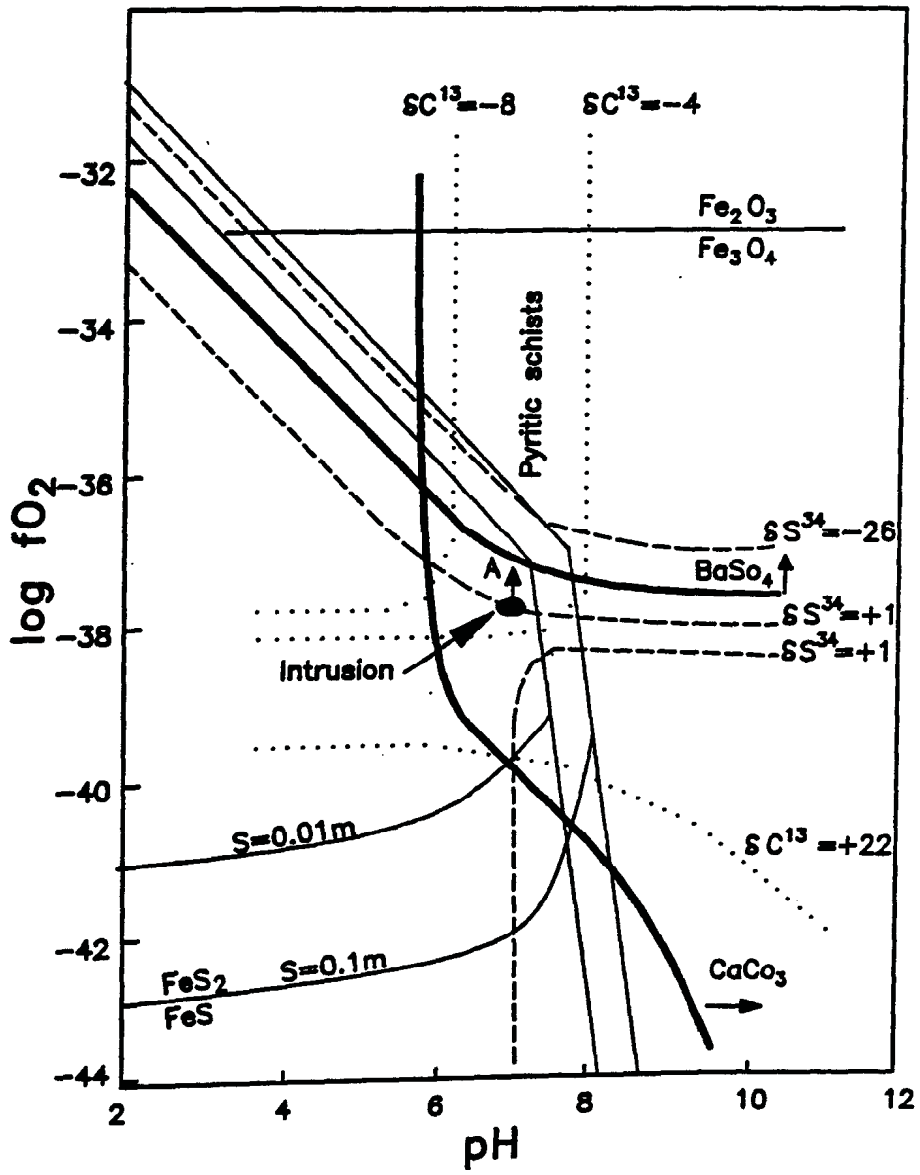


Figure 5.4.1. Plot of pH versus log fO_2, showing the positions of the $\delta^{34}S$ and $\delta^{13}C$ contours and the stability fields of the Fe-S-O and carbonate minerals at 250°C.
$\delta^{13}C$ contours for calcite calculated using
$\delta^{13}C$(solution) = -7 $^0/_{00}$ (from this study)
$\delta^{34}S$ contours for pyrite calculated using
$\delta^{34}S$(solution) = +1 $^0/_{00}$ (from this study)
Fe-S-O minerals calculated at total S = 0.01 and
0.1 moles/ Kg H2O
Carbonate stability calculated at total C = 1.0 moles/ Kg H2O

This increase in the oxidation state of the fluid may be due to the reaction with magnetite-rich layers within the lithology. Minor sulphate minerals (barite) in the mineralized schist indicate that the fO_2 increased to above the sulphate stability curve ($\pm$ log 10^{-35}).

