spudding in and surface casing. Raymond E. Wallace, U.S. Forest Service, served as interested scientist, friend, and councilor as he helped guide us through the necessary channels to receive permission to drill. We thank Captain Eugene Nadeau, Commander, Kalispell Air Force Base, for his generous permission to use a building at the Base for core storage and slabbing, and Charles Curry and Donald Blair of the Engineering Office for their cheerful and prompt solution to some of our technical problems. And, finally, we acknowledge a debt to John Trammell, who several years ago while working as a principal field exploration geologist for Copper Range Mining Company, introduced Harrison to the interesting copper occurrences on Blacktail Mountain.

General Geology

Outcrops in the area of Blacktail Mountain are dominantly of the Spokane Formation, although the basal beds of the overlying Empire Formation are preserved where the strata are dropped down adjacent to one of the faults in the area (fig. 1). The rocks have been

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Figure 1.--NEAR HERE

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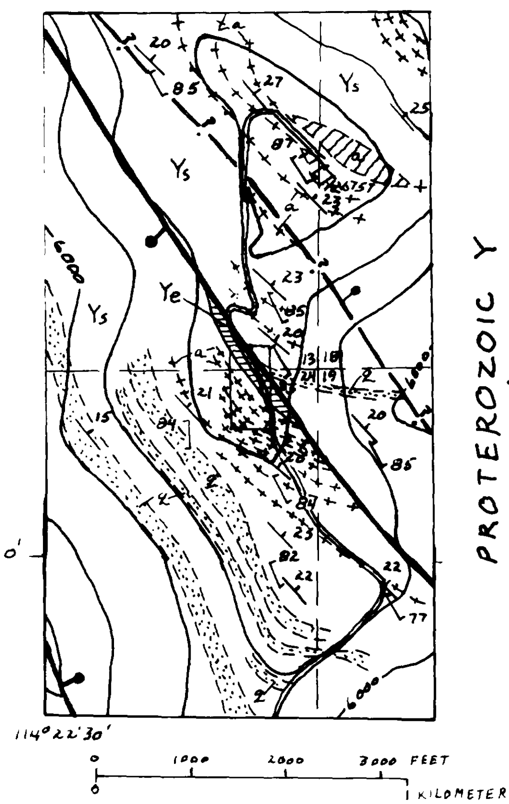
metamorphosed slightly to the chlorite-sericite zone of the greenschist facies as shown by the phylosilicate mineralogy. This metamorphism has also changed the rock color from the relatively bright reds of the type locality in the Spokane Hills (Walcott, 1899) about 250 km to the southeast to purples, purple grays, and grays at Blacktail Mountain. This change results from the metamorphic conversion of some of the original hematite into other iron-bearing minerals of lower chroma.

AREA LOCATION



Note: Base from U.S. Geological Survey 7½' Topographic sheets of Proctor and Lion Mountain Quadrangles, Montana
Geology by Jack E. Harrison, 1978

EXPLANATION

PROTEROZOIC Y

Ye

Empire Formation

Green dolomitic argillite, dolomite, and minor amounts of siltite and quartzite

Ys, q, a

Spokane Formation

Purple slightly dolomitic or sideritic argillite or laminated argillite and siltite interbedded with siltite; middle part contains zones of quartzite (q), shown where traceable; green argillitic units (a) ranging in thickness from 1' to 30' that are common in upper part and sparse in lower are also shown where traceable

—?—?

Fault

Bar and ball on downthrown side; dashed and questioned where only probable

22

Strike and dip of beds

85

Strike and dip of cleavage

Figure 1. Geologic map of the Blacktail Mountain area, Montana. Rectangle in center of map shows area of drilling site (Figure 3).

