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THE GEOLOGY, MINERALIZATION, AND GEOCHEMISTRY OF THE MILESTONE HOT-SPRING SILVER-GOLD DEPOSIT, NEAR THE DELAMAR SILVER MINE, OWYHEE COUNTY, IDAHO

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ABSTRACT

The Milestone deposit, one mile northwest of the DeLamar Silver Mine, is a Miocene, hot-spring, silver-gold deposit hosted by Middle Miocene, hot-spring sinter, by hydrothermal breccia, and by an underlying porphyritic rhyolite. The ore body is exposed at the surface and probably contains more than one million tons of 3.85 oz./ton Ag and .02 oz./ton Au. The deposit is at the site of a "fossil" geothermal system, as inferred from the geology, mineralogy, and geochemical characteristics of active, high-temperature ($150^{o}C.$), precious-metal-depositing, geothermal systems. The mineral deposition was about 16 m.y. ago, probably from deep-circulating, hydrothermal solutions along an active, northwest-trending fault. The area was influenced by extensional tectonics of the Basin and Range and Snake River Plain provinces.

The ore mineralogy of the Milestone deposit includes naumannite, Se-rich pyrargyrite, and gold, suggesting a mineralization temperature above $192 \pm 5^{o}C$. The hydrothermal alteration and gangue minerals include quartz and subordinate illite, montmorillonite, kaolinite, pyrite, marcasite, and jarosite. Rock geochemistry indicates that Au, Ag, Se, As, Sb, Hg, Mo, Ni, Cr, and Cu are probably useful pathfinders for precious metals in the Silver City-DeLamar district.

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INTRODUCTION

The Milestone area, a joint venture property of NERCO Minerals Company and Superior Oil Company, is in the Owyhee Mountains of southwestern Idaho, 50 miles southwest of Boise, Idaho, and one mile northwest of the DeLamar Silver Mine. The Milestone deposit is a Miocene-aged, "fossil" hot-spring, silver-gold deposit hosted by hot-spring sinter, by hydrothermal rhyolite-breccia, and by an underlying, porphyritic rhyolite. The ore body is exposed at the surface and probably contains more than one million tons with 3.85 oz./ton Ag and .02 oz./ton Au. Evidence of the geology, mineralization and geochemistry of the Milestone area has permitted conclusions to be drawn about the geologic setting and mineralization history, and enabled the formation of a model for the Milestone deposit.

HOT-SPRING AREAS AND EPITHERMAL ORE DEPOSITS

A hot-spring area is the surface expression of a geothermal system (White and others, 1971). It includes hot-springs, fumaroles, and hydrothermally altered rocks. A geothermal system includes a local heat source in the earth's crust, such as an igneous intrusion, and the rocks and water affected by the heat (White and others, 1971). A geothermal system with hot, circulating water is called a hydrothermal system (Ellis, 1979). The outer parts of a hydrothermal system involve the deep, convective downflow of cold, recharging water which rises when heated. Where an impermeable cap rock exists, heated water may be stored near the surface. Hot water generally boils upon rising when the vapor pressure exceeds the hydrostatic pressure. If the vapor pressure exceeds the lithostatic pressure, a hydrothermal eruption occurs because of explosive flashing of water to steam. The steam and water expelled from fumaroles and springs are recirculated. Ellis (1979) indicates that most geothermal fields are associated with recent silicic volcanic rocks and structures due to tectonic activity.

An epithermal ore deposit is a near-surface deposit formed in a hydrothermal system under low to moderate pressure and a temperature less than 300°C. Mineralized "fossil" geothermal systems are analogous to some active geothermal systems such as Steamboat Springs, Nevada and Broadlands, New Zealand that are related to volcanic centers and that are depositing significant amounts of precious and base metals, both at the surface and at depth (White and others, 1971; White, 1981). Geothermal systems most likely to deposit precious metal ore generally have temperatures above 150°C. (Blakestad and Stanley, 1984).

