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TITLE OF THESIS FLUID INCLUSION AND STABLE ISOTOPE STUDIES OF THE GOLD DEPOSITS IN OKANAGAN VALLEY, BRITISH COLUMBIA

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ABSTRACT

Two kinds of gold mineralization, epithermal and mesothermal, occur in the Okanagan Valley, southern British Columbia. Fluid inclusion and stable isotope studies indicate that two distinctive hydrothermal fluids were responsible for the mineralization events. At Dusty Mac, the epithermal fluid had a temperature of about 240°C, a low salinity of about 0.5 wt% NaCl equivalent and a low value for $\delta^{18}O$(SMOW)= -7--9 per mil. The mineralization process probably occurred at a depth of more than 380 meters. At Oro Fino and Fairview, the mesothermal fluids had a high CO_2 content, temperatures of 280°-330°C, salinities of 4-6 wt% NaCl equivalent and $\delta^{18}O$(SMOW) of +4-+6 per mil. The mineralization occurred at a depth of 3-4 km. The data indicate that fluids involved in both mineralization processes originated from meteoric water, with the shallow circulation responsible for the epithermal deposit(Dusty Mac) and deep circulation for the mesothermal ones(Oro Fino and Fairview).

TABLE 1. MICROTHERMOMETRY DATA

Sample	Mineralogy	Inclusion type	Temperature (°C) TmCO$_2$ Range	Mean	Tmice Range	Mean	Tmclath Range	Mean	ThCO$_2$ Range	Mean	Th Range	Mean
					DUSTY	MAC						
D-14-V	Qtz	3			-0.3--2.6(11)	-1.5					236-303(13)	264
		4			-0.7(1)						131-209(5)	184
D-15	Qtz	3			-0.3--1.0(7)	-0.5					163-283(18)	219
		4			-0.2-0.0(2)	-0.1					116-146(6)	131
D-29-V	Qtz	3			-0.3--0.9(9)	-0.5					193-295(24)	242
		4									148-186(3)	163
D-13	Qtz	3			-0.3--1.0(6)	-0.5					168-284(11)	228
D-28	Qtz	3			-0.2--1.1(7)	-0.4					161-276(19)	215
D-29-B	Qtz	3			-0.6-0.0(5)	-0.3					204-276(10)	234
					ORO FINO							
O-1	Qtz	1									318-349(3)	333
		4									197-221(2)	212
O-8	Qtz	1	-56.9--57.3(4)	-57.1			7.7-8.1(4)	7.9	30.2-30.9(4)	30.5	289-323(4)	301
O-11	Qtz+py	1	-56.7--56.8(2)	-56.8			5.5-7.1(2)	6.3	28.6-29.4(2)	29.0	302-314(2)	308
		3			-0.4-0.0(9)	-0.2					246-351(12)	310
O-12	Qtz+Py	1	-56.6--57.5(8)	-57.0			5.6-7.3(9)	6.5	27.0-30.3(10)	29.1	277-343(10)	298
		3									251-318(3)	278
					TWIN	LAKE						
T-10	Qtz	1	-56.5--57.1(5)	-56.9			4.8-8.3(9)	6.3	21.7-31.0(15)	27.1	264-342(19)	306
T-11	Qtz	1	-56.9--57.2(2)	-57.1			7.0-7.7(2)	7.4	28.1-28.4	28.3	285-303(5)	294
		2	-57.0--57.3(2)	-57.2					27.0-29.9(2)	28.5		
		3			-1.3-0.0(4)	-0.7					250-302(7)	270
		4			-0.7--2.2(4)	-1.6					160-201(10)	177
T-12	Qtz	3			-5.1--5.7(3)	-5.5					220-328(9)	267
					STEMWINDER							
S-3	Qtz	1	-56.6--57.1(5)	-56.9			6.1-8.5(9)	7.5	8.9-27.6(13)	20.0	229-313(21)	263
		4									172-199(4)	186
S-8	Qtz	1	-56.8--58.3(7)	-57.6			8.1-9.6(12)	9.0	17.0-27.1(12)	21.1	245-320(21)	285
		2	-56.5						12.9			
S-12	Qtz+Py	1	-56.9--57.5(8)	-57.2			7.6-9.5(16)	8.7	16.2-27.5(19)	24.7	224-313(31)	258
		4			-0.3--0.7(2)	-0.5					168-238(7)	190

gases on melting temperature of clathrate is small.