The Spokane Formation, about 915 m thick (fig. 2), is a small part

Figure 2.--NEAR HERE

of the more than 5,000 m of the Proterozoic Y rocks exposed near Blacktail Mountain. The Spokane lower member, about 530 m thick, is dominantly purple to purple-gray thinly laminated argillite or argillite and siltite that commonly exhibits mud cracks, ripple marks, water-escape structures, small ball and pillow structures, flute casts, and mud chip breccias. Argillite-siltite couplets are commonly graded, but siltite lamine a few millimeters thick also form small cut-and-fill structures. Many of the units that appear purple in aspect actually contain thin green laminations where secondary chlorite is the dominant coloring agent, commonly in less argillitic parts of the rock. The lower member is slightly carbonate bearing, mostly through sparse dolomitic cement but also through scattered siderite crystals. Beds of pale purple to pink siltite and quartzite, generally less than 2 m thick, form a few percent of the member. Near the top and base of the lower member are scattered green dolomitic argillite layers a few meters thick. They tend to be more evenly laminated, contain less siltite, and show fewer sedimentary structures than the purple argillites. At places, the green beds contain anomalous amounts of copper sulfides.

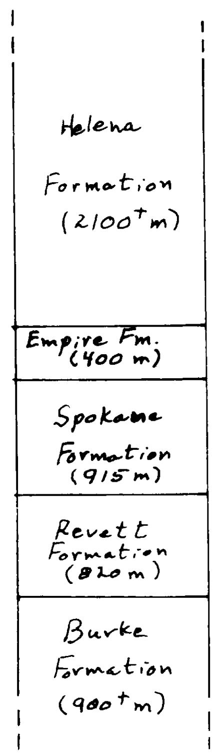


Figure 2. Formations of the Belt Supergroup of Proterozoic Y age exposed near Blacktail Mountain Approximate thickness in meters shown in parentheses.

The middle member consists of about 275 m of alternating layers of argillite and quartzite. All argillite layers are purple and are similar in rock type and sedimentary features to those of the lower member. Feldspathic quartzite beds as much as 15 m thick characterize the middle member. The quartzite is pink to purple-gray, thinly laminated, fine sand to coarse silt, and commonly shows low-angle planar crossbedding. Although a zone of quartzite layers in approximately the same stratigraphic position can be identified at many places within a 100 km radius of Blacktail Mountain, exposures are so poor that individual quartzite beds can be traced for only relatively short distances. This characteristic is indicated in Figure 1 where quartzite beds appear to stop abruptly but most likely continue in mixed float or isolated exposures that do not allow confident mapping of any one given quartzite bed.

The upper member, about 110 m thick, consists of purple argillite and siltite (70 percent) in beds alternating with green dolomitic argillite and argillitic sittite (30 percent). Minor amounts of fine- to medium-grained white quartzite in beds as much as 10 cm thick are scattered through the units. In general, the purple units tend to contain thicker siltite layers, fewer quartzite layers, and less carbonate than the green units. More detailed descriptions of the various layers are given in the part of this report concerning the geology of the drilling site.

The zone of alternating green and purple or red beds in the upper part of the Spokane Formation is widespread in Belt terrane. Of particular interest in this study is the observation that copper sulfides in anomalous amounts commonly occur in one or more of the green beds in this zone. Where best exposed within a 100 km radius of Blacktail Mountain, the number of green beds ranges from 5 to 8 and total from about 5 to 30 percent of the zone; individual green-bed thicknesses range from 0.5 m to 11 m. At some localities, no anomalous amounts of copper are evident in outcrop, but at most places, one or two green beds contain obvious copper sulfide minerals. The white quartzites increase in abundance and thickness towards the east and northeast; they are as much as 1.5 m thick in channel deposits in the southern Whitefish Range about 50 km north of Blacktail Mountain and are even more abundant farther north in the Grinnell (= Spokane) Formation in southern British Columbia. Collins and Smith (1977) note that these quartzites in southeastern British Columbia tend to be on cut surfaces, are crossbedded, have mud chips in their lower part and ripple marks at the top, and contain copper sulfides. They interpret them as flash-flood deposits (sheetwash and poorly-formed channel fillings) on a floodplain where the sheetwash deposits contained organic carbon that eventually caused a reducing environment that trapped copper. We are not prepared to comment on that interpretation at this time, but it seems probable that the thinner white quartzites of the Blacktail Mountain section are related stratigraphically and genetically to those described by Collins and Smith.

