

OREGON GEOLOGY

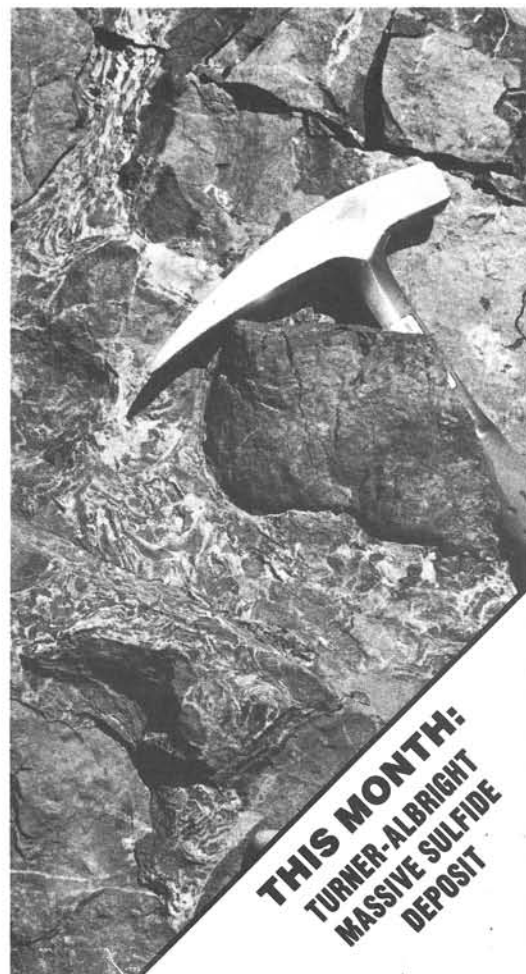
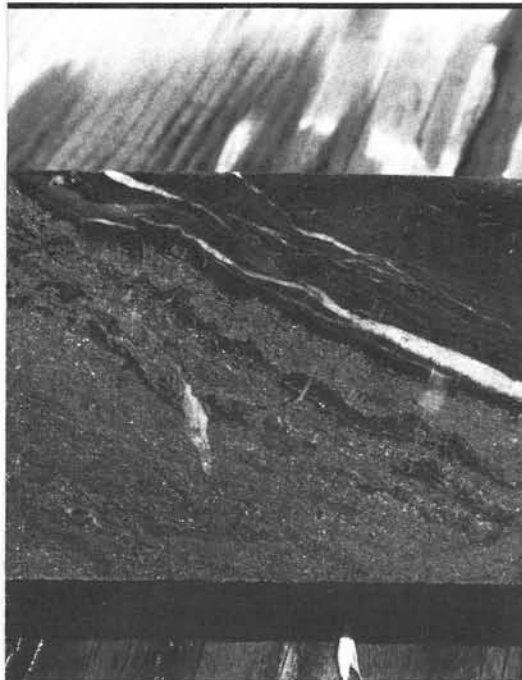
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Oregon Department of Geology and Mineral Industries



VOLUME 48, NUMBER 10

OCTOBER 1986



THIS MONTH:
TURNER-ALBRIGHT
MASSIVE SULFIDE
DEPOSIT

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Information for contributors

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors*, 6th ed., 1978). The bibliography should be limited to "References Cited." Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the "Acknowledgments."

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER PHOTO

Details from Turner-Albright massive sulfide deposit discussed in article beginning on next page. Clockwise from upper left: Cut drill core from stratigraphic top of Main Upper Zone (p. 120), showing contact between massive colloform banded pyrite/sphalerite and finely laminated black (carbonaceous) mudstone. — Large "llozzan" outcrop associated with South Zone gossans (p. 117 and 120, footnote). — Cut drill core showing massive sphalerite replacement of basalt within basin-floor rubble (p. 119). — Hyaloclastite breccia between basalt pillows (p. 117). — Cut drill core from basin-floor rubble showing hydrothermally altered basalt and silicification and pyritization of matrix. — Fragmental and brecciated textures associated with "llozzan" (above), including partially silicified and pyritized basalt and completely silicified basaltic glass.

OIL AND GAS NEWS

ARCO successful at Mist

ARCO Oil and Gas Company drilled the well Columbia County 14-23 to a total depth of 2,180 ft and has completed it as a producer from the Clark and Wilson sandstone at a rate of 3.2 MMcf/d. ARCO next drilled the Longview Fibre 41-35 to a total depth of 1,585 ft. This well has also been completed as a producer, but the flow rate has not yet been released. The third well drilled this summer was the Cavenham Forest Industries 33-9. This well was drilled to a total depth of 3,242 ft and was plugged and abandoned. ARCO next plans to drill the Cavenham Forest Industries 41-4. This well is permitted as a 2,400-ft test.

Exploratory well planned for Marion County

Damon Petroleum Corp., located in Woodburn, will drill its Stauffer Farms 35-1 this fall. The well is to be located in sec. 35, T. 4 S., R. 1 W., near the city of Hubbard. The well has a proposed depth of 2,800 ft.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
376	ARCO Col. Co. 42-8-54 009-00213	NE¼ sec. 8 T. 5 N., R. 4 W. Columbia County	Application; 2,750. <input type="checkbox"/>

Mineral industry costs to be studied

With today's unpredictable mineral markets, it is more critical than ever before to accurately predict production costs. Both new and existing operations are saddled with small profit margins and highly variable product prices.

To help mineral producers understand costs, the Northwest Mining Association will hold its "Mineral Industry Cost" short course on Dec. 1, 2, and 3, 1986, at the Sheraton Hotel in Spokane, Washington.

Jack Hoskins, head of the metallurgy and Mining Department of the College of Mines, University of Idaho, will serve as course director. "The problems of accurate cost estimating and control continue to be foremost in the minds of property developers and operators," Hoskins says.

Otto L. Schumacher, president of Mining Cost Service in Spokane, will act as co-director. "Although mineral industry costs have been the topics of short courses in 1976 and 1980, the drastic changes in our industry and in metal markets make a new review essential," Schumacher says.

Hoskins and Schumacher have assembled nineteen industry and academic experts to provide practical and up-to-the-minute information on the costs of exploration, development, operating, marketing, and environmental control for existing and proposed operations. The short course will be a series of working sessions, not lectures. Financial systems and control, labor costs and productivity, environmental permitting, comparison of costs of mining methods, processing costs including leaching of gold, and case studies of cost estimating will be studied.

The course, along with the Association's second short course, "Industrial Minerals — Are They for You?" will immediately precede the Northwest Mining Association's 92nd Annual Convention, which will be held in Spokane on Dec. 4, 5, and 6, 1986. College credit will be available. Enrollment will be limited to 200. To register or for more information, contact the Northwest Mining Association, (509) 624-1158.

