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INDICATIONS OF MINERAL ZONING IN A FOSSIL HYDROTHERMAL SYSTEM AT THE
MEAGER CREEK GEOTHERMAL PROSPECT, BRITISH COLUMBIA, CANADA,
FROM INDUCED POLARIZATION STUDIES

by

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ABSTRACT

By measuring the induced-polarization parameters m (chargeability) and τ (time-constant) we have found evidence that the center of a presumed fossil hydrothermal system at Meager Creek, British Columbia, lies south of the main manifestation of the present-day convective hydrothermal system. What implication this finding has for development of the present-day system is unknown. However, some of the fractures formed during the development of the fossil hydrothermal system may serve as conduits for fluids of the present-day system. The analysis is limited by the lack of availability of a good subsurface distribution of core samples. Nevertheless, a surface induced-polarization survey is expected to yield information about the geometry of the fossil system. Such knowledge would have implications not only for Meager Creek but for other hydrothermal systems of Cascades volcano type.

INTRODUCTION

Meager Mountain, the northernmost volcano in the Cascade and Garibaldi volcanic belts of the U.S. and Canada has been the site of intensive geothermal exploration since 1973 (Fairbank et al., 1981; Souther, 1976). This Pliocene-to-Recent volcano is located approximately 150 km north of Vancouver in the Coast Mountains of southwestern British Columbia. Geothermal exploration efforts during the past ten years have been concentrated primarily on the southern flank of Meager Mountains, 8 km from an area of hot springs which discharge into Meager Creek (Figure 1). Fifteen core holes to depths to 1 140 m and three 3 000-3 500 m rotary wells have been drilled (Figure 2). One well, MC-1, is capable of sustained steam production.

Cuttings and core from the wells have been studied petrographically and chemically (Moore et al., 1983, 1985). These data indicate that the plutonic and metamorphic rocks underlying Meager Mountain were extensively altered prior to the onset of volcanic activity and development of the modern day geothermal system. The geochemical characteristics of these rocks are typical of those found in the zones of propylitic and sericitic alteration that characterize the outer portions of many porphyry-copper systems (Lowell and Guilbert, 1970; Rose and Burt, 1979).

This paper presents new data on the electrical properties of the altered rocks. Induced electrical polarization spectra were obtained on 25 core samples from six of the shallow drill holes and from core taken during drilling of the three deep wells. The results of these measurements have been used to locate more accurately the position of the geothermal wells relative to the principal features of the porphyry system. It seems to us that any knowledge we can gain of the porphyry, i.e. fossil-hydrothermal, system should have a

HOT SPRINGS

▲ 500
59.5°C
Pebble Cr.

Flow in liters per minute
Temperature
Name

COLD SPRINGS

● 200
Ca

Flow in liters per minute
Dominant cation in sinter

FOSSIL SPRINGS

○ Si

Dominant cation in sinter

VENT

★ 4.2

Known, inferred; age in Ma

Figure 1.

Figure 2.

significant impact on understanding the present-day hydrothermal system.

Indeed, it is conceivable that the fractures of the fossil system may have reopened and therefore may now serve as conduits for the present-day system.

GEOLOGIC RELATIONSHIPS AND ROCK DESCRIPTIONS

Pre-volcanic rocks exposed near the base of Meager Mountain and penetrated in the drill holes consist of metamorphic and intrusive rocks of the Mesozoic Coast Range Complex, although intrusive rocks as young as Tertiary are also present (Fairbank et al., 1981; Reed, 1979). Locally, the basement rocks are intruded by dikes of the Mount Meager Volcanic Complex. The most recent volcanic activity produced the Bridge River Ash $2\,440 \pm 10$ years B.P. from a vent on the north side of Meager Mountain (Nasmith et al., 1967).

Dikes related to the active volcanism intrude the basement complex and range from silicic to basic in composition although intermediate compositions predominate. The dikes contain sparse phenocrysts of plagioclase, and less commonly biotite, hornblende, pyroxene, or quartz. Locally intense alteration of the dikes suggests that fractures associated with them have been important conduits for the movement of the geothermal fluids.