5.4.1. Gold Solubility

Figure 5.4.2. is a plot of pH versus fO_2 at 250 °C, which also shows the calculated solubility of Au in solution as an $Au(HS)_2^-$ complex. The stability fields of Fe-O-S minerals is calculated for a sulphur content of 0.01 moles/kg H_2O. At the estimated fO_2 and pH conditions prevailing within the intrusions, the solubility of gold is at a maximum of >1000 ppb).

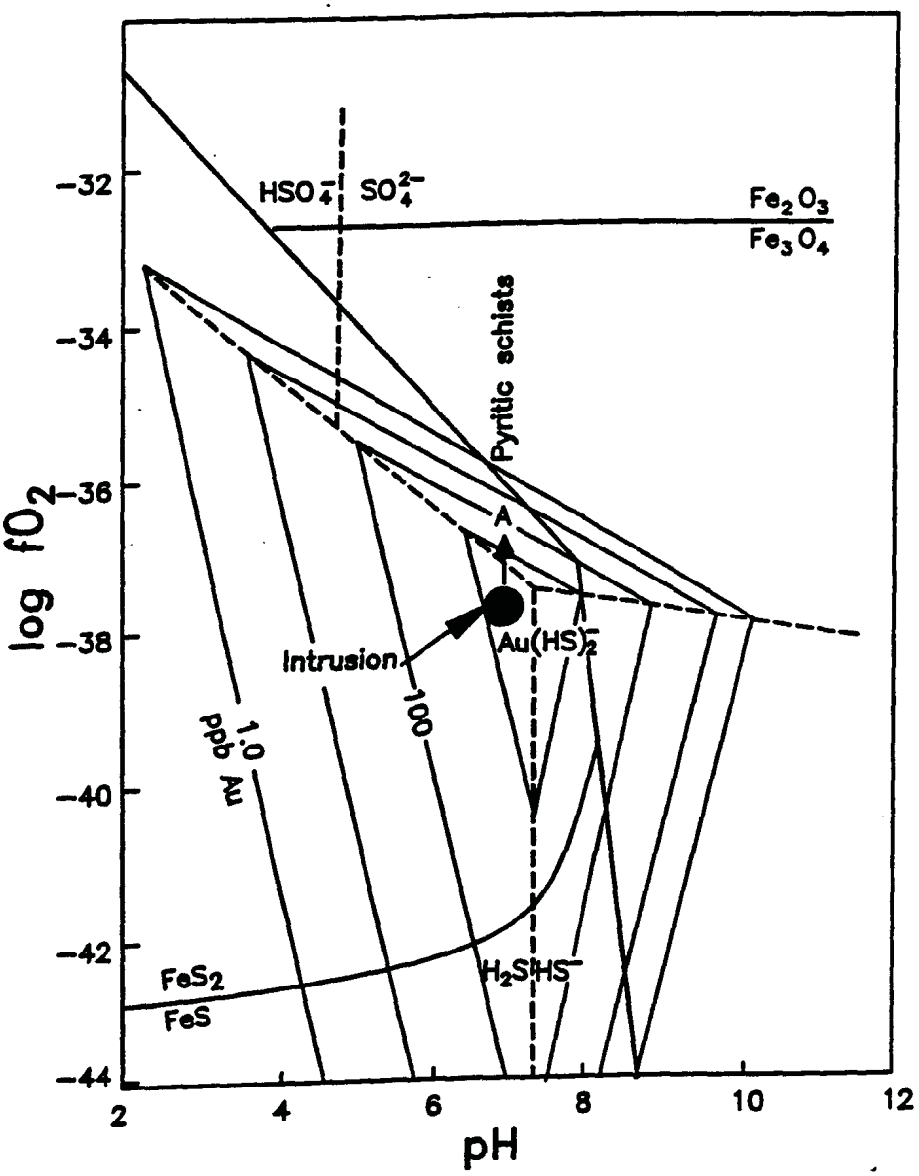


Figure 5.4.2. Plot of pH versus log fO_2, with the calculated solubility of gold in solution as a $Au(HS)^{2-}$ complex at 250°C and the stability fields of the Fe-S-O minerals and the H-S species.
Total S = 0.01 moles/ Kg H_2O
Total Cl^- = 0.1 moles/ Kg H_2O