— Northwest Mining Association news release

Geologic setting of the Turner-Albright massive sulfide deposit, Josephine County, Oregon

by Michael D. Strickler, Geologist, Litho-Logic Resources, 207-A SW "G" Street, Grants Pass, OR 97526

INTRODUCTION

Several small- to medium-sized volcanogenic massive sulfide deposits have been identified within ophiolitic volcanic rocks of Josephine County, Oregon. The most notable occurrence located to date is the Turner-Albright deposit (Figure 1, Plate 1), which was formed by a combination of sub-seafloor replacement and seafloor exhalative (venting) processes within a back-arc rifting environment. As currently defined, the Turner-Albright contains minimum drill-indicated reserves of 6.5 million tons of massive and semimassive sulfides. Values are reported for gold, silver, copper, zinc, and cobalt, with 2 to 4 million tons being potentially economic at current metal prices. Geological and geophysical data suggest that the deposit may be significantly larger and that the present reserves may be substantially increased by additional exploration adjacent to the known mineralization. This brief discussion is intended to summarize the geologic setting and history of the Turner-Albright and to relate some of the factors that may affect a future production decision.

REGIONAL GEOLOGIC SETTING

The regional geology of southwestern Oregon and northwestern California has been the subject of numerous studies, especially in recent years (Cater and Wells, 1953; Wells and Walker, 1953; Helming, 1966; Garcia, 1976, 1979; Vail, 1977; Cunningham, 1979; Ramp and Peterson, 1979; Harper, 1980, 1983; and others). Pioneer workers, including Diller (1914), Winchell (1914), and Shenon (1933a,b), mapped the many

mines and prospects that were being actively worked in the region in the early 1900's.

The Turner-Albright deposit occurs in the Western Jurassic Belt (WJB), the westernmost and youngest of four arcuate, north-south-trending lithotectonic belts that comprise the Klamath Mountains geomorphic province. The lithologies and age relationships within the Klamaths indicate repeated accretion, beginning in the early to middle Paleozoic and continuing through the Mesozoic, of ophiolitic and/or island-arc terrains and associated sedimentary units to the western edge of the North American continent. Jurassic and Cretaceous intrusives (gabbroic to granitic) intrude all the units. The WJB is in thrust contact with a similar suite of upper Paleozoic and Triassic ophiolitic/arc units to the east and is underthrust from the west by the upper Jurassic to Cretaceous Franciscan (Dothan) melange.

Prominent features of the WJB in southwestern Oregon and northwestern California are the Josephine Ophiolite (Figure 2) and coeval volcanoclastics and flows associated with island-arc development. The Josephine Ophiolite, dated at 157 million years (m.y.) (Harper and Saleeby, 1980), is interpreted to be the product of Jurassic back-arc spreading, with island-arc development occurring relatively westward. The ophiolite sequence, which regionally trends north-northeast with a steep southeast dip, is essentially complete, with preservation of all major lithologies associated with classic ophiolite stratigraphy. The basal ultramafic portion (Josephine Peridotite) is comprised predominantly of tectonized harzburgite that has undergone partial to locally complete serpentinization. Cumulate and massive gabbro is well exposed approximately 2.5 mi southwest of the Turner-Albright in the headwaters of the Monkey Creek drainage. The entire sheeted dike complex, from the lower transition with the gabbro to the upper gradational contact with extrusive volcanic flows and pillows, is preserved essentially intact on both flanks of Monkey Creek Ridge.

In southwestern Oregon, Jurassic extrusive rocks (both ophiolitic and arc-derived) have been collectively named the Rogue Volcanics and include basic to locally felsic flows, tuffs, breccias, and agglomerates. Volcanic members associated with the Josephine Ophiolite include basaltic flows and pillows with interlayered breccias, hyaloclastites, and relatively thin clastic and/or chemical sedimentary horizons. The Josephine Ophiolite, as well as the associated island-arc volcanic rocks, are conformably overlain by the Galice Formation, which is composed predomi-

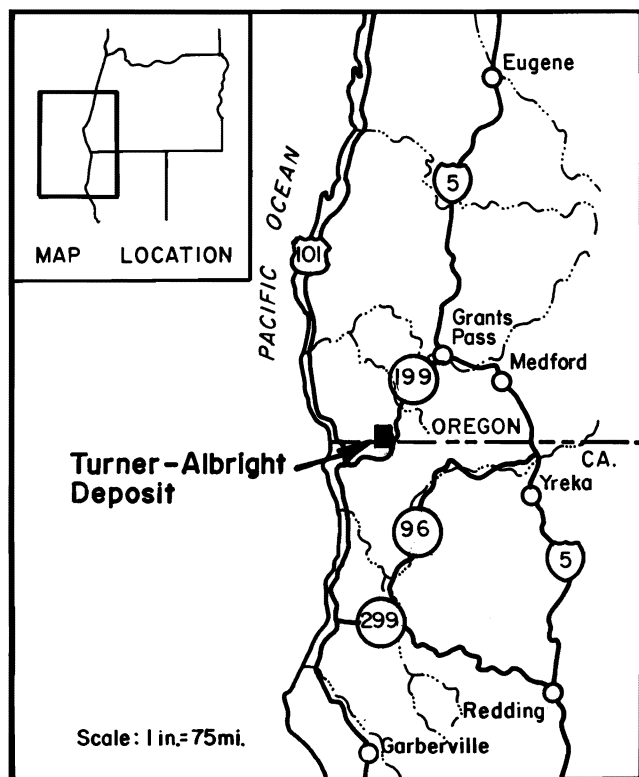


Figure 1. Map showing the location of the Turner-Albright massive sulfide deposit.

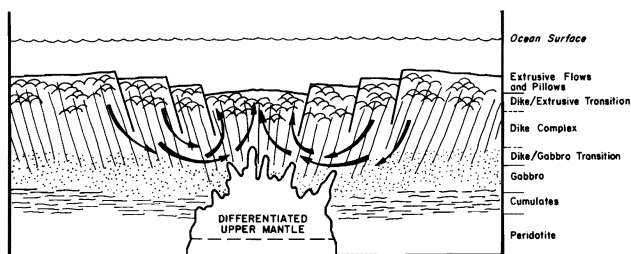


Figure 2. Schematic diagram showing the gross stratigraphy of the Josephine Ophiolite and the relative positions of the various units that occur in ophiolite suites. The Turner-Albright deposit is located immediately above the base of the extrusive flows and pillows.

nantly of interbedded graywacke and shale. Type localities for the Rogue and Galice Formations occur northwest of Grants Pass in the Galice District and as such are associated with island-arc development. Harper (1983) has proposed that the WJB be divided into two terrains: a northern Rogue River terrain, which would include the intermediate to locally felsic island-arc volcanoclastic rocks and flows typical of the Galice District, and a southern Josephine terrain, represented by the mafic and ultramafic units of the Josephine Ophiolite.