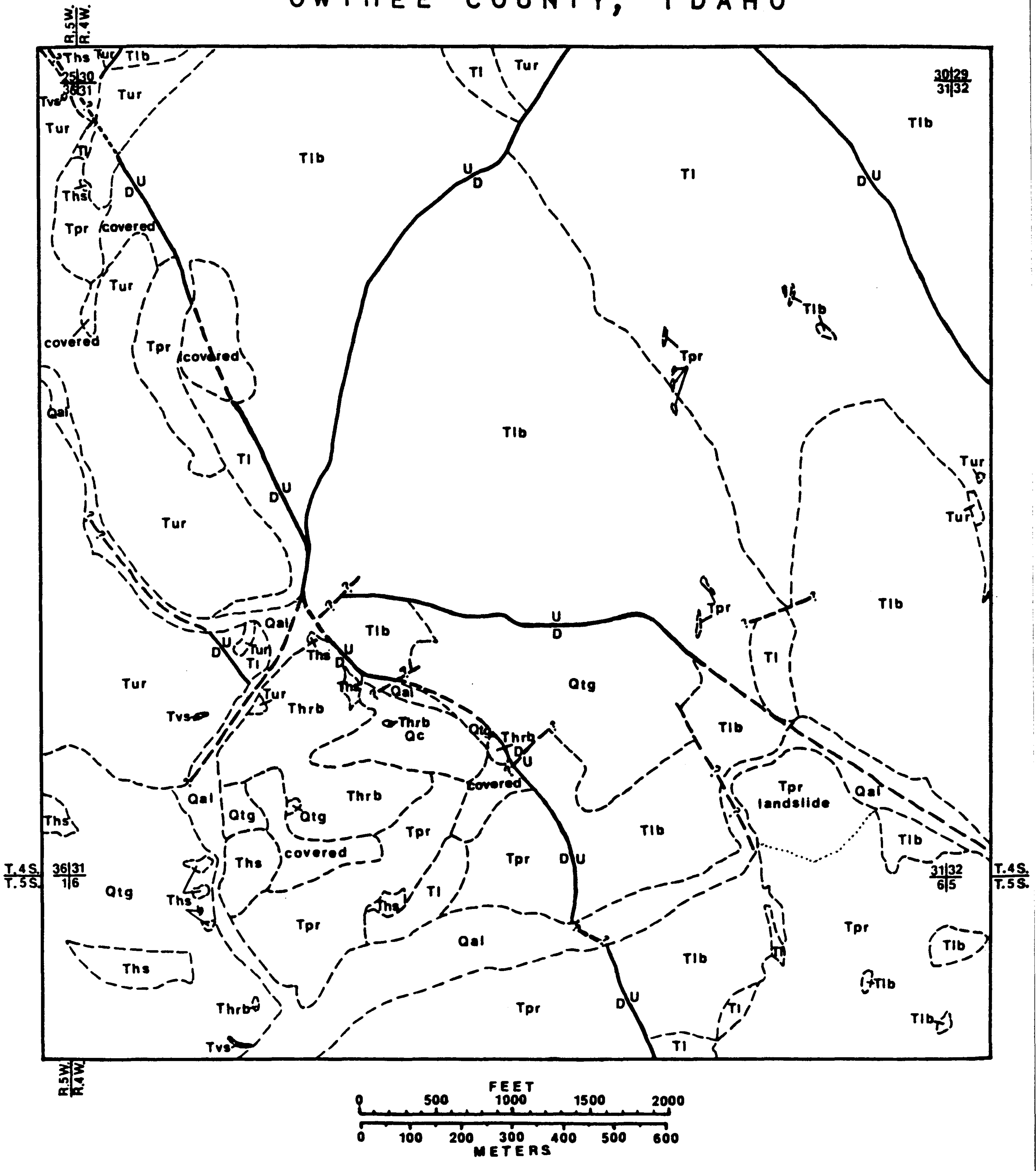
PREVIOUS INVESTIGATIONS

Previous investigations in the Silver City-DeLamar region are included in papers and maps by Lindgren (1900), Lindgren and Drake (1904), Piper and Laney (1926), Asher (1968), Pansze (1975), Ekren, McIntyre, Bennett, and Malde (1981), Thomason (1983), Halsor (1983), and Bonnichsen (1983). Previous work in the DeLamar area is included in company reports at the DeLamar Silver Mine by W. Rodgers, J. Knox, T. Weitz, K. Moss, W. Strowd, M. Beebe, and R. Hagni.