A marked "solubility cliff" exists on the diagram towards higher fO_2 values, indicating that a slight increase in fO_2 would result in a major decrease in Au solubility. It is therefore, suggested that gold precipitation within the pyritic schist took place as a

consequence of increasing fO_2 in fluids transporting gold as a thiosulphide complex. The solubility of Au is also decreased with a decrease in temperature. However the apparently constant fO_2 conditions and fairly constant temperatures within the intrusions indicate that changes in these parameters were not the mechanism responsible for gold precipitation. It is suggested that phase separation was the process responsible for gold precipitation within the intrusions (See Chapter 6).

5.4.2. Isotope Conclusions

The isotope data indicate that the fluid responsible for alteration and mineralization within the albitized granodiorites intrusions had a uniform isotopic composition and was derived from a large isotopically uniform source external to the schist belt. The isotope data indicate that the mineralizing fluid contained dissolved carbon with a $\delta^{13}C$ ratio of $\pm$ -7 $^0/_{00}$ and the aqueous fluids had a $\delta^{18}O$ content of $\pm$ +6.0 $^0/_{00}$. The sulphur isotope ratio is estimated at $\pm$ +1.0 $^0/_{00}$.

The isotope data are consistent with the suggestion that the fluids were derived from a magmatic source and contained dissolved sulphur as reduced sulphur complexes which carried gold as a $Au(HS)_2^-$ complex. The Discovery Shaft intrusion was altered at temperatures of 300°C to 350°C and the Malati Store intrusion between 250°C and 300°C. The apparently higher temperatures in the Discovery Shaft intrusion is confirmed by fluid inclusion data (See Chapter 6). The fluids responsible for regional quartz-lode mineralization, as well as the mineralization along the Antimony Line, appear to be intimately related to the mineralization within the granitoids, both in terms of paragenesis and the similar isotopic composition of fluids involved in the mineralization. This infers that fluids responsible for the mineralization along these structures were derived from within the granitoids. The isotopic data negates an exhalative origin for the Antimony Line.

Two sources of carbon exist within the Murchison Schist belt, a regional sea water carbonate ($\delta^{13}C$ = -3 $^0/_{00}$) and a juvenile source ($\delta^{13}C$ = -7 $^0/_{00}$). The distinctly heavier ^{13}C signature of the sea water carbonate excludes its involvement in mineralization processes within the Murchison schist belt.

CHAPTER 6
Fluid Inclusion Microthermometry

6.1. Introduction

Fluid inclusion studies are most commonly used to characterize the physical and chemical properties of a fluid. From these studies, the nature and amount of dissolved salt in solution, the density of the solution and a minimum temperature of fluid entrapment may be estimated. These data are derived from the interpretation of temperatures at which phase changes occur, during controlled heating and freezing of the fluid inclusions.

Three types of fluid inclusion are commonly recognized, i.e. primary, pseudosecondary and secondary. Detailed guidelines for the classification and identification of fluid inclusion types are presented in Roedder (1979, 1984b) and Shepherd *et al.* (1985). Most inclusions studied in this dissertation were pseudosecondary in nature. The standard techniques utilized during fluid inclusion studies have been discussed by Roedder (1984b) and Shepherd *et al.* (1985). The basic assumptions made during fluid inclusion microthermometry are that the inclusions are representative of the fluids which were present during growth of the host mineral and that the inclusions have acted as a closed system and maintained constant volumes.