Overlying the Spokane Formation in apparent conformity is the Empire Formation (fig. 2). The Empire Formation is about 400 m thick and consists dominantly of green thinly laminated calcareous and dolomitic argillite. A few beds of purple argillite, each a few meters thick, occur near the middle of the formation. Flat elipsoids of pink or white calcite, called horizontal pod structures, are common in some layers and are particularly evident on weathered outcrops where the surface shows voids formerly occupied by the pods. The appearance of thick (greater than 11 m) green calcareous and dolomitic argillite marks the base of the Empire Formation and corresponds with the top of the uppermost purple argillite bed of the upper member of the Spokane Formation. Although only a thin interval of the basal part of the Empire Formation is present next to a fault at the drilling site (fig. 1), the lithologic characteristics of the rock and exposed thickness (more than 20 m) are adequate to identify the formation.

Structurally, the Blacktail Mountain area, on the east-facing limb of a broad northwest-trending anticline, shows an almost homoclinal dip (fig. 1). This anticline is one of several broad open north-northwest-trending folds marking the broad crest of the Purcell anticlinorium, which is about 15 km west of Blacktail Mountain. The rocks are broken by high-angle faults (fig. 1) that are part of the extensive basin-and-range type of faulting superposed in Cretaceous-Tertiary time on the broad folds of presumed late Proterozioc age (Harrison, et al, 1974). Pronounced cleavage subparallel to and nearby the faults (fig. 1) is characteristic of these horst and graben structures. The cleavage tends to be particularly well-developed in the more argillitic purple beds of the Spokane Formation. Cleaved surfaces in outcrop commonly are coated by chlorite, and quartz or carbonate minerals.

Geology of the drilling site

Natural exposures and associated rock float are limited to the southwestern part of the drilling site near the crest of a hill (fig. 3). The remainder of the site has been bulldozed for construction

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Figure 3.--NEAR HERE

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materials needed at a radar installation nearby on the top of Blacktail Mountain. Although the bulldozing created a number of artificial rock exposures that aid surface geologic studies, it also left much of the surface slightly to greatly disturbed. Thus precise tracing of contacts, individual thin quartzite beds, and copper-bearing zones in surface geology is not possible. Geologic structure, however, is reflected in a reasonably uniform strike and dip so that geologic contacts, at least, can be traced and projected with reasonable accuracy at the scale of the map.

The upper part of the Spokane Formation on Blacktail Mountain contains eight green beds alternating with purple beds (fig. 1). The drilling site and cored section contain the upper most five green beds, six purple beds, and a few meters of the overlying Empire Formation (figs., 3, and 4). For convenience in core logging and discussion of

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Figures 3, and 4--NEAR HERE

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the section, we refer to the various stratigraphic units in the Spokane by color and number starting with the lowest bed intercepted in the core. Thus the persistent purple beds are labeled p_1 through p_6 and the green ones from g_1 through g_5. Boundaries of the units are gradational through interlaminations of thin green and purple layers, although the gradational zone at the top of a purple bed tends to be a few centimeters thick, whereas the one at the base may be as much as a meter thick. Our field logs have arbitrarily included all transition zones in the purple beds.

Most of the mapped and logged units have individual lithologic and sedimentologic characteristics that distinguish them from other units. Brief descriptions that stress the megascopic differences among the units are given in the following paragraphs. The units are described from youngest to oldest, the sequence in which they are encountered in the core holes.