Densities of CO_2 were based on the table of Amagat(in He Zhili, 1980), which gives the experimental data for liquid-vapor saturation curve for CO_2. By measuring homogenization temperature of the CO_2, the densities of CO_2 were obtained.

Homogenization temperatures were not corrected for pressure at this stage.

5.3.1 Dusty Mac

Both brecciated and vein quartz contain a few aqueous inclusions. The inclusions are usually small in size with some larger inclusions ranging up to 10 to 15 μm. The vapor bubble occupies only about 5 percent of the inclusion volume in samples from brecciated quartz, but about 10 percent for samples from vein quartz. The results(table 1) show that the properties of the inclusions are basically the same between two kinds of quartz. As a consequence, we can statistically consider them together as a whole.

Homogenization temperatures of primary inclusions range from 161°C to 303°C, with the average of individual samples from 215°C to 264°C. A histogram of homogenization temperatures(Fig. 10) shows a peak at 245°C, compared with the average of 95 inclusions of 233°C. Melting temperatures of ice range 0.0°C to -2.6°C. This gives a salinity of 0.0 to 4.3 wt% NaCl equivalent. Histogram of melting temperatures of ice(Fig. 11) shows a peak at -0.3°C, which corresponds to a

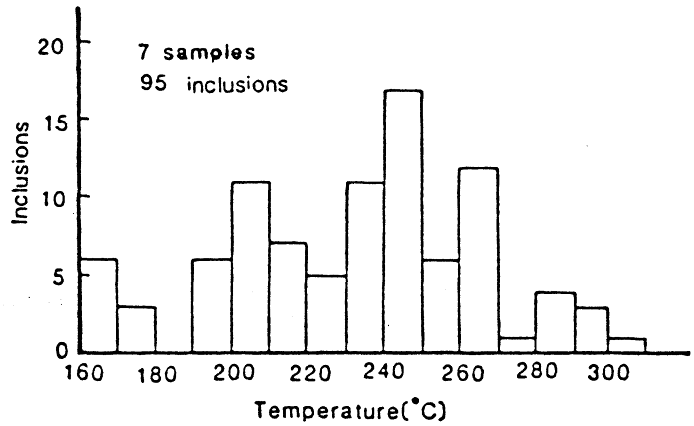

Fig. 10. Histogram of homogenization temperatures of aqueous inclusions from Dusty Mac. The mode is at 245°C.

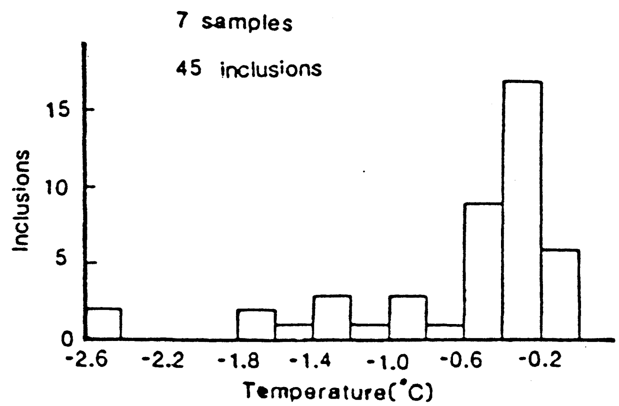

Fig. 11. Histogram of ice melting temperatures of aqueous inclusions from Dusty Mac. The mode is at -0.3°C, which corresponds to a salinity of 0.5 wt% NaCl equivalent.

salinity of 0.5 wt% NaCl equivalent.