6.2. Fluid Inclusions in Archaean Gold Lode Deposits

An increasing number of fluid inclusion studies from Archaean mesothermal gold deposits have been carried out in recent years (Robert and Kelly, 1987; Smith *et al.*, 1984; Wood *et al.*, 1984, 1986; Roeder 1984a; Ho *et al.*, 1985; Foster, 1980; Groves *et al.*, 1984; Burrows and Spooner, 1987). Generally, Archaean auriferous fluids appear to be characterised by high fluid pressure, low salinity and the presence of CO_2. Colvine *et al.* (1988), note that few of these studies have demonstrated unequivocally that gold occurs either in an inclusion or along a fluid inclusion-filled fracture plane and it is therefore not always possible to conclude which fluid inclusion population was associated with transport and precipitation of the gold. Furthermore, fluid inclusion data from various deposits indicates complex cross-cutting relationships between various fluid inclusions

which are not always recognised. Roedder (1984), has also emphasized the difficulties associated with investigating deformed lode gold deposits as a result of the complex assemblages of secondary inclusions which develop in such cases.

The fluids involved in gold precipitation are usually of a low salinity (< 6 wt% eNaCl), aqueous and CO_2-bearing, with a moderate to high CO_2 density (0.65 to >1.0 g/cm^3). Homogenisation temperatures indicate minimum trapping temperatures between 200 °C and 400 °C, with an average around 350 °C. As the homogenization temperature is only an indication of the minimum trapping temperature the actual trapping temperatures are likely to be higher. Estimated trapping pressures, suggest pressures of between 1.5. and 4.5 kba (Smith *et al.*, 1984; Robert and Kelly, 1987), which correspond to a depth of 4 to 12 km, assuming lithostatic load. A common feature with Archaean lode deposits is the presence of high density CO_2 which commonly results in the decrepitation of inclusions prior to homogenisation (Colvine *et al.*, 1984; Roedder, 1984a). Various CO_2/H_2O ratios in coexisting fluid inclusions are observed in several deposits (Macdonald and Ray, 1984; Wood *et al.*, 1986; Robert and Kelly, 1987; Ho *et al.*, 1985; Phillips and Groves, 1984). The presence of two spatially related fluid inclusion populations (i.e. saline, aqueous phase with minor CO_2 and a low salinity, CO_2-rich fluid with minor H_2O), suggests immiscibility of a single homogenous fluid phase of low to moderate salinity, containing 5 to 30 mole percent CO_2 (Robert and Kelly, 1987; Wood *et al.*, 1986). It is important to note that the theory of "reconstruction" of auriferous fluids, which have undergone immiscibility, is based on the assumption that similar wetting characteristics of the separate phases are approximately equal and that they are equally likely to have been trapped within growing quartz. Alternatively, such inclusions may have formed from CO_2 generated from metamorphic devolatilization, co-mingling with H_2O of indeterminate origin.

6.3. Fluid Inclusion Microthermometry

6.3.1. Freezing Data

During melting of frozen inclusions, phase changes are observed from the solid to the liquid phase. The freezing of minute amounts of fluid commonly requires supercooling and in some cases temperatures as low as -150°C are required. The rate of fluid melting is controlled by regulating the heat supply which allows the phase changes to be observed under controlled and repeatable conditions. Measurements obtained during freezing and

reheating provide data primarily on the composition and density of the fluid. Pure H_2O and CO_2 freeze at +0.015 °C, and -56.6°C respectively. The presence of dissolved salts depresses the melting temperature of water by an amount that is proportional to the quantity of salts in solution (Figure 6.1.).