Precious- and base-metal mineralization within the WJB is widespread and consists of several varied genetic types. In addition to the Turner-Albright, several other massive sulfide deposits have been located. While a lack of data prohibits a definitive genetic classification for most of the showings, it is probable that several may be associated with ophiolite development (e.g., Monumental, Fall Creek, Eagle Group), while others appear to be related to island-arc development (e.g., Almeda, Goff, Silver Peak, Yankee Silver Lode). Numerous very high-grade gold/silver/copper/zinc occurrences commonly associated with mafic to granitic intrusives occur throughout the Klamath Mountains. Both vein and high-grade gold "pockets" have eroded to form locally rich placer deposits, many of which have been extensively worked by methods ranging from pick-and-shovel to large-scale hydraulic mining.

TURNER-ALBRIGHT DEPOSIT

Geographic setting

The Turner-Albright deposit is situated in southern Josephine County, immediately north of the California border and approximately 2 mi west of Highway 199 (Figure 1). Access to the Turner-Albright is via Lone Mountain Road in O'Brien, Oregon, which parallels the West Fork of the Illinois River to the turnoff to the property, a distance of approximately 6 mi. From the turnoff, an extensive system of access and drill roads provide year-round entry to most portions of the deposit.

Relief at the Turner-Albright is moderate to locally steep, with elevations ranging from 2,000 to 3,100 ft. Area rainfall during the winter months is quite heavy, with seasonal averages in excess of 100 in. to be expected. Snowfall is common above 3,000 ft and can last from December through April. Storms come in groups, with weeks of clear weather common between systems. Summers are hot and dry, with highs above 100° F not uncommon from July through mid-September. Steep slopes covered with thick stands of brush and timber, old-growth poison oak, and yellow jackets with a special vengeance for geologists all tend to hinder field activities during the summer months.

Property history

Mineralization associated with the Turner-Albright deposit

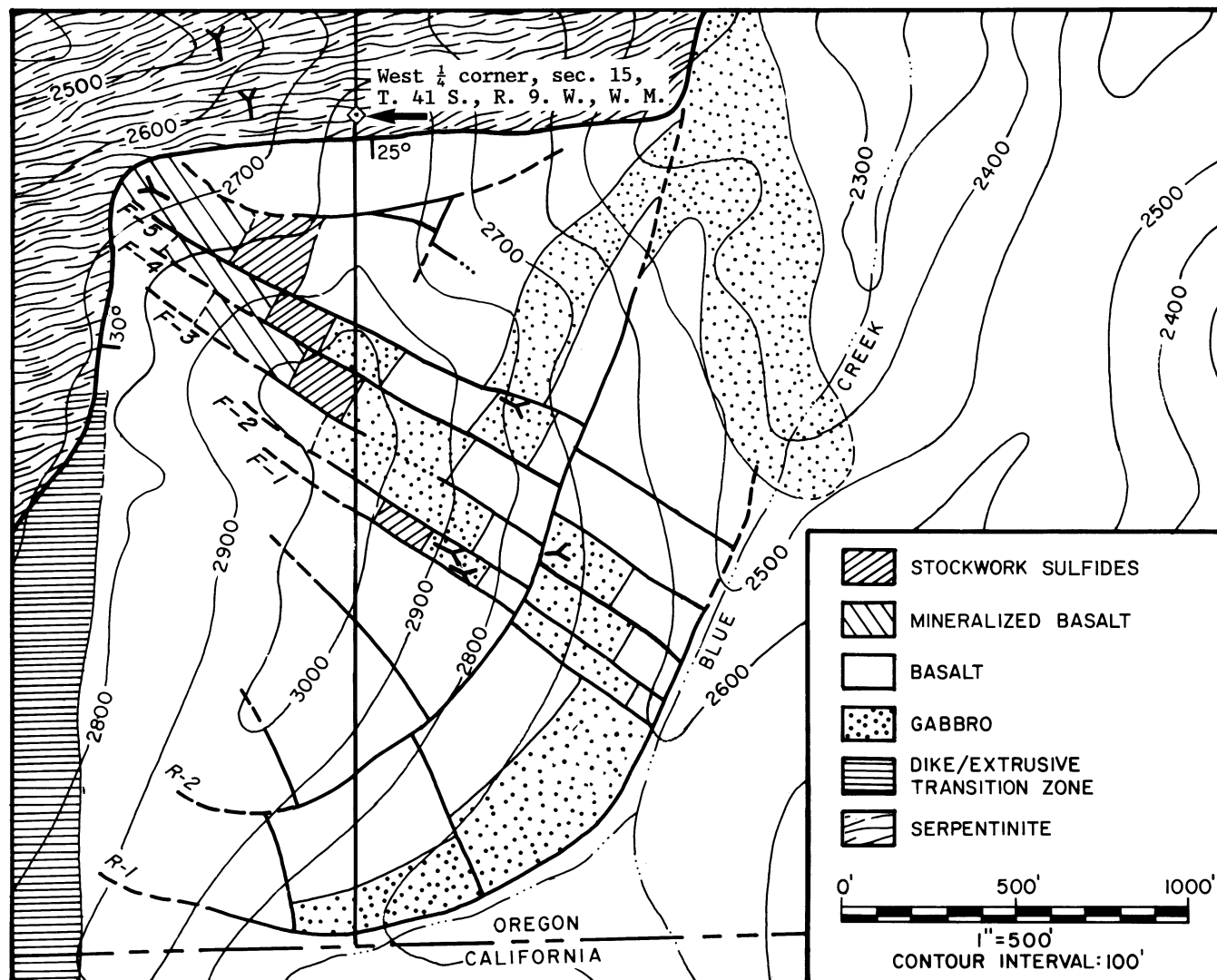


Figure 3. Generalized surface geology of the Turner-Albright deposit and vicinity. F-1 through F-5 indicate F-series faults; R-1 and R-2 indicate R-series faults.

was originally located in the late 1800's. Early efforts concentrated on developing the potential gold content of several discontinuous gossan outcrops located on or near the ridge separating Blue Creek from the headwaters of the West Fork of the Illinois River. Sporadic exploration and limited development continued through the 1930's, but these efforts were not successful in defining an economic reserve. Several short crosscuts driven at the base of the oxide horizon reached primary sulfides that were of sufficient grade to allow three claims to be patented in the late 1950's.

Exploration of the underlying sulfide deposit began in earnest in 1954 with a one-year program by Granby International. Associated Geologists of Grants Pass continued exploration below the gossans intermittently throughout the 1960's and early 1970's with several programs consisting of churn and shallow diamond core drilling. A two-year program by American Selco in 1974-1975 explored the potential of the southernmost (South Zone) gossans and resulted in drill-indicated reserves of 150,000 tons of sulfide ore averaging 1.70 percent copper and 0.03 oz/ton of gold across an 8-ft-wide zone of highly siliceous basaltic breccias. Evidence of a large mineralized body north of the South Zone was indicated by an induced polarization geophysical survey and three short diamond drill holes; however, American Selco considered the prospects of locating an economic deposit poor and allowed its option to expire at the end of 1975.