The basement rocks consist primarily of regionally metamorphosed quartz diorite characterized by the mineral assemblage quartz + hornblende + epidote + biotite + andesine + opaques. Propylitic alteration is superimposed on the metamorphic assemblage. This alteration assemblage consists of chlorite + illite + epidote + Fe-Ti oxides. Veins containing quartz, epidote, potassium feldspar, calcite, fluorite and the sulfides pyrite, chalcopyrite, sphalerite and galena occur sporadically in the metamorphosed rocks.

At depths below 2 500 m (vertical depth) in MC-3 and at depths greater than 1 600 m (vertical depth) in MC-1, the metamorphic rocks are intruded by fresh quartz diorite. The quartz diorite consists of a porphyritic phase containing phenocrysts of plagioclase and biotite, and an equigranular phase

characterized by hornblende. These rocks appear to form the core of the porphyry system.

The elemental association Hg + Cu + Zn + Pb + Ba + K is diagnostic of the hydrothermally altered basement complex. Figures 3 and 4 illustrate the distribution of K and Cu in the shallow drill holes. The diagrams were prepared by plotting the distribution of samples whose concentration differed from local background values by more than one standard deviation. The threshold values for the two lower intervals are mean plus 1 standard deviation and mean plus 2 standard deviations. The highest interval contains samples within the upper 2-1/2 percent of the data. The figures display a strong correlation between K and Cu. In the altered rocks, K is present in sericite, whereas Cu occurs mainly in chalcopyrite. Chemical analyses of the volcanic dikes, hot spring deposits and geothermal scales indicate that these elements are present only in low concentrations and that they have not been significantly remobilized by the present geothermal system.

Inspection of Figures 3 and 4 shows that K and Cu are concentrated primarily near the base of M-8 and in the lower third of M-10. Similarly altered rocks are found in the deep wells M-1, M-2 and M-3. The absence of significant enrichments in M-9 and M-12, on the other hand, suggest that alteration may not extend south of Meager Creek. The apparently restricted distribution of these elements suggests that their abundance has been strongly controlled by structure.

Despite widespread evidence of fracturing and brecciation in the altered rocks, the structural features of the field and their relationship to the alteration patterns have not yet been established. In part this reflects the extensive surficial cover in the area, and in part the lack of suitable marker

Figure 4.

horizons at depth. Fairbank et al. (1981) concluded that northerly and easterly trending faults are the dominant fault directions on the southern flank of Meager Mountains. The striking alignment of volcanic vents across Meager Mountains (Figure 1; Reed, 1979), however, suggest that the northerly trending faults are a reflection of a deep-seated zone of weakness beneath the volcano. Consequently, they may have been of particular significance in localizing both the past and present hydrothermal systems.

THE LOWELL-GUILBERT MODEL OF A PORPHYRY SYSTEM AND ITS IP SIGNATURE

Figure 5 portrays the Lowell and Guilbert (1970) model of a porphyry copper system. The propylitic zone is typically low in pyrite and other electrically polarizable minerals. The phyllic zone contains abundant pyrite, sometimes up to 20 percent, and hence is highly polarizable. An argillic zone, sometimes present between the phyllic and propylitic zones, is polarizable due to the presence of pyrite plus kaolinite, montmorillonite, and other clay minerals. The moderately polarizable chalcocite-bornite-chalcopyrite ore occurs as a shell localized just inside the potassic core. The inner part of the core is relatively barren and only slightly polarizable. If such a porphyry system is eroded to, say A-A' of Figure 5, then the classical IP plan view of Figure 6 occurs. The pyrite halo is clearly visible in the IP data but the location of the ore must be inferred from this data by reference to the Lowell and Guilbert model of Figure 5. On the other hand, if erosion has only proceeded to level B-B' of Figure 5, then the plan view of Figure 7 occurs; the response of the cap of pyrite obscures the response of the shell of mineralization within it. Many variants on these two patterns may be seen for the classical Lowell and Guilbert model (Ward, 1982). The model of Lowell and Guilbert was derived from a reconstruction of the San Manuel-Kalamazoo quartz monzonite system which had been tilted by 70 degrees and then faulted roughly along the overturned axis.

The mineral zoning of the Lowell and Guilbert model is typical of porphyry systems occurring in continental interiors such as that of the southwestern U.S.A. When porphyries develop in marine-sediment environments of coastal margins, then the compositions of the intrusive and the mineral zoning will be different. The diorite model of Hollister (1975) pertains to such environ-

Figure 5.