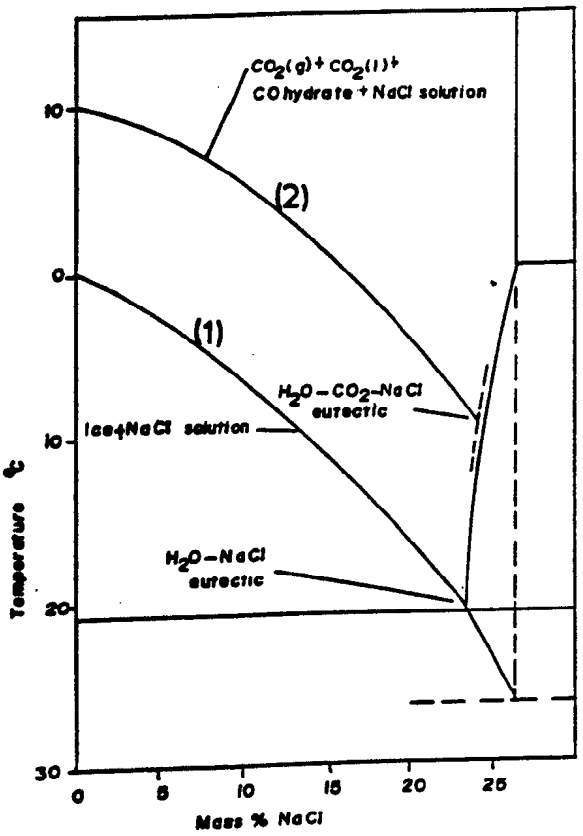


Figure 6.1. Depression of the melting temperature of H_2O (1) by NaCl and CO_2-H_2O (2) by NaCl in the presence of CO_2 liquid and CO_2 gas. (Collins, 1979)

The temperatures of initial melting (the eutectic) are diagnostic of the fluid system (i.e. a pure solution of H_2O-NaCl will begin to melt at -21.2°C). Results are commonly modelled on eutectic fluid systems. However, such fluids rarely exist in nature and the presence of unidentifiable minor phases will cause variations from the ideal temperature. This temperature is referred to as the temperature of first melting (Tfm). With continued heating, the ice will continue to melt until a temperature at which the ice crystals are completely melted, the final melt (Tm), which is a function of the total salt content of the fluid. The presence of carbon dioxide in mixed aqueous inclusion will result in a pure carbon dioxide hydrate (CO_2 $5.75H_2O$) forming usually at the interface of the CO_2 and H_2O in the inclusions. The presence of this additional solid phase will affect the final melting of the ice phase since it is residually enriched in dissolved salts. In this case,

estimates of salinity are carried out using the depression of the clathrate melting temperature, using the method of Collins (1979) (Figure 6.1).

6.3.2. Homogenization

During natural cooling, differential contraction between the host mineral and the fluid phase causes a vapour bubble to form in an inclusion. Thus the heating of a two-phase inclusion will cause fluids to homogenize to a single phase at the temperature of homogenization (Th). The temperature of homogenization (Th) represents the minimum temperature of entrapment, which is the departure of the two phase L+V from the boiling curve. If the salinity of the fluid is known, then the bulk density of the fluid can also be calculated (Shepherd *et al.*, 1985). By using independent temperature calculations, a pressure correction may be applied to calculate actual pressure and temperature of entrapment. For fluid inclusions containing daughter minerals, the dissolution temperatures (Ts) of the daughter minerals is used to determine the salinity of the supersaturated fluid. This estimation is based on the solubility of the salts at various temperature (Shepherd *et al.* 1985). Due to the slow rate of melting of salt crystals, the rate of heating is kept low (< 1 °C) on approaching the final dissolution.

At room temperature, fluid inclusions containing heterogeneous H_2O - CO_2 mixtures comprise two immiscible liquids. On heating, a temperature will be reached where the two phases become miscible and this temperature defines the H_2O - CO_2 solvus at a given salinity. The critical point for CO_2 is +31.1°C, thus CO_2 will homogenize below this temperature. The position of the solvus is dependent on the pressure and salinity of the H_2O rich phase at the time of entrapment. An increase in salinity results in a higher solvus, while an increase in pressure has the opposite effect.

Fluid salinities, densities and fluid isochores have been calculated using the "FLINCOR" program (Brown, 1989). FLINCOR is designed to calculate isochores from fluid inclusion observations. The equation of state of Brown and Lamb (1989), for the NaCl-CO_2-NaCl system, forms the basis of the calculations. The salinity of the inclusions containing daughter minerals is calculated using the solubility data of Hall *et al.* (1988).

6.4. Method

Doubly polished thin sections of approximately 200 micrometers thickness were obtained from quartz stockwork from the Discovery Shaft, Malati Store and Minerva Mine intrusions. The sections were initially examined using a petrographic microscope to asses the fluid inclusions for suitability and size and to determine the relationship between the various inclusion phases. Generally the inclusions were small (<5 - 10μm), which limits the amount of microthermometric data that could be obtained.