The lowest part of the Empire Formation, encountered only in drill holes 26 and 27, is dominantly light greenish gray argillitic siltite and argillite. Laminae are planar or slightly wavy, bounded by sharp surfaces. Scour surfaces are sparse and other sedimentary structures are notably absent in cores studied. The Empire rests with sharp conformity on underlying purple beds of the Spokane Formation.

Unit Ysp_6, highest unit in the Spokane Formation, contains interlaminated grayish purple siltite and argillitic siltite. In the top meter, these rock types occur in graded sequences, 2-8 cm thick, fining upward from fine siltite to argillitic siltite or argillite. Individual graded sequences can be correlated between core holes. The remainder of the unit generally is laminated in parallel, locally ripple, or inclined low-angle cross laminae. Local scoured surfaces separate laminae, and the lowest 0.5 m of the unit contains eroded channels 1.5-2 cm deep filled by overlying siltite. Dessication cracks are present in argillitic laminae at several horizons, and fluid escape structures disrupt laminae near the base of the unit. The unit varies in thickness from about 5 to 7 m.

A vertical succession of three sedimentologic types distinguishes green-bed unit Ysg_5 from lower green-bed units. The top 2 m consists of laminated and thinly laminated argillitic siltite and siltite with common argillite laminae. Laminae are even parallel and wavy parallel, bounded by sharp surfaces. They are commonly deformed in gentle undulations by loading or are disrupted by fluid escape structures and scattered syneresis cracks. The middle 3.5 m is a characteristic sequence of graded laminae and beds ranging from 0.2 to 4 cm thick; dark-greenish-gray siltite at the base of graded units fines upward to light-greenish-gray argillitic siltite or argillite at the top. Several sets of graded beds form crossbed sets in relation to adjacent intervals of graded beds. Siltite beds in the lower part of the graded succession are commonly ripple cross-laminated. The basal 2 m of the unit contains beds of siltite 2-30 cm thick separated by laminae and very thin beds of argillitic siltite. A marker bed of coarse siltite, which ranges from 9 to 30 cm across the drilling site, contains ball and pillow structures in some cores or is nearly structureless in others. Adjacent siltite beds are commonly cross-laminated. Laminae of ripped-up argillite clasts are common near the base. Copper sulfides are disseminated through about 4.5 m of the middle part of the unit, primarily in siltite bases of graded beds or as crystals at sites of secondary porosity that resulted from dissolution of local dolomite cement in the upper laminae. Unit Ysg_5, varies in thickness from about 7 to 7.5 m, primarily as a result of thickening and thinning of siltite beds near its base.

The underlying unit, Ysp_5, about 4 m thick, is dominantly siltite and has minor argillitic siltite. Siltite varies from light purplish gray in the lower part where it is parallel laminated, to purplish gray through most of the unit. Laminae are even parallel or discontinuous even nonparallel, locally wavy. Commonly upper surfaces of laminae are scoured and uneven, but irregularities are filled by coarser sediment so that the next distinctive lamina has a nearly planar base. Syneresis cracks are present in argillitic laminae near the center and lower part of the unit. The unit grades upward into Ysg_5 and downward into Ysg_4.

Green-bed unit Ysg_4 is dominantly greenish gray argillitic siltite but has lesser amounts of dark-greenish-gray siltite and minor light greenish gray argillite. A quartzite bed about 1 cm thick occurs near the middle of the unit, and a second quartzite bed, 0-7 cm thick occurs at or just above the base in most cores. Siltite is more abundant in the basal 1-2 m than higher in the unit. The unit is laminated with even parallel or slightly wavy laminae 0.1-1 cm thick. Bases of laminae are generally sharp and nearly planar on underlying laminae, but local scoured bases are present. Several thin intervals contain normally graded laminae. Soft sediment disruption by fluid escape and rip up by moving currents are preserved near the center, top, and locally at the base of the unit. Intervals of argillitic siltite with characteristic alternations of grain size can be correlated from hole to hole across the drill site. Dolomite cement occurs in greater abundance near the center of the unit than in any part of unit Ysg_5. Unit Ysg_4 ranges in thickness from about 5.5 to 6 m, probably as a result of local scour before deposition of the lowest quartzite bed. In some cores the quartzite rests with sharp contact on underlying unit Ysp_4, whereas in other cores the quartzite bed rests on green argillitic siltite and siltite laminae which grade downward into unit Ysp_4.