Baretta Mines, Ltd., of Calgary, Alberta, Canada, obtained an option upon termination of the American Selco program. Through August 1981, Baretta Mining, Inc., a wholly-owned subsidiary, conducted extensive exploration on the Turner-Albright itself, as well as initial exploration of favorable units to the south and southwest. A total of 30 diamond core holes, with an aggregate length of 35,500 ft, were completed at the Turner-Albright, resulting in an indicated in-place geologic reserve of 3 million tons averaging 0.09 oz/ton of gold, with additional values in copper, zinc, silver, and cobalt. Drilling by Noranda Exploration in 1982 and Rayrock Mines, Inc., in 1983-1984 continued to refine both the geologic and structural characteristics of the deposit. Drilling on the deposit to date exceeds 75,000 ft in 80 separate drill holes. At the present time, reserve estimates place the Turner-Albright at 2 to 4 million tons averaging approximately 0.12 oz/ton of gold, 0.60 oz/ton of silver, 1.55 percent copper, 3.70 percent zinc, and 0.50 percent cobalt. The wide range in tonnage reflects the current uncertainty over the full effect that post-mineralization faulting may have had on the continuity of portions of the deposit.

Recently, two separate studies of the Turner-Albright have been initiated by branches of the Federal Government to study the genetic and metallurgical characteristics of the deposit. A team of geologists, marine geologists, and geochemists from the U.S. Geological Survey (USGS) are studying the Turner-Albright to determine its similarities to active hydrothermal systems that have recently been identified at several venting sites along mid-ocean ridges. In addition, the U.S. Bureau of Mines is beginning a detailed mineralogical study of the cobalt-bearing sulfides at the Turner-Albright. Their intent is to help in defining and developing a metallurgical process to treat the complex ores found at the deposit.

Lithology

The Turner-Albright deposit is situated near the base of the extrusive pillow lavas and flows of the Josephine Ophiolite, 50-200 m above their gradational lower contact with the sheeted dike sequence. In the immediate vicinity of the Turner-Albright, the majority of ophiolite-related lithologies normally found stratigraphically below the extrusives are missing due to post-ophiolitic low-angle faulting that has juxtaposed the uppermost portion of the sheeted dike/extrusive rock transition zone and serpentinized mantle peridotite. In comparison with the total

section as exposed south of the Turner-Albright, up to 1.5 km or more of the ophiolite stratigraphy is missing, including the middle and lower sheeted dikes, the entire massive and cumulate gabbro sequence, and an unknown amount of mantle peridotite.

With the exception of numerous mafic pegmatite and rodingite dikes that occur within major shears in the ultramafic mass, all of the lithologies currently exposed at the Turner-Albright are interpreted to be associated with the primary development of the Josephine Ophiolite (Figure 3). Following is a brief description of the major units identified at the Turner-Albright deposit.

Basalt: Extrusive volcanic rocks occurring at the Turner-Albright consist of basaltic flows, pillows, and hyaloclastites that commonly contain plagioclase, clinopyroxene, and/or iron titanium phenocrysts. Feldspar microlites and/or calcite veinlets and amygdules occur locally, and individual units may be locally vesicular. Well-developed pillow structures are evident, both in outcrop and in drill core. Minor to locally intense alteration occurs, consisting of prehnite/pumpellyite, chlorite, sphene, and albite (\pm silica, hematite, and epidote), with increased alteration being localized within and adjacent to zones of shearing and faulting. Except where associated with mineralization, clinopyroxene is rarely altered to any degree. Regional prehnite/pumpellyite-facies metamorphism has overprinted much of the original alteration associated with seafloor and hydrothermal reactions, and it is often difficult to determine the age or origin of specific alteration products.

Recent work by Robert Zierenberg of the USGS has defined a second extrusive unit that is of limited extent and apparently restricted to the mineralized horizons. To date, this unit, which consists of glassy fragments of a relatively primitive mafic magma, has not been found as flows or pillows. The rock typically exhibits phenocrysts of olivine and/or chromium spinel (with occasional plagioclase) in a groundmass of glass and radiating clusters of quenched pyroxene crystals. Extensive hydrothermal alteration within the mineralized horizon commonly masks the nature of many of the fragments; however, where primary textures are still visible, clasts of the regionally dominant plagioclase-bearing lava series appear to be restricted to the lowest portions of the mineralized horizons and may represent minor accumulations of rubble on the seafloor prior to the extrusion of the mafic lavas.

Gabbro (coarse-grained basalt): As applied at the Turner-Albright, the term "gabbro" refers to diabasic to microgabbroic (locally gabbroic) textures that occur within the cores of thick extrusive basalt flows and/or pillows. These units commonly contain plagioclase and/or pyroxene phenocrysts up to 5 mm long in a generally fine-grained to aphanitic groundmass. To date, there is no compelling evidence to indicate an intrusive origin for the unit, and the gabbro is interpreted to represent coarse-grained members of the dominant plagioclase-bearing lava series. Thick sections (>50 m) of gabbroic-textured flows commonly occur within 10 m of the top of the mineralized horizons and may represent ponding of basaltic lavas within the primary depositional basin.

Mudstone: Very fine-grained clastic sedimentary units occur as definable horizons 10 cm to 5 m thick, as minor interpillow and interflow accumulations, and within the matrix of hyaloclastite breccias. Color varies from red (hematitic) to green, brown, gray, and black (carbonaceous). Green and gray mudstones are often indistinguishable from silicified basaltic gouge in drill core. Measurements of bedding from outcrop, as well as subsurface structural calculations from three points, indicate a regular north-northeast strike to the units (subparallel to the regional trend of the ophiolite); however, dips vary from 30° SE. to nearly vertical. Composition of individual clasts is difficult to deter-