Figure 6.

Figure 7.

ments. The Afton deposit in British Columbia and the Skouries deposit in Greece are of this type. The occurrence of a pyrite halo still dominates the induced polarization signature for these deposits. When porphyries of either the Lowell and Guilbert or Hollister descriptions invade limestones, then skarn mineralization occurs in the vicinity of the intrusive-limestone contact. This results in additional zones of polarizable mineralization which may be rich in lead-zinc, iron-copper, or both (Einaudi et al., 1981). These additional zones of mineralization enlarge the size and change the pattern of the zone of polarizable materials. Also, when a porphyritic intrusive invades a batholith, the pyrite halo may be subdued and only the economic mineralization will produce a significant IP anomaly (Ward, 1982). Finally, when a mineralizing porphyry invades a highly faulted terrain, the IP patterns in plan view are apt to be elongate (Pelton and Smith, 1976).

PURPOSE OF STUDY

The Meager Creek hydrothermal prospect is located in rugged terrain of rain forests and glaciers in which earth slides are common. Hence, performing electrical resistivity and IP surveys, is extremely difficult (Shore, 1978). Thus we have chosen to make laboratory measurements on core samples in order to ascertain if IP may contribute to delineation of the fossil hydrothermal system. If these pilot laboratory experiments provide useful information on the trends of mineral zoning in the fossil hydrothermal system, then field IP surveys may be warranted. The implications for application of IP surveys in other convective hydrothermal systems of the Cascades are unknown. We maintain, however, that fundamental studies such as this are essential if we are ever to arrive at exploration architecture suitable for delineation of hydrothermal systems of the Cascades volcanoes.

PROCEDURES

The samples were selected on the basis of their petrologic characteristics and spatial distribution in order to correlate the induced electrical polarization (IP) measurements with the porphyry system. Table 1 shows that the samples represent the various rock types in the Meager Creek area. The variation in the intensity of alteration in Table 1 reflects the fact that the different zones in the hydrothermal system are also represented. The sample location map (Figure 8) confirms that the samples cover a sparse distribution of the study area; additional core samples were not available.

The core samples were cut into parallel-faced slabs for mounting in a standard four-electrode sample holder. The geometric factor, the ratio of area to thickness, ranged from 0.15 to 0.50 m. They were then vacuum-saturated and measured at NaCl concentrations of 0.05, 0.15, 0.30 and 0.45 molar. These NaCl concentrations were chosen by calculating the resistivity of the in-situ pore fluid as derived from water chemistry.

Measurements of the amplitude and phase of electrical resistivity were made at binary frequency steps over the range of 1/256 to 1 024 Hz using an instrument manufactured by the Zonge Engineering and Research Organization. The data reduction and amplitude-drift correction was performed on an Hewlett Packard 9825A desktop computer. From our experience the drift correction yielded accurate amplitude if the total drift was kept below 5 percent of the amplitude. The drift was kept to a minimum by letting the temperature of the sample holder equilibrate to room temperature for a period of three to four hours prior to measurement.

TABLE 1 SAMPLE LOCATIONS, DESCRIPTIONS, MINERALOGY, AND IP PARAMETERS

SAMPLE NUMBER	ROCK TYPE	Smectite	Illite- Smectite	Illite	Chlorite	Quartz	K- feldspar	Epidote	Calcite	Iron Oxides	Pyrite	Cpy.	Bornite	Intensity	m				T			
															For mol. concentration							
															.05	.15	.30	.45	.05	.15	.30	.45
4 (M-12-190)	dike	X							X					S		.090	.055	.030		.090	.056	.061
5 (M-12-90)	m.q.d	X	X	X	X			X	X	X				W		.21	.15	.13		.100	.047	.038
6 (M-12-150)	m.q.d			X	X			X	X					M								
7 (M-10-280)	dike		X	X	X	X			X	X				S								
8 (M-10-480)	h.b			X	X				X		X			S								
9 (M-10-140)	m.q.d	X		X	X			X	X	X				W								
10 (M-7-130)	dike	X	X	X	X	X			X	X				S	.18	.17	.12	.10	.035	.031	.024	.021
11 (M-7-330)	m.q.d			X	X			X	X	X	X			M								
12 (MC-1-1539.3)	m.q.d			X	X	X		X	X	X	6	X		S	.32	.30	.25	.25	.098	.065	.030	.030
14 (MC-3-1380.5)	m.q.d			X	X			X		X				M								
15 (MC-3-2369.8)	q.diorite			X	X						7	3		M	.20	.17	.13	.08	.710	.180	.100	.080
16 (MC-1-820)	m.q.d			X	X	X		X	X		4	X	2	S		.24				.090		
17 (MC-1-2030.2)	q.diorite											X		W		.14				.037		
18 (MC-1-3039.7)	q.diorite			X	X			X	X		X			W								
19 (MC-2-2626.2)	m.q.d			X	X	X	X	X	X					W								
20 (MC-2-3501.5)	m.q.d				X			X						W								
21 (MC-2-2220.4)	m.q.d			X	X	X	X	X			X	X		M		.12				.017		
22 (MC-1-2437.1)	q.diorite			X	X			X				X		W								
23 (MC-3-3500.7)	q.diorite				X									W								
24 (MC-3-2871.0)	m.q.d			X	X				X		5			M		.11				.024		
25 (MC-3-1857.3)	m.q.d			X	X			X			X			W