Grayish-purple siltite containing minor amounts of argillitic siltite constitutes unit Ysp_4. It is laminated and very thin bedded with even or discontinuous even parallel or wavy beds. Laminae disrupted by loading and fluid escape occur near the base, middle, and top of the unit. A light brownish purple coarse siltite, 20-25 cm thick, forms a key marker bed near the base of Ysp_4. This coarse siltite is parallel laminated and contains angular rip-up clasts of very dusky reddish-purple silty argillite; a similar silty argillite bed, 1-3 cm thick, occurs at the base of the coarse siltite in most cores. Unit Ysp_4 is about 4.4-4.7 m thick and grades downward into unit Ysg_3.

Unit Ysg_3 is greenish-gray and light-greenish-gray argillitic siltite and siltite with laminae and beds of white quartzite 0.8–7 cm thick near the center. Generally the unit is evenly to wavy parallel laminated, lacking evidence of either significant scour and fill or grading. Scattered very thin beds of siltite are ripple cross-laminated. Fluid escape and load structures commonly disrupt laminae at the top and base of Ysg_3, and bases of quartzite beds in the unit are locally deformed as a result of loading while poorly consolidated. Dolomite cement is common throughout the unit, and "bleaching" of the green pigment to very light greenish gray is characteristic of the interval containing the quartzite beds. Copper sulfide minerals are particularly abundant in the middle half of the unit and are concentrated in siltite laminae, in silty argillite of fluid escape structures, and in fractures parallel or at high angles to bedding. Copper sulfides and hydroxides occur together in a 3–7 cm thick quartzite bed near the center of the unit. The thickness of unit Ysg_3 ranges from about 3.1–3.9 m, and the unit is gradational with Ysp_3 beneath.

Unit Ysp_3 is dominantly grayish-purple siltite with common laminae of argillitic siltite. The unit contains more argillitic siltite than unit p_4. Laminae are even parallel or discontinuous wavy parallel in form, with some laminae graded from siltite at the base to argillitic siltite upward. Common fluid escape structures disrupt laminae, and the tops of some laminae are deformed in flame structures. Of the purple units cored, Ysp_3 is the thinnest, generally 2.3–2.5 m thick, except in hole 27 where it is only 1.2 m thick. It grades downward into unit Ysg_2.

Unit Ysg_2 is greenish-gray siltite and light-greenish-gray argillitic siltite and argillite in nearly equal amounts. Beds 1-3 cm thick are even and parallel, commonly graded normally, and, in several coarser siltites, ripple cross laminated. Beds in the lower part of the unit are generally disrupted by fluid escape structures or contain syneresis cracks. The unit grades downward into Ysp_2 and ranges from about 0.40-0.45 m in thickness.

Nearly equal proportions of grayish-purple argillitic siltite and siltite in the lower part and dominantly siltite in the upper part compose unit Ysp_2. Siltite beds are ripple cross laminated or planar even-parallel laminated, whereas argillitic siltite laminae and beds are commonly wavy bedded. Argillitic laminae locally have upper surfaces contorted in flame structures or are disrupted by fluid escape structures. Some siltite beds were deposited on scoured surfaces of low relief. Unit Ysp_2 is 3.1-3.7 m thick and is gradational downward into unit Ysg_1.