Only a few of the secondary inclusions were large enough for measurement. Their homogenization temperatures range from 116°C to 209°C.

5.3.2 Oro Fino

The samples of Oro Fino and Twin Lake deposits used for the study were collected from the veins near the main shafts and waste dumps.

Both CO_2-H_2O and aqueous inclusions were observed in the samples from Oro Fino, but the CO_2-H_2O type dominates. The inclusions are generally smaller than 10 μm. At room temperature, the CO_2-H_2O inclusions usually show three phases(liquid H_2O, liquid CO_2 and vapor CO_2). The CO_2 phase is about 10 to 30 volume percent of the inclusion. The vapor bubbles of aqueous inclusion occupy a similar percentage of the volume.

Homogenization temperatures of the CO_2 phase range from 27.0°C to 30.9°C, with the average of 29.4°C. This gives a CO_2 density of 0.62 g/cm^3. The range of melting temperatures of clathrate is from 5.5°C to 8.1°C and the corresponding salinity ranges from 3.8 to 8.3 wt% NaCl equivalent. Average melting temperature of clathrate of 6.4°C corresponds to a salinity of 6.8 wt% NaCl equivalent. Homogenization of H_2O-CO_2 varies from 277°C to 349°C, with an average of 305°C.

Determinations of the depression of the freezing point of aqueous inclusions range from 0.0°C to -0.4°C(sample

Several CO_2 inclusions show th... ey have a relatively pure CO_2 composition(triple point temperature -56.9°--57.5°C) and a similar CO_2 density to those of the CO_2-H_2O inclusions.

Since the aqueous inclusions were rare, only a few measurements were done. Two samples show salinities of 2.7 to 4.6 wt% NaCl equivalent and homogenization temperatures of 275° to 313°.

Homogenization temperatures of secondary inclusions range from 150°C to 211°C.

5.4 Pressure-depth estimation

No exact determination of pressure can be obtained from Dusty Mac, but an estimation of vapor pressure by using Hass's data(1971, 1976) for H_2O-NaCl system can give some information about pressure. At Dusty Mac, as shown above, the fluids have very low salinities and are essentially pure water. Assuming pure water, at homogenization temperature of 240°C, the minimum vapor pressure is 34 bars which corresponds to a depth of 380 meters, assuming a hydrostatic pressure gradient, or 120 meters, assuming a lithostatic pressure gradient. This pressure is only a minimum estimate, since the fluid inclusions show no evidence of boiling. Existence of faulting systems, pervasive water/rock interaction(see next chapter) and very low salinity at Dusty Mac suggest that the vein system was open to the surface, and the pressure gradient was hydrostatic. Thus, in the case of Dusty Mac, an approximate minimum trapping depth of 380

TABLE 2. OXYGEN ISOTOPIC COMPOSITIONS OF QUARTZ AND ROCKS FROM DUST MAC

Sample	Mineral/Rock	$\delta^{18}O$
D-14-V	Vein quartz	+1.2
D-15	Vein quartz	+1.3
D-29-V	Vein quartz	+0.8
D-8	Brecciated quartz	+2.8
D-13	Brecciated quartz	+2.0
D-28	Brecciated quartz	+1.6
D-29-B	Brecciated quartz	+2.3
D-3	Shale	-1.1
D-4	Andesite	-2.0
D-9	Andesite	-2.7
D-14	Andesite	-1.7
DA-3	Andesite	-0.8
DB-24	Lahar	-3.7

7. MODEL OF THE MINERALIZATION

A compilation of the characteristics of the hydrothermal fluids for Dusty Mac, Oro Fino and Fairview is presented in table 5. Two distinct fluids can be recognized from the comparision of the characteristics of the fluids(Fig. 23, Fig. 24). At Dusty Mac, the fluid had an extremely low salinity, low $\delta^{18}O$ values and very low CO_2 contents and the ore was precipitated at a relatively shallow depth. At Oro Fino and Fairview, the fluids were low salinity, but had high $\delta^{18}O$ values and high CO_2 contents, and the ore was precipitated at a relatively deep depth. Two general terms, epithermal(Dusty Mac) and mesothermal(Oro Fino and Fairview), are used here to describe two kinds of gold mineralization in the Okanagan Valley.