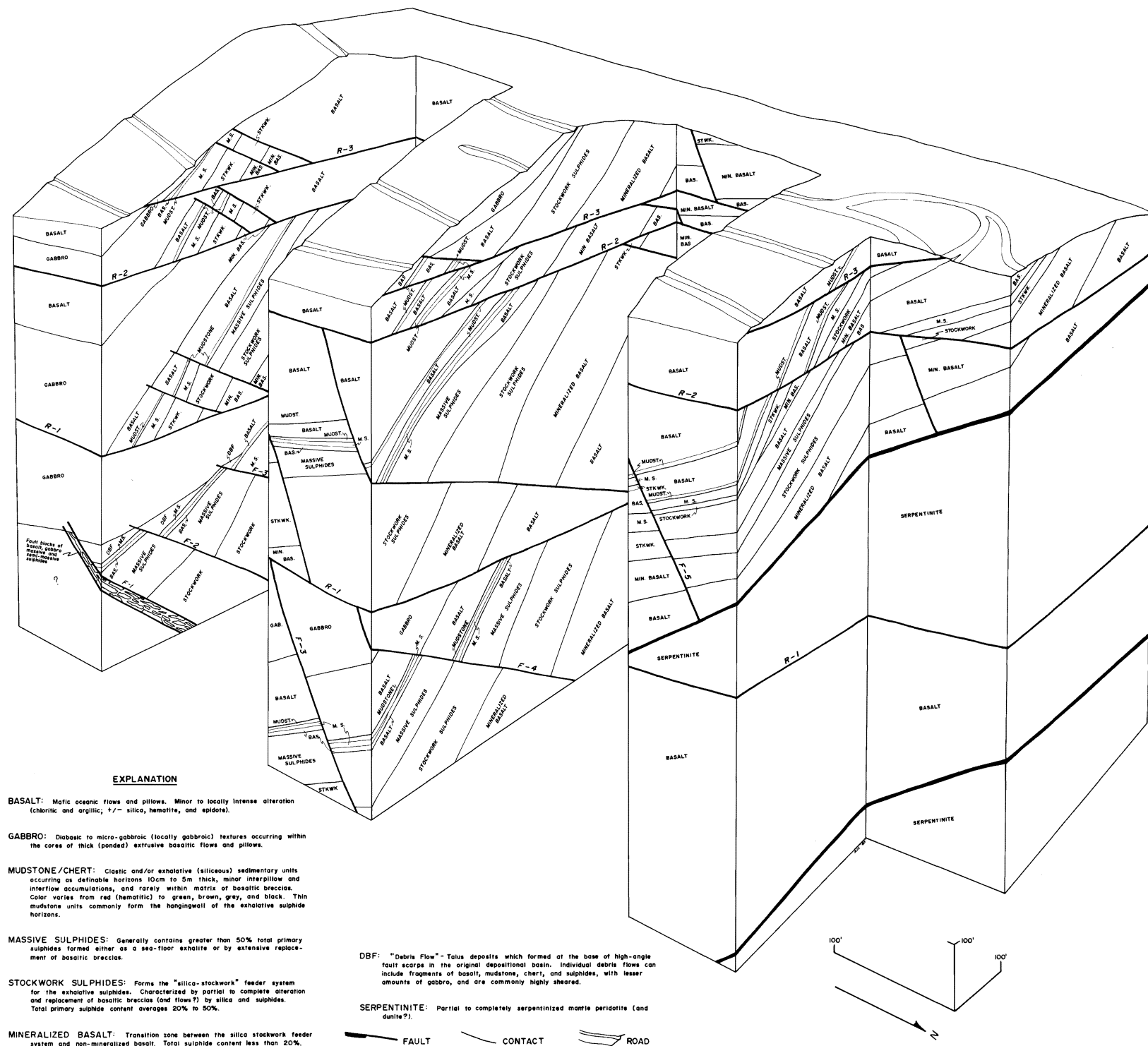


Plate 1. Simplified schematic block diagram of the Turner-Albright massive sulfide deposit.

mine, but both hemipelagic and local sources probably contributed to the formation of the muds. Local increases in the silica content of the sediments indicate an exhalative or biogenic source for at least a portion of the material. Radiolarians have been observed in several of the more siliceous mudstones, and confirm an approximate 155-m.y. date for the ophiolite (Harper, personal communication, 1984). Thin (up to 1-m-thick) mudstone layers commonly cap the exhalative horizons and appear to be laterally more extensive than the sulfide bodies themselves, as several mud horizons extend beyond the known limits of sulfide mineralization. At least two, and possibly three, additional clastic horizons have been identified at the Turner-Albright but are not known to be associated with sulfide development.

Basin-floor rubble: From an examination of textures associated with the sulfide bodies located at the Turner-Albright, it is apparent that a large portion of the deposit occurs as a replacement of brecciated basalt fragments. The basin-floor rubble (Figure 4) represents accumulations of up to 75 m of brecciated basalt that covered the original depositional basin prior to the onset of hydrothermal activity and the venting of the sulfide horizons. The majority of the silica stockwork sulfides, as well as a large portion of the massive sulfide horizon, may occur within highly altered portions of this unit. Intense hydrothermal alteration within this section of the Turner-Albright stratigraphy obscures the composition of many of the fragments; however, it is apparent that fragments of the mafic lava series form the majority of the unit, with clasts of the regionally dominant plagioclase-bearing lava generally restricted to the base of the rubble pile.

Talus deposits: High-angle faulting associated with the formation of the Turner-Albright deposit resulted in several moderate- to high-relief fault scarps in the original depositional basin. Brecciation and erosion led to the accumulation of talus deposits at the base of these structures. Individual talus piles can include fragments of basalt, mudstone, and sulfides, with minor amounts of gabbro. The talus deposits commonly have been subjected to a high degree of internal shearing. Sulfides occur as angular to subrounded fragments derived from preexisting, faulted exhalative and stockwork horizons, as well as replacement deposits formed by later fluid movement through units. As defined at the Turner-Albright, the talus deposits are differentiated from the basin-floor rubble by their stratigraphic position at the top of the sulfide horizons, their lack of extensive hydrothermal alteration, and the presence of mineralized fragments derived from the existing sulfide bodies. It is likely, however, that portions of the basin-floor rubble may actually represent pre-mineralization talus deposits and may account for mineralized areas containing plagioclase-bearing lava fragments within the predominantly mafic basin-floor rubble.

Sheeted dikes: Ophiolitic sheeted dikes are characterized by subparallel diabasic dikes and are interpreted to represent the conduits for the magma that supplied the overlying extrusive flows and pillows. The upper and lower contacts of the unit as a whole are commonly gradational. The upper transition zone with the extrusive lavas is composed of diabasic dikes with a downward decreasing proportion of basaltic screens, while the lower contact zone with the massive gabbro is characterized by extremely erratic and confusing diabase/gabbro textural variations.

Due to faulting that has completely removed the lower portions of the ophiolite, only the uppermost portion of the upper transition zone remains at the Turner-Albright. This portion of the Turner-Albright stratigraphy is poorly exposed and has been identified only in several drill holes in the northwest portion of the deposit and in extensively weathered outcrops in fault contact with serpentinite. Individual dike margins are marked by chill zones up to 1 cm across and are often brecciated. Moderate to

locally intense epidote alteration is common. Textures within the cores of individual dikes and the enclosing basaltic screens are often indistinguishable, which makes identification of this transition zone extremely difficult in outcrop where the chill and/or breccia margins are generally obscured.

Peridotite/serpentinite: Partially to completely serpentinized mantle peridotite occurs immediately west of the Turner-Albright in the headwaters of the North Fork of the Illinois River. Pods of serpentinized dunite also occur and may represent primary cumulate differentiation within the upper mantle. Mafic pegmatite and rodingite dikes are common along the faulted contact with the extrusive basalt/sheeted dike transition zone, as well as in shear zones within the peridotites. Thin (1- to 3-cm-thick) seams of powdered magnetite also occur locally along the contact. The serpentinites are highly magnetic relative to the other units in the vicinity and can be readily located by their magnetic signature.