THE GEOLOGY OF THE MILESTONE AREA

The geology of the Milestone area (Figure 1) involves a sequence of Middle Miocene volcanic rock units on a basement of Silver City granite which crops out about 1000 feet to the northeast of the map area. A major, high-angle, westward-dipping, northwest-trending, normal fault, called the Northwest Fault, can be traced from the DeLamar Silver Mine, through the Milestone area to the northwest. Northwest-trending, northeast-trending, and east-west-trending faults are also common. The basalt-rhyolite assemblage of the area is characteristic of an extensional tectonic setting (Christiansen and Lipman, 1970; Lipman and others, 1970). The area was influenced by rifting in the Snake River Plain and extension in the Basin and Range tectonic provinces during the Miocene

GEOLOGIC MAP OF THE MILESTONE AREA, OWYHEE COUNTY, IDAHO



(Pansze, 1975). Eruptive centers for the volcanic rocks of the region are many exogenous domes, plugs and dikes (Pansze, 1975).

A lower basalt unit (Tlb) overlies the Silver City granite and is exposed to the east of the Northwest Fault. Overlying the lower basalt is a latite unit (Tl) which may have a source at a dike which cuts basalt in the eastern part of the map area. Stratigraphically overlying the latite is a porphyritic rhyolite unit (Tpr) with which much of the mineralization of the area is associated. An upper rhyolite unit (Tur) overlies the porphyritic rhyolite. It is interbedded locally with volcaniclastic sediment (Tvs). The volcaniclastic sediment also underlies some terrace gravels (Qtg). Terrace gravels cover a large hill in the central map area. A hydrothermal rhyolite-breccia unit (Thrb; described subsequently) crops out in the central part of the map area and is a major host for the mineralization. Hot-spring sinter (Ths) partially overlies the hydrothermal breccia at the main knob outcrop (Figure 1), a distinct topographic feature, and is at other scattered localities. Colluvium (Qc) and alluviun (Qal) exist along the Northwest Fault and alluvium is also present along the creeks.

Hydrothermal Rhyolite-Breccia

The hydrothermal rhyolite-breccia is either a matrix-supported type of breccia or a clast-supported type of breccia. The matrix-supported, hydrothermal breccia is exposed throughout most of the breccia zone. It has randomly oriented, rounded to subangular clasts of various sizes and various rock units including porphyritic rhyolite, upper rhyolite, hot-spring sinter, and minor latite. The clasts are surrounded by a gray or brown chalcedonic matrix containing pyrite and marcasite and vugs with drusy or lamellar quartz. The clasts are commonly rounded due to the effects of brecciation and replacement by silica. Where the sulfides in the breccia are oxidized, the rock is a brown color around clasts and where fractured. The clast-supported, hydrothermal breccia appears to be a surface feature overlying part of the matrix-supported breccia. It is exposed on the north and west parts of the main knob outcrop, and also at an outcrop 100 feet to the west of the main knob. The clast-supported breccia has randomly oriented, angular to subrounded clasts of various sizes which are surrounded and held together by a thin coating of light yellow silica, leaving open space between the clasts. The clasts are hot-spring sinter, and lesser amounts of porphyritic rhyolite and upper rhyolite. The minor cement consists of microcrystalline quartz, lamellar quartz, pyrite and marcasite. The hydrothermal breccia contains numerous silicified wood fragments, indicating that the deposit formed at the present topographic surface.

Hot-spring Sinter

The hot-spring sinter is bedded and forms a terrace about 280 feet long, 120 feet wide, and 30 feet thick at the main knob outcrop where it overlies the hydrothermal breccia. The siliceous sinter is a host rock for part of the Milestone deposit. The sinter is irregularly layered, multi-colored chalcedony. Much of it is bedded with sinter fragments or brecciated. It also contains numerous silicified wood fragments. The sinter beds strike N35°W, dip 45°NE, and were probably originally deposited within 20° of horizontal. Post-depositional tilting of the main knob outcrop has caused the hot-spring sinter to dip northeast toward the Northwest Fault.