7.1 Epithermal Mineralization

Numerous studies on Tertiary epithermal precious and base metal deposits(e.g., Nash, 1972; O'Neil et al., 1974; Hayba, 1983) have shown that in this type of deposit, the fluid inclusions usually have homogenization temperatures of 200°-300°C, and low salinities. For example, the fluid involved in the formation of the Au-Ag veins of National district in Nevada were dilute, with the salinity of 1-2 wt% NaCl equivalent(Virke, 1985). The salinity of the fluid for Au-Ag and base metal veins of Sunnyside in Colorado were 0.5-1 wt% NaCl equivalent(Casadevall et al., 1977). Isotopic studies show low $\delta^{18}O$ and δD values for this type of deposit.

TABLE 5. SUMMARY OF THE CHARACTERISTICS OF HYDROTHERMAL ORE-FORMING FLUIDS IN THE OKANAGAN VALLEY

	Dusty Mac	Oro Fino	Fairview
Temperature (°C)	≃240	≃330	≃280
Depth (meters)	≥380	≃3600	≃4000
Salinity (wt%NaCl)	≃0.5	≃6	≃4
CO_2 content	Very low	High	High
$\delta^{18}O_{H_2O}$SMOW(‰)	-7--9	+4-+6	+4-+6
$\delta^{13}C_{CO_2}$PDB(‰)			-8--9
W/R ratio	1-2		

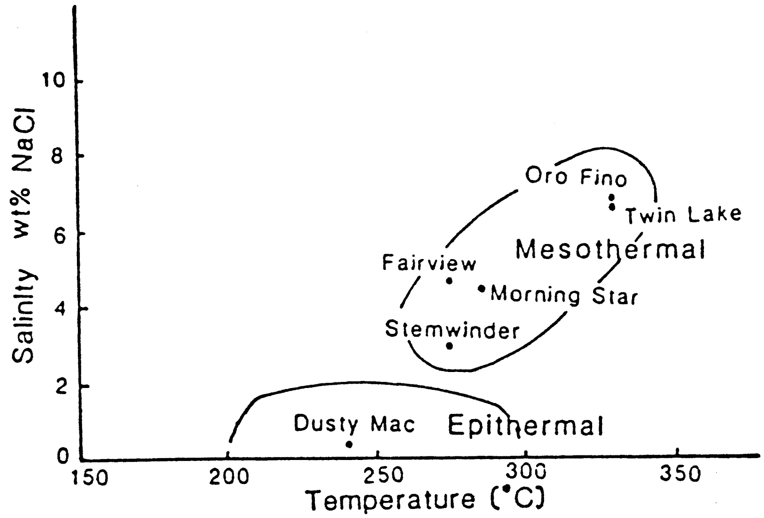

Fig. 23. Temperature-salinity relationship of the hydrothermal ore-forming fluids in the Okanagan Valley.

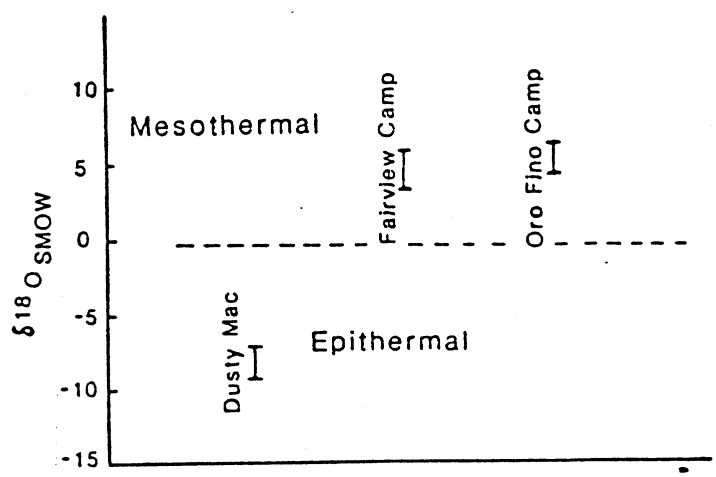

Fig. 24. Oxygen isotopic compositions of the hydrothermal ore-forming fluids in the Okanagan Valley.