Mineralization

Sulfide minerals identified at the Turner-Albright include pyrite (\pm marcasite), sphalerite, chalcopyrite, and linnaeite, with trace amounts of tetrahedrite, stannite, galena, and pyrrhotite. While assumed contributions from multiple vent sources and extensive post-mineralization faulting complicate any study of the primary zonation patterns, it appears that the original metal distribution resulted in copper/gold-rich centers at depth within the basin-floor rubble and proximal to the vents, with zinc/silver and pyrite with cobalt zones occurring with increasing distance from the venting sites. Limited thin- and polished-section work indicates that the metallurgical characteristics of the deposit are complex and may complicate extraction of the base and precious metals. Fine-grained chalcopyrite and sphalerite are tightly intergrown with pyrite and, to a limited extent, with each other. Gold occurs as discrete micron-sized blebs within chalcopyrite (and, to a limited extent, sphalerite) and pyrite. This gold/pyrite association results in low to locally moderate gold values (0.02 to 0.07 oz/ton) in the distal pyrite halo in the absence of any base metal credits. Cobaltiferous linnaeite occurs as rims on pyrite grains. Porous colloform marcasite is most abundant in the uppermost portion of the deposit and may in part be a product of near-surface alteration of the primary ion sulfides. It must be stressed that these findings are fragmentary and that a final metallurgical definition of the deposit remains to be made.

As currently defined, the sulfide bodies at the Turner-Albright are composed of three interrelated types of mineralization (Figure 4). Massive sulfide horizons up to 30 m thick and containing >50 percent total sulfide content occur at the stratigraphic top of

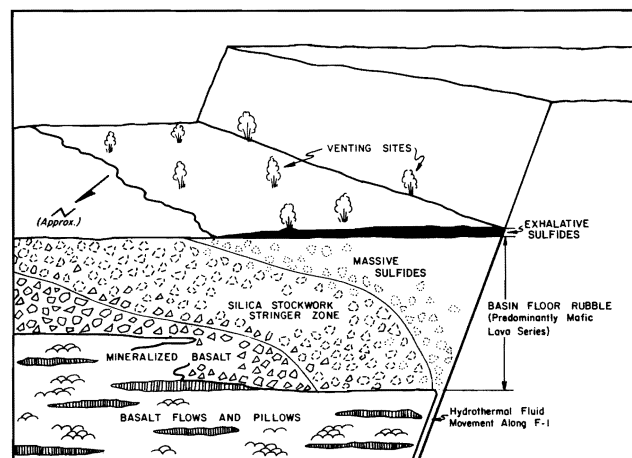


Figure 4. Stratigraphic cross section during the late stages of the development of the Turner-Albright deposit and prior to the deposition of the clastic (\pm silica) mudstone horizon.

the mineralized section. A silica stockwork stringer zone consisting of highly altered breccias occurs below and lateral to the massive sulfides. Total sulfide content generally decreases to trace amounts in the stringer zone with distance from the main exhalative centers, resulting in a third definable horizon, termed a mineralized basalt, which contains less than 20 percent total sulfides. The potentially economic portions of the deposit are generally restricted to the massive and stringer horizons but are not necessarily associated with the greatest sulfide content. A large percentage of the massive horizon at the northern end of the deposit is composed essentially of massive pyrite/marcasite and is of a relatively low economic grade. Where exposed at the surface, all three units oxidize to form gossans or "llozzans"* that mark the updip, western limit of the deposit. Limited outcrop sampling and shallow drilling support the interpretation that the majority of the gossans (and "llozzans") were derived from portions of the deposit with a relatively low gold content and therefore have little potential to develop substantial reserves of leachable ore.

The massive sulfide horizons that occur at the Turner-Albright are interpreted to have been formed either as seafloor exhalites or by the extensive alteration and replacement of basaltic breccias resulting in nearly complete obliteration of all primary textural features. Evidence of brecciation within the massive horizon commonly increases at lower stratigraphic levels, with ghosts of almost completely replaced basaltic clasts grading into highly mineralized rock with identifiable basalt and chert(?) fragments. It is probable that many or all of the chert fragments, which are commonly nonmineralized, are actually completely silicified basaltic glass. The origin of any given portion of the massive horizon (i.e., exhalite or total replacement) may be difficult to determine due to this extensive alteration, and it is often impossible to define the original rock/water interface. From the amount of basaltic fragments within the sulfide horizons, it is clear that the majority of the mineralization at the Turner-Albright was the result of partial to complete replacement of basaltic breccias. The uppermost portion of the massive horizon, however, commonly exhibits fragmental textures, and it is possible that some of this sulfide brecciation may represent collapsed chimney structures that were initially built by the venting of sulfide-rich fluids on the sea floor. In addition, several small worm casts (1-2 mm in diameter) have been tentatively identified. These two bits of evidence support an exhalative seafloor origin for the upper 1-3 m of the deposit.

At the Turner-Albright, the silica stockwork stringer zone contains from 20 to 50 percent primary sulfides and represents a conformable transition from essentially complete replacement of basaltic breccias to nonmineralized flows, pillows, and hyaloclastites. The contact between the silica stockwork zone and the overlying massive sulfides (as well as with the more distal mineralized basalt) is gradational, and the actual location is somewhat irregular and arbitrary. The silica stockwork is almost certainly a result of the percolation of mineralizing fluids through basaltic rubble and is characterized by silica flooding of the breccias, with the addition of pyrite (\pm marcasite), chalcopyrite, sphalerite, and accessory sulfide minerals. Mineralized flows and/or pillows have not been identified within the silica stockwork. Hydrothermal penetration of the breccia pile resulted in substantial alteration of the original rock (silica+sulfides+chlorite+albite). From a study of partially altered fragments within the silica stockwork, it is apparent that the majority of the clasts are related to the mafic lavas discussed above. The degree of mineralization and the

*"Llozzan" is a term coined by the writer to describe "gossanlike" material derived from the oxidation of sulfide-bearing rocks containing less than 50 percent total primary sulfide minerals. The term is in honor of Lloyd Frizzell, whose faith in the "llozzans" at the Turner-Albright kept the project alive through the early days of exploration in the 1960's and 1970's.

economic value of the silica stockwork stringer zone are both somewhat erratic. This may in part be due to the original configuration of the rubble pile, with areas of higher mineralization reflecting increased fluid movement along paths of greatest permeability.

Mineralized basalt includes the portions of the volcanic breccias and flows that were subjected to alteration by hydrothermal fluids but that contain a total sulfide content of less than 20 percent. Preliminary relogging of selected drill core indicates that, while some of the breccia fragments are related to the mafic lavas, clasts of the plagioclase-bearing lava series occur. It is also evident that mineralization within flow units, as opposed to being restricted to altered breccias, occurs to a limited extent at the northern end of the deposit. An increase in hematitic alteration has also been noted within breccias and flows that occur stratigraphically below and lateral to the sulfide-rich portions of this unit. The mineralized basalts, which are generally of very low economic grade, are interpreted to represent the most distal effects of the mineralizing fluids.