Figure 8.

RESULTS

Nine of the twenty-three samples measured displayed appreciable chargeabilities (m), as displayed in Figure 8, for NaCl concentrations ranging from 0.5 to 0.45. The chargeabilities (m), the time constants (τ), for a concentration of NaCl (molar) of 0.15 are all plotted in Figure 8 opposite each sample measured. The values of high chargeability all occur in an arcuate zone which trends from northeast in the west to southeast in the east, and which is therefore concave to the south. Clearly the sampling is not as thorough as one might wish, but this is solely controlled by *available* core. The chargeabilities range from $m = 0.09$ to $m = 0.30$ with a mean of 0.18. The time constants range from 0.017 to 0.180 with a mean of 0.07. There is no systematic geographic pattern to either m or τ .

A typical example of resistivity spectra phase and amplitude is shown in Figure 9. The amplitude data has been normalized by the amplitude at the lowest frequency and the phase is plotted on a logarithmic scale. The amplitude of the resistivity decreases with increasing frequency as is typical of an induced polarization response. The phase has a characteristic IP mid-frequency ($\sim 10^{-1}$ Hz) high and a high frequency "phase tail" which is attributed to the effect of the sample-holder.

The data was modeled using a Cole-Cole dispersion multiplied by an asymptotic phase expression which represents the high-frequency "phase tail". The mathematical expression for the model is

$$Z(\omega) = R_0 \left[1 - m \left(1 + \frac{1}{1 + (i\omega\tau_1)^{c_1}} \right) \right] \left[\frac{1}{1 + (i\omega\tau_2)^{c_2}} \right], \quad (1)$$

where

Figure 9.

$Z(\omega)$ = complex impedance ($\Omega \cdot m$)

R_0 = low frequency asymptotic resistivity ($\Omega \cdot m$)

R_∞ = high frequency asymptotic resistivity ($\Omega \cdot m$)

$m_i = 1 - \frac{R_\infty}{R_0}$ = chargeability (dimensionless)

τ_1 = time constant (s)

c_i = frequency dependence (dimensionless)

ω = angular frequency (rad/s)

i = $\sqrt{-1}$

The data was fit to this model using a Marquardt least-squares inversion algorithm. Figure 10 shows the fit to a data set where the dashed line shows the theoretical data of the Cole-Cole model with the effect of the sample-holder removed.

The time constant (τ) and chargeability (m) parameters have been shown (Pelton et al., 1978) to be functions of the particle size and distribution of the sulfide mineralization as well as the ionic concentration of the pore fluid. In an effort to determine the effect of pore fluid concentration on the time constant and the chargeability, samples were measured at different pore fluid concentrations of the NaCl. The results are plotted in Figures 11 and 12. The chargeability and the time constant both decrease with increasing pore fluid concentration, as expected. Without knowing the precise fluid chemistry underground, we cannot say which are the correct values of chargeability and time constant to use in subsequent analysis. However, it may be seen that for each concentration the chargeabilities and time constants remain relatively the same for each sample. Thus when we later say that the chargeability of a sample is high, intermediate, or low, it refers to any concentration within the range studied.

Figure 10.

Figure 11.

Figure 12.