For example, O'Neil et a... studied the isotopic compositions of some epithermal Au-Ag deposits in terrestrial volcanics in Nevada and found that the $\delta^{18}O$ and δD for the fluid were -6 to -16 and -90 to -140 per mil, respectively.

All the data on fluid inclusions and oxygen isotopes from Dusty Mac are consistent with the characteristics of the Tertiary epithermal Au-Ag vein deposits described by various authors(O'Neil et al., 1974; Taylor, 1974; Hayba, 1983). A mineralization model involving the circulation of meteoric water in the formation of epithermal deposits has been extensively used and can be applied to the Dusty Mac deposit. As demostrated in the stable isotope chapter, a large amount of meteoric water flowed through the country rocks at Dusty Mac. It is probable that the ore-forming components leached from the rocks were transferred into the water and concentrated in the ore-forming fluid. A rough calculation indicates that only 0.5 ppb Au needs to be removed from the rocks with a volume of 0.5 km^3 to account for the total gold content of the Dusty Mac deposit.

Figure 25 is an idealized cross section, showing the proposed hydrothermal system for Dusty Mac deposit. An intrusive pluton is presumed as the heating source. Meteoric water penetrated the volcanic pile through the fault and plume fracture system, along the topographic lows of the basin. Driven by heat from the pluton, the metal-carrying capacity of the water increased and the metals were leached from the rocks, enriching the water in ore-forming

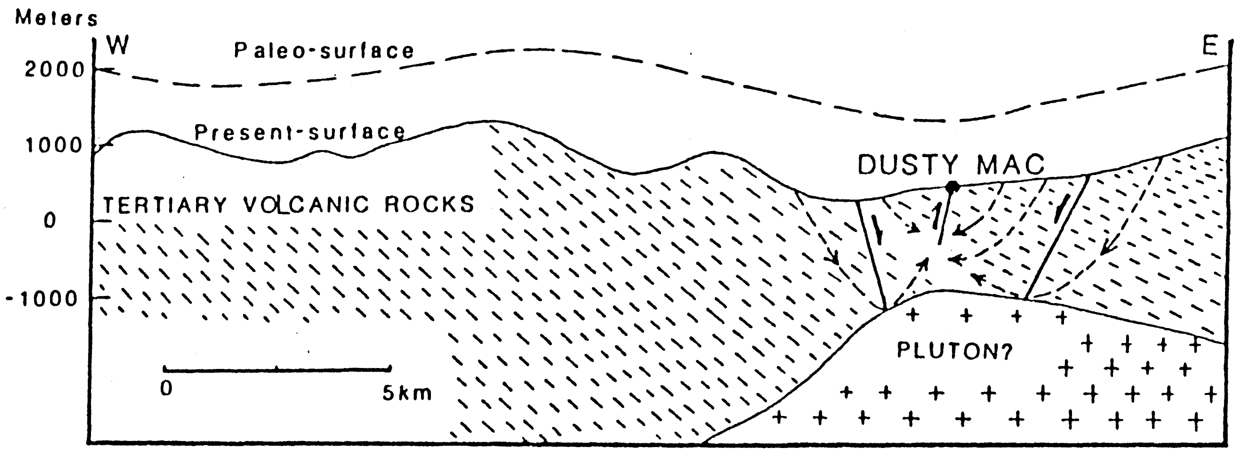

Fig. 25. Idealized cross section showing the proposed hydrothermal system for the formation of the Dusty Mac deposit.