The melting and homogenisation data was derived using a USGS (Fluid Inc) adapted stage (Shepherd *et al.*, 1985) at the Department of Geology, University of the Witwatersrand. Where applicable, the temperature of first melting (Tfm), final melting (Tm) and homogenization (Th), as well as the clathrate melting (Tmcl) temperature were recorded for each inclusion. All freezing observations were carried out prior to heating observations to prevent problems with inclusion stretching and possible decrepitation. The homogenization temperatures of the inclusion were repeated to check for inconsistencies arising from possible leakage. The homogenization temperatures were repeated to within 3.0°C and the final melting to within 0.3°C.

Fluid inclusion determinations were then entered into the FLINCOR package to determine the salinity density and, hence, isochores of the inclusions.

6.5. Results

Petrographic and microthermometry on the inclusions from the quartz stockwork indicate that the Malati Store, Discovery Shaft and Minerva Mine intrusions have similar fluid inclusion characteristics. A summary of the microthermometric data for each intrusion is presented in Figures 6.2, 6.3 and 6.4. The histograms of the data are presented in Figures 6.5, 6.6, 6.7 and 6.8.

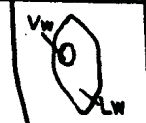
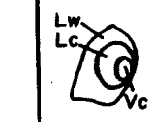
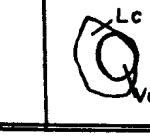
Inclusion Type		FREEZING TEMPERATURE			HEATING TEMPERATURES			
		Tm CO_2	Tm Ice	Tm Clath	Th CO_2	Th	Ts1	Ts2
A1			-1.9 - -4.9 **-2.3 °C**	Rare +7.1 -+8.2 **+7.6 °C**		198 - 294 **254 °C**		
A2			-10.1 - -12.5 **-11.5 °C**			350 °C		
A3			-0.9 - -2.2 **-1.1 °C**			± 130 °C		
B			-16.8 - -22.1 **-19.8 °C**			205- 298 **+258 °C** (L+V)	325 - 410 °C	320-450 °C
C		-57.2 - -58.5 **-58.5 °C**	-2.2 -4.8 **-3.5 °C**	+5.5 - +8.8 **+7.6 °C**	+17.9 - 20.5 **+19.1 °C**	228 - 289 **263 °C**		
D		-58.2 - -58.9 **-58.5 °C**		+5.6 - +5.9 **+5.7 °C**	+18.2 - 19.9 **+19.2 °C**			

Figure 6.2. Range and average values for the thermometric data from the Malati Store intrusion

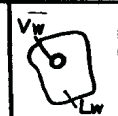
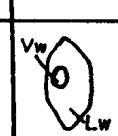
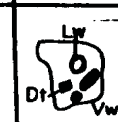
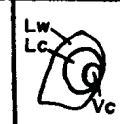
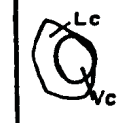
Inclusion Type		FREEZING TEMPERATURE			HEATING TEMPERATURES			
		Tm CO_2	Tm Ice	Tm Clath	Th CO_2	Th	Ts1	Ts2
A1			-1.5 - -5.2 **-2.5 °C**	Rare +5.2 - +6.5 **+5.8 °C**		280 - 365 **325 °C**		
A2			-8.1 - -9.5 **-9.1 °C**			±380 °C		
A3			-0.4 - -2.1 **-1.4 °C**			121 - 130 **128 °C**		
B			-15.1 - 21.1 -19.8 °C			295 - 352 **332 °C**	350 - 395 **390 °C**	380 - 450
C		-56.9 - -59.1 **-57.4 °C**	-1.9 - -3.2 **-2.8 °C**	+4.8 - +8.5 **+6.5 °C**	+16.9 - +19.2 **+18.2 °C** (L+V)	285 - 352 **321 °C**		
D		-57.2 - -58.9 **-58.4 °C**		+5.3 - +7.6 **+6.1 °C**	17.3 - 18.5 **+17.9 °C**			

Figure 6.3. Range and average values for the thermometric data from the Discovery Shaft intrusion