The rock parameters which contribute to chargeability and time constant are the grain size, volume percent of polarizable minerals and the mineralization texture. The functional relationships of each of these are shown in Figures 13 and 14 (Pelton et al., 1978). Both the time constant and the chargeability increase as the volume percent of polarizable minerals increase. The same plot demonstrates that increasing the grain size increases the time constant but has little effect on the chargeability. The texture of the mineralization has a strong influence on the chargeability in that the chargeability for disseminated textures ranges from 0.1 to 0.5 and for veinlet textures from 0.5 - 1.0. The time constants and chargeabilities for the textures of the Meager Creek samples show good agreement with the results of Pelton et al. (1978).

The chargeabilities plotted on the plan map (Figure 8) and cross-section (Figure 15) indicate that the zone of high chargeability is a hemispherical shell. Since high chargeability correlates to high pyrite and chalcopyrite volume percent, this hemispherical shell would correspond to the phyllic zone in the Lowell and Guilbert model of a porphyry system. Therefore, data from these samples indicate that at Meager Creek the top of the phyllic zone is at a depth of 500-1 000 m below drill hole MC-1 (see Figure 8).

Figure 13.

Figure 14.

Figure 15.

DISCUSSION

While the limited sampling by drilling is grossly imperfect, one may conclude from Figure 8 that all high values of chargeabilities are contained within an arcuate zone extending from just southeast of the deeper regions encountered by MC-1 and MC-2, and thence southeastward to span the collar of M-12. There is no obvious order of the time constants within this zone, indicating that grain size is variable.

The chargeability and time constant data for borehole MC-1 and MC-2 were projected onto a north-south cross-section through the collar of borehole MC-1. Figure 15 reveals that the values of high chargeability are concentrated in a north-south zone which appears to dip steeply to the south.

CONCLUSIONS

While the knowledge of the distribution of values of IP chargeabilities suffers from insufficient sampling, there is reasonable evidence to suggest that IP has mapped an arcuate zone of IP chargeability that could be related to a fossil convective hydrothermal system. This zone dips to the south, suggesting that the center of the fossil hydrothermal system is to the south of most of the manifestations of the present-day hydrothermal system.

An extensive surface IP survey appears totally warranted as a means of establishing the nature, size and location of the fossil hydrothermal system which the current hydrothermal system pervades.

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REFERENCES

- Einaudi, M., Meinert, L. D., and Newberry, R. J., 1981, Skarn deposits *in* Skinner, B. J., Ed.: Econ. Geol., Seventy-fifth Anniversary Vol., 317-381.
- Fairbank, B. D., Openshaw, R. E., Souther, J. G., and Stauder, J. J., 1981, Meager Creek geothermal project, an exploration case history: Bull. Geotherm. Res. Counc., 10, 3-7.
- Hollister, V. F., 1975, An appraisal of the nature and source of porphyry copper deposits: Min. Sci. Eng., 1, 225-233.
- Lowell, J. D., and Guilbert, J. M., 1970, Lateral and vertical alteration--mineralization zoning in porphyry ore deposits: Econ. Geol. 65, 373-408.
- Moore, J. N., Adams, M. C., and Stauder, J. J., 1983, Geochemistry of the Meager Creek geothermal field, British Columbia, Canada: Trans. Geotherm. Res. Counc., 7, 315-320.
- Moore, J. N., Adams, M. C., and Stauder, J. J., 1985, Geologic and geochemical investigations of the Meager Creek geothermal system, British Columbia, Canada: Proc. Tenth Workshop, Geothermal Reservoir Engineering, Stanford, in press.
- Nasmith, H., Mathews, W. H., and Rouse, G. E., 1967, Bridge River ash and some other recent ash beds in British Columbia: Can. Jour. of Earth Sci., 4, 163-170.
- Pelton, W. H., and Smith, P. K., 1976, Mapping porphyry copper deposits in the Philippines with IP: Geophysics, 41, 106-122.
- Pelton, W. H., Ward, S. H., Hallof, P. G., Sill, W. R., and Nelson, P. H., 1978, Mineral discrimination and removal of inductive coupling with multifrequency IP: Geophysics, 43, 588-609.
- Reed, P. B., 1979, Geology, Meager Creek geothermal area, British Columbia: Geol. Surv. Can. Open File 603, map, legend and descriptive notes.
- Rose, A. W., and Burt, D. M., 1979, Hydrothermal alteration: *in* Geochemistry of Hydrothermal Ore Deposits, Barnes, H. L., ed., John Wiley and Sons, Inc., 173-235.
- Seraphim, R. H., and Rainboth, W., 1976, Poison Mountain, *in* Brown, S. A., Ed., porphyry deposits of the Canadian Cordillera: Can. J. Earth Sci., Spec. Vol. 15, 323-328.
- Shore, G. A., 1978, Meager Creek geothermal system, British Columbia, part III: Resistivity methods and results: Trans. Geotherm. Res. Counc., 2, 593-596.