THE MINERALIZATION OF THE MILESTONE AREA

A surface projection of the Milestone ore body shows it to be V-shaped. It is hosted by the hydrothermal breccia, by the underlying, silicified, porphyritic rhyolite, and by the hot-spring sinter. The deposit is associated with a flexure in the Northwest Fault. The east end of the ore body plunges under the colluvium. Across the deposit at the main knob, in a southwest to northeast direction, the ore body is cone-shaped and widens upward. A high-grade ore zone is localized within a lower grade ore zone. Silt and sandy silt were deposited between the Northwest Fault and the main knob outcrop. The age of mineralization is about 16 m.y. (Pansze, 1975; Strowd, oral communication, 1984).

Ore and Gangue Mineralogy and Hydrothermal Alteration

The ore mineralogy consists mainly of naumannite (Ag_2Se), selenium-rich pyrargyrite ($Ag_3Sb(S,Se)_3$), and gold (Au) which is probably micron-sized, native gold. Quantitative electron microprobe data shows the naumannite to be relatively pure with little S substituting for the Se. The Se-rich pyrargyrite is shown by quantitative electron microprobe data to have a stoichiometric formula of Ag_3SbS_2Se. An isomorphous substitution of Se for S in the pyrargyrite structure is assumed. The mineral indicates a temperature of formation of at least 192 $\pm 5^{o}C$. (Keighin and Honea, 1969; Chang, 1963), otherwise, the monoclinic polymorph pyrostilpnite would have formed. However, it is not known how the Se in the pyrargyrite structure may affect this temperature constraint.

Naumannite occurs as anhedral grains less than .15 mm in size, and often occurs as inclusions in Se-rich pyrargyrite. Se-rich pyrargyrite occurs as anhedral grains less than .55 mm in size. It commonly rims naumannite grains, indicating that it was deposited later than the naumannite.

The gangue minerals in the Milestone deposit are quartz, including predominantly chalcedony, and also lamellar quartz and clear, crystalline, medium- to fine-grained quartz which lines vugs. Pyrite and marcasite are the most prevalent metallic gangue minerals. Hydrothermal alteration minerals such as illite, montmorillonite, and kaolinite indicate somewhat acidic and oxidative conditions due to boiling of hydrothermal fluids and fluid mixing (Berger and Eimon, 1982; Schoen and others, 1974). Silicification and limonitization are pervasive alteration types.

THE GEOCHEMISTRY OF THE MILESTONE AREA

A geochemistry study of the Milestone area involved element analyses for 101 surface rock samples and 89 core rock samples from an inclined, 450-foot deep, diamond drill hole in the main knob outcrop. The surface rock samples include 87 from mineralized outcrops of hydrothermal breccia and siliceous sinter, and 14 from outlying outcrops.

High element values in many of the samples made it impractical to establish background values using these analyses. Instead, the average values of the elements were compared with the average element values for granite because of the equivalent chemistry and little available data for average element values in silicic volcanic rocks. An element mean greater than the mean for granitic rocks may be considered anomalous, and an element mean more than twice that for the granitic rocks may be considered very anomalous.

The means of elements in the hot-spring sinter and hydrothermal rhyolite-breccia show that Ag, Au, As, Sb, Se, Hg, Mo, Ni, Cr, and Cu are very anomalous elements (Table 1). Nonanomalous elements include Mn, Sn, Zn, Te and Tl. Estimates of concentration factors for mineralized outcrop samples compared with the average element values for granite are also shown in Table 1. Silver shows a concentration factor over 900 times the the granite average. It is determined that there are no significant differences of mean values for Au and Ag in the matrix-supported, and clast-supported, hydrothermal breccias. Mercury values are somewhat higher in the clast-supported breccia. Correlations of elements include Ag with Se in the clast-supported breccia and Au with As and Au with Sb in the siliceous sinter. The values of these pairs also fit simple linear regression lines at a .05 level of significance.