The lowest green bed of the succession, Ysg_1, ranges markedly in thickness from 0.11 to 0.76 m, but its composition is similar across the drill site. At its base, resting sharply on unit Ysp_1, is laminated fine-to medium-grained quartzite, 1.5-8 cm thick. Pale yellowish green argillite partings occur in the quartzite locally. In holes 13 and 21, 1.5 cm of greenish gray argillitic siltite underlie the basal quartzite. The remainder of Ysg_1 consists of evenly laminated to wavy laminated greenish gray and light greenish gray argillitic siltite and siltite. Generally surfaces bounding the laminae are sharp, although locally they are deformed by loading or rarely disrupted by fluid escape structures. Small-scale ripple cross laminae are present locally. "Bleaching" of the green colors of the unit impart to it a "pistachio" green color, which together with the underlying "bleached" hues of pink and pale reddish-purple at the top of Ysp_1, constitute a readily identifiable thin unit.

Unit Ysp_1 is the main body of the upper part of the Spokane Formation. Drilling was always halted within the top 2.5 m of the unit. Ysp_1 consists of grayish purple and grayish-red purple siltite and argillitic siltite. Laminae and very thin beds of coarse siltite and very fine quartzite are scattered through the unit. Argillitic laminae are locally injected into overlying siltite strata, or are broken by syneresis cracks. Siltite laminae and very thin beds are planar, wavy, or cross laminated, locally resting on scoured surfaces cut across underlying laminae. Distinctive beds or sequences of beds within unit Ysp_1 could not be recognized in the thin interval cored.

Preliminary results and continuing studies

Twenty two core holes, whose locations are shown on figure 3, were drilled on a hexagonal pattern that has a maximum separation of 30 m between holes. Graphic logs for the cores are shown in Figure 5, where

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Figure 5.--NEAR HERE

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the base of Ysg_3 was used as a stratigraphic reference plane. Selected cores were slabbed, photographed, and logged in detail (an example of the detailed logs is shown in figure 6) as drilling progressed to aid us

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Figure 6.--NEAR HERE

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in adjusting our drilling plan to obtain the most information possible from the 550 m of drilling allowed by our budget. Numbers missing in the consecutive numbering of core holes are for holes abandoned from the original drilling plan in favor of new sites or extension in depth of other holes. Most holes have at least two nearest neighbors at equal distances--a design that simplifies study of statistical variations in rock properties and geochemistry from hole to hole and across the entire area.