Souther, J. G., 1976, Geothermal potential of western Canada: Proc. of the 2nd U.N. Sympos. on the Development and Use of Geothermal Resources, San Francisco, 259-267.

Ward, S. H., 1972, Mining geophysics--new techniques and concepts: Mining Congress J., **58**, 58-68.

Ward, S. H., 1982, State of the art and perspective for mining geophysics: Proc. Internat. Sympos. on Applied Geophys. *in* Tropical Regions, Lourenco, J. S., and Rijo, L., Eds.: Brazilian Geophys. Soc. (SBGS), Belem, Brazil, 3-86.

FIGURE CAPTIONS

- Fig. 1. Geologic map of Meager Mountain, British Columbia, Canada.
- Fig. 2. Locations of boreholes at Meager Creek geothermal prospect, British Columbia, Canada.
- Fig. 3. Distribution of K in quartz diorite, Meager Creek geothermal prospect, British Columbia, Canada.
- Fig. 4. Distribution of Cu in metaquartz diorite, Meager Creek geothermal prospect, British Columbia, Canada.
- Fig. 5. The Lowell and Guilbert (1970) model of a porphyry copper system.
- Fig. 6. Plan view of the first-separation, induced-polarization chargeability at Poison Mountain porphyry copper deposit, British Columbia, Canada (after Seraphim and Rainboth, 1976).
- Fig. 7. Plan view of the first-separation, induced-polarization percent frequency effect at the Dungen Creek porphyry molybdenum prospect in British Columbia, Canada (after Ward, 1972).
- Fig. 8. Plan view of zone of high chargeability at Meager Creek geothermal system, British Columbia, Canada (NaCl concentration, 0.15 molar).
- Fig. 9. Typical amplitude and phase spectra fitted to a Cole-Cole model. Data from Meager Creek geothermal prospect, British Columbia, Canada.
- Fig. 10. Measured data (dots), best-fit single Cole-Cole model (dashed line), and Cole-Cole model multiplied by asymptotic phase expression (solid line). Data from Meager Creek geothermal prospect, British Columbia, Canada.
- Fig. 11. Chargeability versus NaCl concentration for core samples from Meager Creek geothermal prospect, British Columbia, Canada.
- Fig. 12. Time constant versus NaCl concentration for core samples from Meager Creek geothermal prospect, British Columbia, Canada.
- Fig. 13. Data from porphyry deposits plotted in chargeability-time constant space. The larger dots indicate high sulfide concentration. Superimposed on the plot is an arrow which indicates the trend due to increasing volume percent sulfides in artificial rocks (after Pelton et al., 1978).
- Fig. 14. Data from porphyry deposits plotted in chargeability-time constant space. There is a grouping of veinlet mineralization (open symbols) versus discretely disseminated mineralization (closed symbols) but there is no distinct grouping of pyrite mineralization (triangles) versus copper mineralization (circles). Superimposed on the plot is an arrow which indicates the trend due to increasing grain size in artificial rocks (after Pelton et al., 1978).

Fig. 15. Section view of zone of high chargeability at Meager Creek geothermal prospect, British Columbia, Canada (NaCl concentration, 0.15 molar).

TABLE CAPTION

Table 1. Sample Locations, Descriptions, Hydrothermal Mineralogy, Parameters and IP.

The sample numbers in parentheses refer to the well number and the depth in meters. Abbreviations: dike = dike of Mount Meager Volcanic Complex; m.q.d. = metaquartz diorite; h.b. = hydrothermal breccia; q. diorite = quartz diorite. (W) weak, (M) moderate, and (S) strong refer to the intensity of hydrothermal alteration.