The results of depth distribution profiles for elements in the Milestone deposit show that Ag, Hg, and Sb increase with depth, although Ag and Hg decrease abruptly at a clay-altered zone at the bottom of the core. Gold values decrease with depth and then increase abruptly at the bottom of the core. Arsenic and Tl values are variable with depth. Correlations of elements in the core include Au with Se in the hydrothermal breccia and Ag with Se in the porphyritic rhyolite. Pathfinder elements for precious metals, based upon a direct association with Au and Ag determined by anomalous values, element correlations, and distribution associations, are determined to be Au, Ag, As, Sb, and Se on a detailed scale and Hg, Mo, Ni, Cr, and Cu on a regional scale. Mercury and Mo are generally

Table 1. Average Geochemical Element Abundances for Granite Standards and Average Element Values for Specific Rock Types in the Milestone Area.

Average Element Abundances in Granite - PPM	Average Element Values (PPM) of Rock Types and Number of Samples			C. F.
	Ths (11)	Thrb(ms) (57)	Thrb(cs) (27)	
Au - .013	.27	.18	.22	17
Ag - .042	26	31	27	915
Hg - .10	.58	2.05	4.67	24
As - 1.0	57	92	47	65
Sb - .2	15	26	29	117
Se - .1	13.2	11.7	16.4	138
Tl - 1.34	.95	1.60	1.16	1
Te - .03	<.03	<.03	<.03	NC
Zn - 52.3	<52.3	<52.3	<52.3	NC
Mn - 332.5	186	215	207	1
Cr - 10.8	66	65	64	6
Cu - 11.2	44	47	42	4
Mo - 2.7	12	17	18	6
Ni - 3.0	24	32	32	10
	Ths (2)	Thrb(ms) (8)	Thrb(cs) (6)	
Sn - 2.9	<2.9	<2.9	<2.9	NC

Data Source - 95 Outcrop Samples from the Milestone Area.
U.S.G.S.-Atomic Absorption Analyses- Au, As, Sb, Se, Tl, Te, Zn
U.S.G.S.-Semiquantitative Emission Spectrographic Analyses- Ag, Mn, Cr, Cu, Mo, Ni
DeLamar Silver Mine Laboratory- Atomic Absorption Analyses- Hg
CHEMEX Labs, Inc.- Sn