BLACKTAIL MOUNTAIN, MONTANA   CORE HOLE BT-2

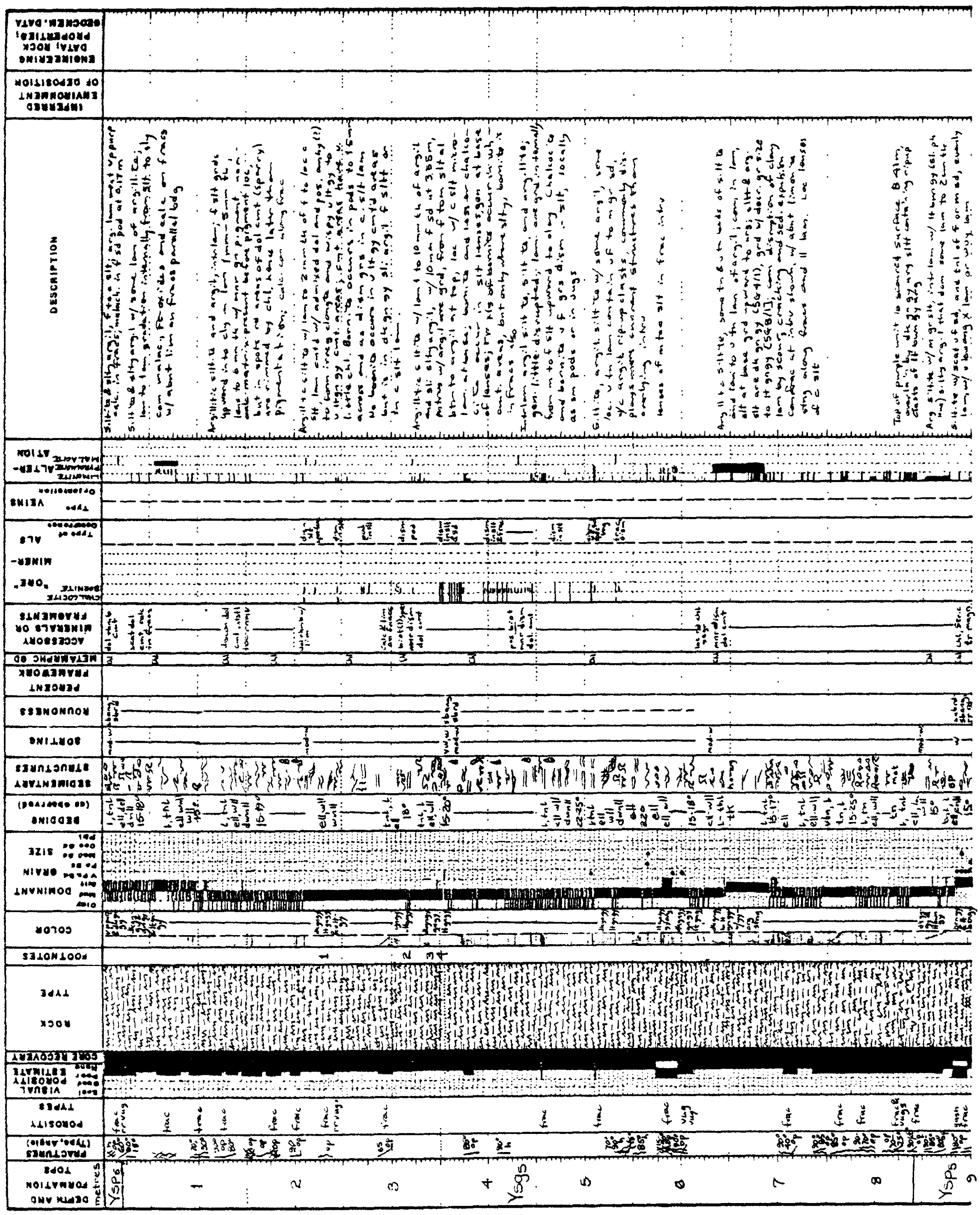

FIGURE 6. — Example of detailed log for part of core hole BT-2. Abbreviations and symbols are described in U.S. Geological Survey Open-file Report 79-941.

Environment of deposition of the upper part of the Spokane Formation as seen at the drilling site is tentatively interpreted as tidal flat and shallow shelf along or near a coastline of exceedingly low relief. Sediment supplied to the area was mainly silt and mud; sand was likely transported across the shelf only during storms, or was transported and concentrated by winnowing during times of transgression. Purple units represent intertidal muds and silts alternating with coarse silt and fine sand deposited near low water lines or in migrating channels having low topographic relief. Early post-depositional oxidation of the sediment may thus have occurred during original subaerial exposure. Green beds are interpreted as shallow shelf sediments deposited in part by suspension and in part by traction during drift produced by weak tidal or longshore currents. The shelf environment was one of slow chemical reduction.

If the interpretation is valid, the alternating succession of green and purple units represents successive slow transgression and regression of the coastal environments. Quartzite laminae at the sharp base of Ysg_1 may represent a basal lag deposit developed as the shelf environment initially transgressed over the older intertidal deposits. The thin quartzite at or near the base of Ysg_4 may have originated in the same manner. If so, the fundamental depositional couplet is green unit succeeded by purple unit, and transgression across an erosional surface having low relief initiated two (Ysg_1-p_2 and Ysg_4-p_5) of the transgressive-regressive cycles. Green and purple units otherwise grade into one another, suggesting both gradual transgression and regression, and the absence of extensive sand bars or flats separating the coastal environments. Little sand was arriving at the site. Persistent siltite beds containing ball and pillow structures may represent shortlived intervals of rapid silt sedimentation on mud substrates. Rates of sedimentation were otherwise probably slow.