Structure

The majority of the known sulfides at the Turner-Albright occur as three vertically stacked horizons that trend northeast with a moderate southeast dip. These three zones occur in two, and possibly three, separate time-stratigraphic horizons, and have been designated the Upper High-grade Zone (UHZ), the Main Upper Zone (MUZ), and the Main Lower Zone (MLZ). Post-mineralization faulting has broken the MUZ and MLZ into somewhat discrete fault-bounded mineralized blocks; however, in many cases the original thickness of the disrupted sulfide horizon was greater than the displacement along the fault, so that when the fault is intercepted in drill core, no readily discernible lithology change occurs across the structure. This is especially true in the MUZ, which is up to 100 m thick. A minimum of three generations of faulting (pre-mineralization, post-mineralization, and emplacement) have been recognized to date. Additional and extensive faulting severely disrupts the stratigraphy associated with the UHZ.

A complex series of pre- and post-mineralization high-angle northwest-trending normal faults have been partially defined (F-series faults). At least five separate structures (F-1 through F-5) (Figures 3 and 5) have been identified within the known sulfide horizons, and there is evidence of additional faulting south of the deposit. Outcrop measurements and correlations between drill intercepts indicate that the F-series faults strike approximately N. 60° W. and dip to the north from 65° to 85°. The pattern is complicated by poorly defined branching and interconnecting near-vertical east-west splay faults.

The southernmost structure, F-1, is interpreted to have existed prior to the onset of hydrothermal activity and to have controlled the movement of the primary mineralizing fluids. While there is no evidence to indicate that other F-series faults predate the mineralization, the possibility of hydrothermal penetration and/or pre-mineralization movement along some or all of the remaining F-series faults cannot be ruled out. Post-mineralization movement along the F-series faults disrupted the stratigraphy immediately after deposition of the sulfide horizons, with a resulting downdropping of the overall sulfide horizon to the northeast (Figure 5). Timing of post-mineralization activity along the F-series faults is bracketed by the deposition of the sulfide horizons and the extrusion of the thick gabbroic-textured flows that generally appear to have been unaffected by their movement. Post-mineralization displacement, calculated by measuring the offset of the tops of adjacent sulfide horizons, averages 30-40 m. Due to the steepness of the structures and their orientation normal to the strike of the sulfide horizons, standard cross sections are not sufficient to fully define their characteristics. A series of horizontal and longitudinal sections are currently being prepared

to aid in reconstruction of the original depositional setting and interpretation of these critical structures.

A later series of low-angle east-west-trending post-mineralization reverse(?) faults is indicated (R-series faults) (Figure 3). Timing of the R-faults is unknown, but it is possible that these structures were associated with the emplacement of the Josephine Ophiolite along the continental margin, as well as with the faulting and removal of the lower portion of the ophiolite at the Turner-Albright. At least three R-series faults have been identified to date (R-1, R-2, and R-3). Three-point structural calculations and outcrop measurements indicate that these faults strike generally east-west and have a very shallow north dip (approximately 20°). The major impact of these low-angle structures was along R-1, where an apparent 150-200 m of displacement resulted in dislocation of the original single sulfide horizon into the MUZ and MLZ. Offsets along R-2 and R-3, which are located above R-1, are minor and generally do very little to disrupt the MUZ. It is probable that additional R-series faults exist within the MLZ. It is important to note that the R-series faults cut and displace the F-series faults, which greatly complicates any attempt to reconstruct both the original setting of the deposit and the geometry of the depositional basin. The ultimate effect of all these structures on the Turner-Albright stratigraphy is still poorly understood, and it is probable that a full understanding will require underground mapping.

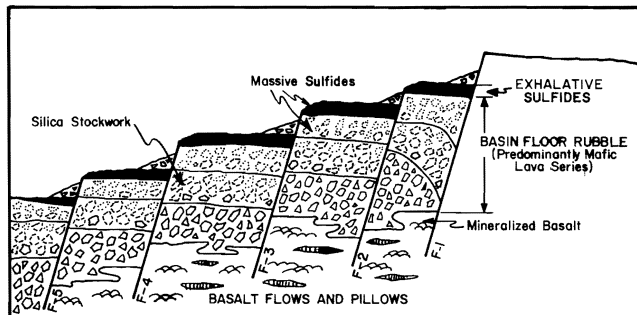


Figure 5. Cross section through the Turner-Albright deposit prior to dislocation along the R-series faults and emplacement along the continental margin.

Sulfide geometry and exploration potential

The uppermost sulfide horizon (UHZ) is relatively thin (2-15 m) but of very high grade and located within 25 m of the surface. Drill-indicated reserves for the heart of the UHZ total 50,000 tons at an average grade of 0.40 oz/ton of gold, 1.70 oz/ton of silver, 4.30 percent copper, 1.35 percent zinc, and 0.08 percent cobalt. Geologic and structural interpretations indicate that the UHZ is laterally extensive and directly overlies the MUZ toward the southern end of the deposit, with a thickening wedge of basalt, mudstone, and/or hyaloclastite separating them to the north. There is also evidence that mineralization associated with the UHZ overlies portions of the MLZ as well, which supports the theory that a single sulfide horizon was faulted into the MUZ and MLZ along R-1. Extensive post-mineralization faulting at the north end of the deposit has severely disrupted the UHZ. Drilling to date has delineated the known zone both along strike and updip. The potential is good for locating additional mineralization to the southeast (down dip), as well as faulted portions to the north.

The relationship between the MUZ and MLZ, which contain the bulk of the reserves, is uncertain at this time. Drill-indicated reserves for the combined MUZ and MLZ total approximately 3 million tons at an average grade of 0.12 oz/ton of gold, 0.60 oz/ton of silver, 1.55 percent copper, 3.70 percent zinc, and 0.05 percent cobalt.

The majority of mining engineers who have examined the

Turner-Albright have indicated that the MUZ may be amenable to surface mining methods. Preliminary estimates of waste to ore ratios are fairly high, however, and without a substantial increase in pitatable reserves, the MUZ would probably have to be developed from underground. The possibility of significantly expanding reserves associated with the MUZ is relatively poor. The general boundaries of the MUZ have been well defined and consist of surface outcrop (updip), R-1 (down dip), F-1 (southwest), and the serpentinite (northeast) (Figure 3). From the suggested fault pattern, several unexplored wedges still exist within these limits, which could increase reserves in the MUZ by as much as 250,000 to 300,000 tons of potentially economic ore. In addition, approximately 1 to 1.5 million tons of mineralized basalt, containing from 0.02 to 0.07 oz of gold and 2 to 5 lb of cobalt to the ton, occur within the northern part of the deposit. This portion of the Turner-Albright, while of subeconomic grade at current metal prices, would represent a substantial cobalt/gold reserve given the proper economic conditions. The inclusion of these units as minable reserves would help in reducing the waste to ore ratio to a level acceptable for surface mining methods.