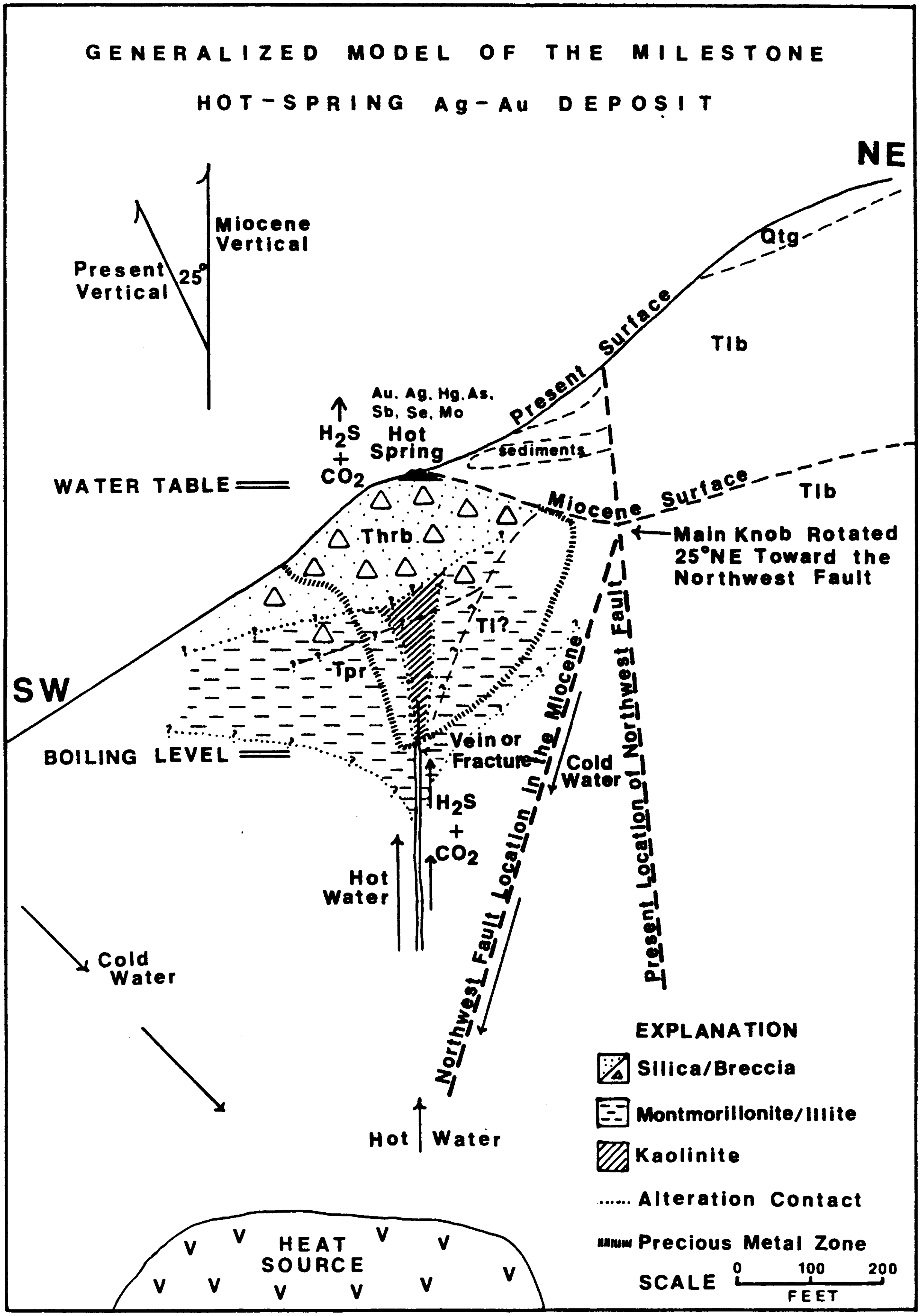
Ths - Hot-spring Sinter
Thrb(ms) - Matrix-supported, Hydrothermal Rhyolite-Breccia
Thrb(cs) - Clast-supported, Hydrothermal Rhyolite-Breccia
C. F. = Concentration Factor for Thrb values plus Ths values
NC = Not Calculated

References for average element abundances in granite:
(Carmichael, 1982, p. 112)
(Mason, 1952, p. 45)
(Beus and Grigorian, 1975, p. 8)
(Flanagan, 1976, p. 171)

associated more with Ag than with Au. No direct correlations could be found for Hg, Mo, Ni, Cr, or Cu with either Au or Ag, although they are generally associated with the precious metals.

MODEL FOR THE MILESTONE DEPOSIT

An epithermal hot-spring model (Figure 2) is consistent with the mineralization and the geologic and geochemical characteristics of the Milestone deposit. The model is based on models for hot-spring-related, epithermal Au-Ag deposits by Berger and Eimon (1982) and Buchanan (1981) and on descriptions of hot-spring deposits by Bonham and Giles (1983). The Northwest Fault is a major structure along which the precious metal mineralization occurred. The hydrothermal explosion breccia and hot-spring sinter are evidence for explosive pressure release of the system and boiling of the hydrothermal fluids. The bedded, hot-spring sinter containing silicified wood fragments suggests that the water table was at or near the surface and the system discharged at the surface. The siliceous sinter is enriched in Au, Ag, As, Sb, Se, Hg, Mo, Ni, Cr, and Cu. Many mobile elements in the sinter are typical of the hot-spring type of epithermal deposit. A magmatic intrusion or associated volcanic rocks was probably the local high heat source. Continuous recharging of meteoric water into an area of high heat flow, and boiling of hydrothermal fluids