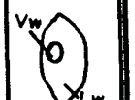
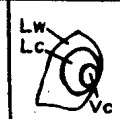
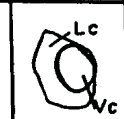
Inclusion Type		FREEZING TEMPERATURE			HEATING TEMPERATURES			
		Tm CO_2	Tm Ice	Tm Clath	Th CO_2	Th	Ts1	Ts2
A1			-2.9 - -5.1 **-4.1 °C**	Rare +5.1 - +6.1 **+5.3 °C**		235 - 271 **260 °C**		
A2			-11.4 - -13.2 **-12.4 °C**			± 375		
A3			-1.1 - -2.1 **1.4 °C**			±150 °C		
B			-16.2 - -19.1 **-18.2 °C**			239 - 271 **256 °C**	± 320 °C	
C		-56.8 - -57.9 **-57.9 °C**	-2.3 - -3.3 **2.2 °C**	+5.3 - +6.1 **+5.9 °C**	± 19 °C	235 - 264 **258 °C**		
D		-57.2 - -58.1 **-57.3 °C**		+4.5 - +6.9 **+6.4 °C**	± 19 °C			

Figure 6.4. Range and average values for the thermometric data from the Minerva Mine intrusion

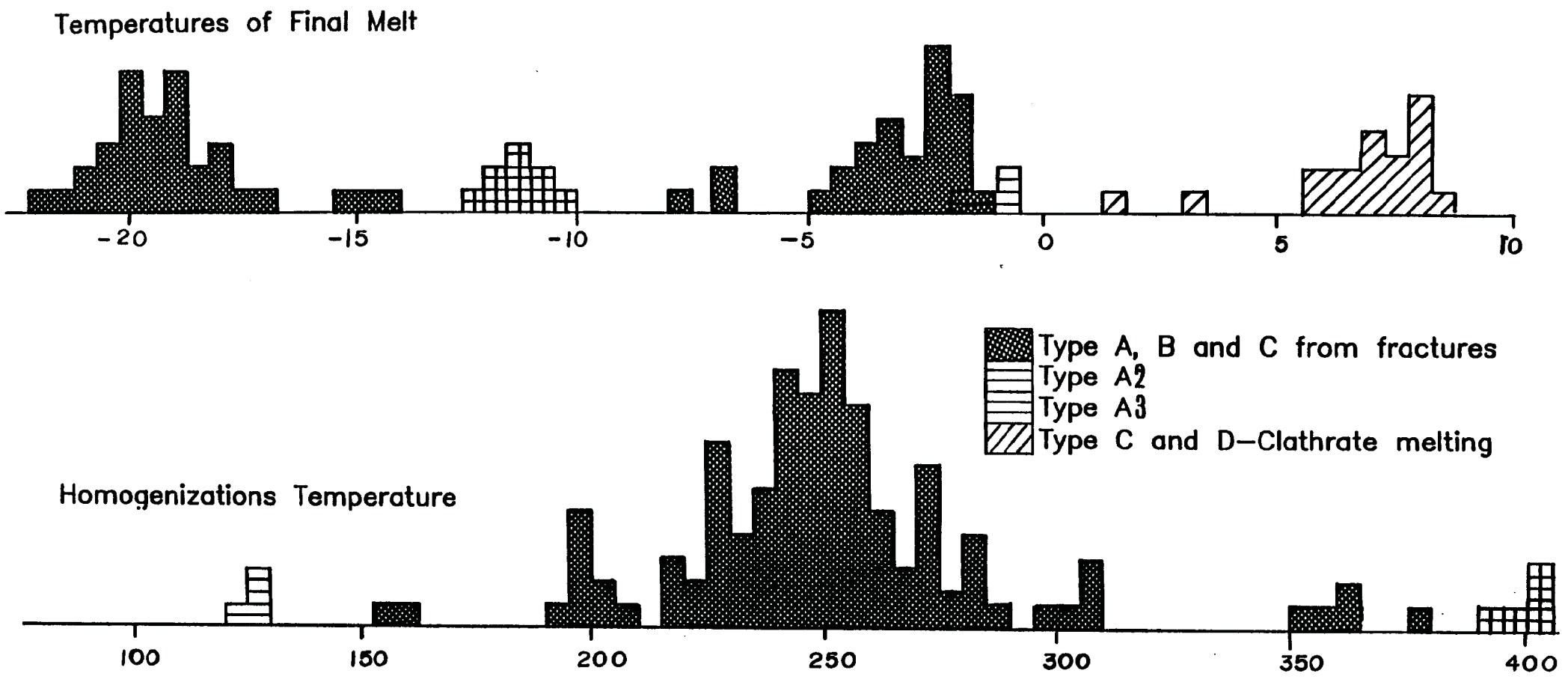


Figure 6.5. Histograms for the microthermometric data from fluid inclusions from the Malati Store intrusion.