Apparent variation in thickness of individual purple and green layers is shown on figure 5 where we have adjusted our logs for core recovery. Some differences in thickness from hole to hole are undoubtedly caused by variation in thickness of the transition zones between purple and green units, and we expect to refine the correlations through detailed logging and identification of marker beds within the units. Variations which we have already identified from our detailed logs for a few of the holes, suggests a microtopography on a tidal flat. It seems highly unlikely to us that the mm-thick alternating laminations of oxidized (purple) and reduced (green) rock represent a secondary alteration process; therefore, we suggest that the variations in thickness of these transitions reflect oxidation and reduction related to deposition of the laminae and that variation in thickness of the zones may reflect microtopography on a shallowly flooded surface.

Two principal copper-bearing zones, in beds Ysg_3 and Ysg_5, were indicated by surface exposures and were found in the cores (figs 4 and 5). Our preliminary data suggest that, although the zones are confined to specific beds, both the thickness of the zone and the stratigraphic position in the bed vary from core to core. Chip samples 30 cm long were cut across two exposures each of Ysg_3 and Ysg_2 in prior studies of the drilling site; analyses of selected elements in those samples are shown on Table 1. These analyses indicate the range of copper-silver

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Table 1.--NEAR HERE

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content to be expected in the mineralized and non-mineralized zones. Our detailed studies will use a 15 cm core interval for geochemical analyses to refine our knowledge of element distribution in the rocks.

Sample number and stratigraphic position	Ca (percent)	Cu (Parts	Ag per	Pb	Zn million)
Top of Ysg_3					
1	5.0	5000	5.0	15	80
2	2.0	2000	3.0	15	100
3	1.5	300	<.5	15	75
4	.3	50	N	10	85
5	.15	30	N	10	55
Top of Ysg_3					
6	1.0	20	N	15	90
Covered					
7	7.0	1500	2.0	15	50
8	3.0	3000	3.0	20	60
Covered					
9	.7	50	N	15	90
Top of Ysg_2					
10	.3	20	N	10	100
11	.3	15	N	10	100
12	.15	15	N	15	75
Bottom of Ysg_2					
Top of Ysg_2					
13	.15	15	N	10	110
14	.15	10	N	10	85
15	.1	20	N	15	65
Bottom of Ysg_2					

Table 1. Analyses for selected elements in 30-cm chip samples from green beds of the Spokane Formation, Blacktail Mountain, Montana. N= not detected. Semiquantative spectrographic analyses for Ca, Cu, Ag, and Pb by James Domenico; atomic adsorption analyses for Zn by James Frisken; analyses done in U.S. Geological Survey Laboratories, Denver, Colorado.

Principal copper sulfides in the mineralized zones are bornite and chalcocite; much less abundant are covellite and chalcopyrite. Malachite is the common alteration product from the sulfides. Coarser grains and clots a mm or larger tend to be in the coarser-grained beds and laminae--in quartzites, in silty parts of graded couplets, and even in water-escape structures, mud crack casts, and clastic fill along microfaults. Finer grains are disseminated in the more argillitic parts of the rock. A tiny fraction of the disseminated sulfides can be found in purple beds. The coarser grains seem clearly to be replacing cement, matrix, and clasts of the host rocks. Thus the sulfide mineralization is late diagenetic at the earliest, appears related to permeability of the rock, and could have occurred in part or in total at any time during the geologic history of the rock as long as it was permeable.

We and our colleagues are beginning intensive isotopic, geochemical, mineralogic, and petrologic study of the rocks and sulfides in an attempt to refine our knowledge of timing and genesis of the mineralization. Physical properties of the rocks and cores are also under study, both for scientific data and for evaluation of geophysical methods that could be useful in appraising mineral potential of green-bed copper occurrences.

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