GENERALIZED MODEL OF THE MILESTONE
HOT-SPRING Ag-Au DEPOSIT
NE
SW
Miocene Vertical
Present Vertical
25°
Qtg
Tlb
Present Surface
Au, Ag, Hg, As, Sb, Se, Mo
H2S + CO2
Hot Spring
sediments
WATER TABLE
Miocene Surface
Main Knob Rotated 25°NE Toward the Northwest Fault
Thrb
Tl?
Tpr
BOILING LEVEL
Vein or Fracture
Cold Water
H2S + CO2
Hot Water
Northwest Fault Location in the Miocene
Present Location of Northwest Fault
Cold Water
Hot Water
HEAT SOURCE
EXPLANATION
Silica/Breccia
Montmorillonite/Illite
Kaolinite
Alteration Contact
Precious Metal Zone
SCALE
0
100
200
FEET

allowed for the formation of a silica cap and alteration of the rocks to clays (Berger and Eimon, 1982; Ellis, 1979). Montmorillonite and illite are predominant shallower in the deposit than kaolinite which occurs deeper. The mineralization is near-surface, and the boiling level was below the precious metal zone.

MINERALIZATION HISTORY OF THE MILESTONE DEPOSIT

The mineralization history of the Milestone area probably involved concurrent tectonic activity along the Northwest Fault and hydrofracturing and flashing of superheated, meteoric water to steam. These caused explosive pressure release, hydrothermal brecciation, and boiling of the hydrothermal fluids. The release of H_2S and CO_2 caused an increase in the activity of sulfur (HS^-,S^{2-}; Barnes, 1979); and possibly the activity of Se) and the formation of metal-carrying thio-complexes (Weissberg, 1969). Boiling in the hydrothermal system and also mixing with meteoric water caused oxidation of the hydrothermal fluids. Oxidation was probably an important process for hydrothermal alteration and deposition of metals. H_2SO_4 produced by the oxidation of H_2S (Buchanan, 1981) was probably important for the hydrothermal alteration. Oxidation is also important for the destruction of metal-carrying thio-complexes and deposition of Au, Ag, and other mobile elements and gangue minerals (Buchanan, 1981; Weissberg, 1969).

The hydrothermal alteration and mineral deposition caused resealing of the hydrothermal system with clays and silica. Recurrent hydrofracturing and tectonic activity would begin this process again. This process was cyclic and was repeated periodically. Evidence for this includes the complex hydrothermal breccia containing clasts of breccia, the brecciated hot-spring sinter, sinter fragments included in the hydrothermal breccia, the rounding of breccia clasts and their replacement by silica, and the extensive mineralization and hydrothermal alteration.

CONCLUSIONS

1. The Milestone deposit is at the site of a "fossil" geothermal system, as suggested by the geology, mineralogy, and geochemical characteristics of active, high-temperature (150^{o}C.), precious-metal-depositing geothermal systems.
2. The Milestone deposit is associated with a sequence of Middle Miocene, silicic volcanic flows and domes in an area of high heat flow. The mineralization was associated with a hydrothermal convective cell along an ore-localizing, tectonically active, northwest-trending fault.
3. An epithermal hot-spring model is consistent with the mineralization and geologic and geochemical characteristics of the Milestione deposit. The hot-spring sinter indicates that the water table was at or near the surface and that a

hydrothermal system discharged at the surface. Wood fragments in the siliceous sinter and hydrothermal breccia suggest that the ore deposition was near the present topographic surface. The hydrothermal breccia is evidence for a steep, near-surface, temperature gradient and explosive pressure release of the hydrothermal system.

4. The mineralization history of the Milestone area involved tectonic activity along the Northwest Fault and hydrofracturing and flashing of water to steam. This caused excessive pressure releases, hydrothermal brecciation, boiling of hydrothermal solutions, and mineral deposition. The Se-rich pyrargyrite signifies a temperature of ore deposition of at least 192 $\pm 5^{o}C$. The hydrothermal alteration, including silica and clays, and the mineral deposition indicate an oxidative environment due to boiling of the fluids and an influx of meteoric water. The geochemical suite of Au, Ag, Se, As, and Sb is a useful guide to precious metal ore. Significant regional pathfinders are Hg, Mo, Ni, Cr, and Cu.

5. Clues to the presence of an epithermal hot-spring deposit in the Milestone area include the hydrothermal breccia, the overlying, hot-spring sinter, the complicated structure, the ore and gangue mineralogy, the hydrothermal alteration, pyrite and marcasite, lamellar quartz, the geochemical signature, the element associations, and the general silicic volcanic rock assemblage.

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