Table 1. Approximate drill-indicated reserves

Zone	Tonnage	Gold (oz/ton)	Silver (oz/ton)	Copper (%)	Zinc (%)	Cobalt (%)
UHZ	50,000	0.40	1.70	4.30	1.35	0.08
MUZ	1,600,000	0.13	0.50	1.40	3.00	0.05
MLZ	1,400,000	0.10	0.75	1.75	4.50	0.04

Because of its depth below the surface, the MLZ would require underground mining methods. The base of the known ore body could be reached by a 3,500-ft-long crosscut driven from the east. The possibility of doubling or tripling the MLZ reserves is considered excellent. Structural, geologic, and geophysical evidence indicates that mineralization may extend to the southeast down the plunge of F-1 for a considerable distance. Detailed pulse-electromagnetic geophysical work during the summer of 1985 was successful in defining the known mineralization and indicates that a two- to three-fold increase in MLZ reserves is probable. Due to the increasing depth of the mineralization, however, the pulse-electromagnetic system was unable to define the southeastern limit of the MLZ. Because of this depth of penetration limit, the suggested increase in the size of the zone is considered a minimum value. Recent drilling by Rayrock Mines (prior to the pulse-electromagnetic survey) also indicates that substantially greater thicknesses of high-grade mineralization occur down dip from the deepest intercepts of either Baretta or Noranda. Mineralization encountered in these deep holes is characterized by very high zinc values at the stratigraphic top of the sulfides (>10 percent over 25-m true widths) and increasing copper/gold values near the base of the section. Because chalcopyrite is highly conductive and sphalerite is nonconductive and therefore generally invisible to electromagnetic readings, it has been interpreted that the indicated additional reserves may contain a relatively large percentage of chalcopyrite (Crone, 1985).

Discussion

The Turner-Albright is interpreted to be an ophiolitic, volcanogenic sulfide deposit that was the product of replacement and exhalative processes within a back-arc rifting environment. Convection of oceanic waters that were superheated by ascending (and differentiating) magmatic mantle material resulted in the leaching of sulfur, iron, cobalt, zinc, gold, silver, and copper from the mafic and ultramafic pile, with precipitation of silica and sulfides at or near the rock/water interface. Additional mineralization commonly occurred distal to the venting sites producing a silica stockwork that represents zones of large-scale hydrothermal penetration and replacement and, to a limited extent, the

plumbing system that supplied the exhalative horizon. The actual portion of the massive sulfide horizon that was formed as a result of exhalative seafloor venting may be fairly small. The original depositional basin at the Turner-Albright apparently had an extensive cover of basaltic rubble, which could have had a direct effect on the ultimate strength of the exhalative process. The highly permeable nature of the breccias probably resulted in the spreading out of the mineralizing fluids into this clastic horizon prior to actual venting on the seafloor. Some of the mineralized breccias are compositionally different from all other lavas identified to date and are characterized by phenocrysts of olivine and/or chromium spinel in a groundmass of glass and radiating clusters of quenched pyroxene crystals. Mudstones (locally siliceous) occur at the stratigraphic top of the sulfide horizons. It is probable that the cherty muds are in part the result of the addition of excess silica to the seawater in the vicinity of the sulfide vents.

It is reasonable to infer a period of relative inactivity with respect to volcanism both during and immediately following the formation of the sulfide bodies at the Turner-Albright. This quiescent period would have allowed time for the formation of the existing sulfide horizons and the accumulation of the mudstones. From recent work in the Josephine and other ophiolites, Harper (personal communication, 1986) postulates that magma chambers that feed the extrusive basalts experience cyclical periods of activity, followed by periods when they are essentially frozen and inactive. Partial crystallization of the upper differentiated portions of the magma chamber would possibly allow deeper, less mature lavas to escape and may account for the extrusion of the mafic lava series at the Turner-Albright. It is important to note that the introduction of the sulfides at the Turner-Albright immediately followed the accumulation of the mafic basin-floor rubble, and it is reasonable to assume that the same series of events contributed to both of these apparently anomalous (in a time-stratigraphic sense) events.

Subsequent to the formation of the deposit, the Turner-Albright was subjected to regional emplacement metamorphism and at least two generations of post-mineralization faulting. This structural breakup of the deposit complicates a full geologic and genetic understanding of the Turner-Albright and will certainly have an effect on any future mine plans.

Contemporary geologic studies often categorize mineral deposits by genetic "type," and much effort has been made over the past several years to define the Turner-Albright as a Cyprus-type deposit. While there are many similarities in gross geological features, it is the writer's opinion that there are significant differences between the Turner-Albright and the classic Cyprus-type deposits and that they represent different subtypes of ophiolite-hosted massive sulfide deposits. The writer proposes that a separate classification be considered for the Turner-Albright and that it be classified as a "Josephine-type" deposit based upon the following characteristics:

(1) The Turner-Albright is ophiolite hosted and occurs intimately associated with seafloor volcanism and extensional tectonics. Mineralization is structurally controlled and is restricted to the lowest portions of the extrusive lava series immediately above the sheeted dike/extrusive rock transition zone.

(2) Features common to the Cyprus deposits, including umbers, ochres, "vertically extensive stringer zones," and "extensively altered footwall rocks" (Franklin and others, 1981) have not been identified at the Turner-Albright. Iron-poor, locally siliceous mudstones occur at the Turner-Albright in the same relative stratigraphic position as the Cyprus ochres.

(3) More than 90 percent of the known sulfide mineralization at the Turner-Albright is the result of large-scale replacement of basaltic breccia and talus. The original depositional basin had a cover of up to 75 m of highly permeable basaltic rubble that is compositionally different from both the footwall and hanging-

wall basalts. The permeable nature of the breccias had the effect of dissipating the mineralizing fluids into this clastic horizon prior to venting on the seafloor, with only a minimal amount of the hydrothermal fluids reaching the rock/water interface to form exhalative sulfides.

(4) A true silica stockwork zone, in which hydrothermally altered flows and pillows stratigraphically below the massive horizon represent the feeder system for the overlying exhalative sulfides, does not occur at the Turner-Albright. The silica stockwork at the Turner-Albright is the result of extensive hydrothermal penetration and replacement of basaltic breccias, and in only a very limited sense does it represent the feeder system for the exhalative horizon.

(5) The sulfide bodies at the Turner-Albright have anomalously high gold values. As currently defined, the Turner-Albright contains approximately 6.5 million tons (including the mineralized basalt) with an average gold content of 0.055 oz/ton. Significantly greater values (up to 0.462 oz/ton over a 15-m true width) are found within the higher grade portions of the deposit, and the potentially economic portion averages 0.12 oz/ton.

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