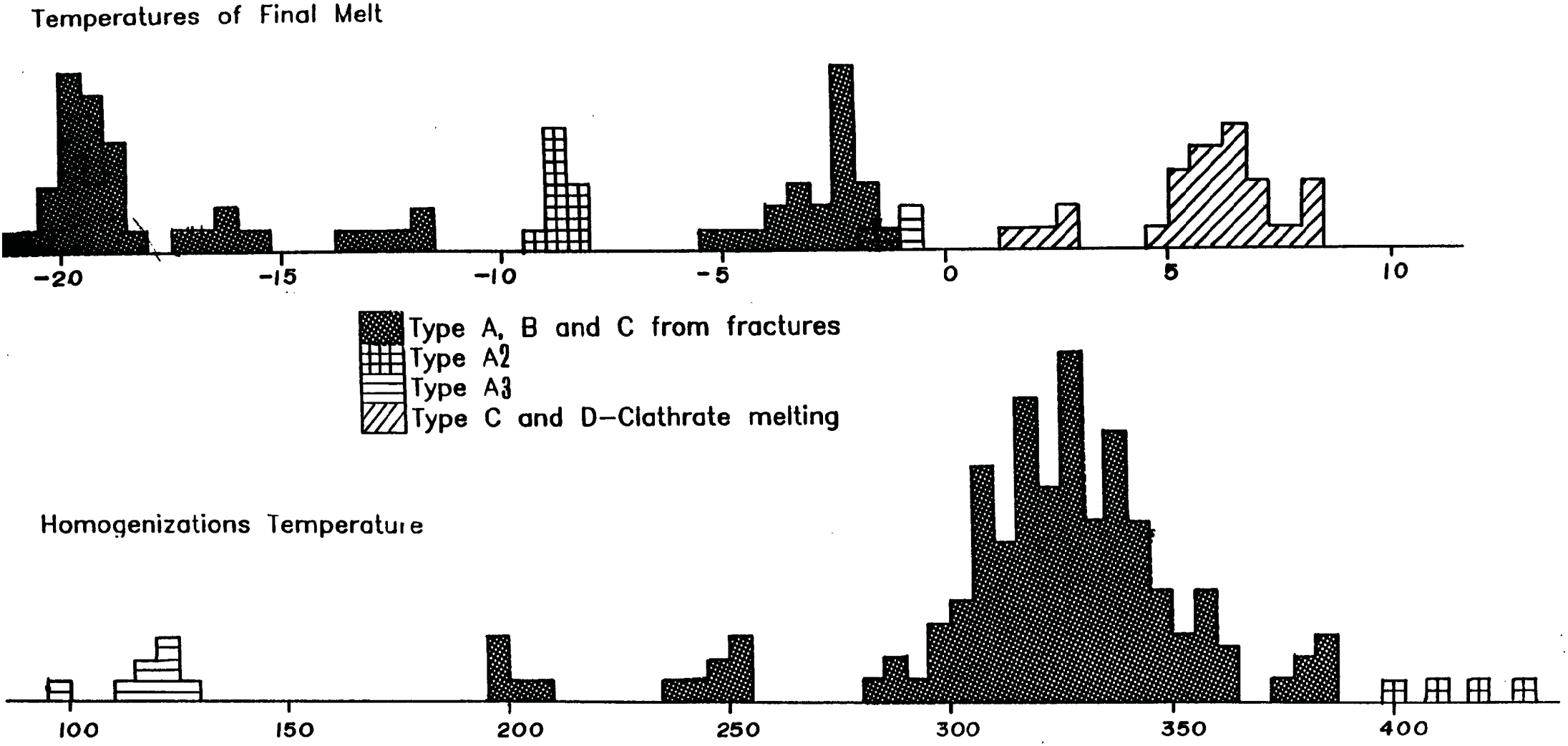


Figure 6.6. Histograms for the microthermometric data from fluid inclusions of the Discovery Shaft intrusion.

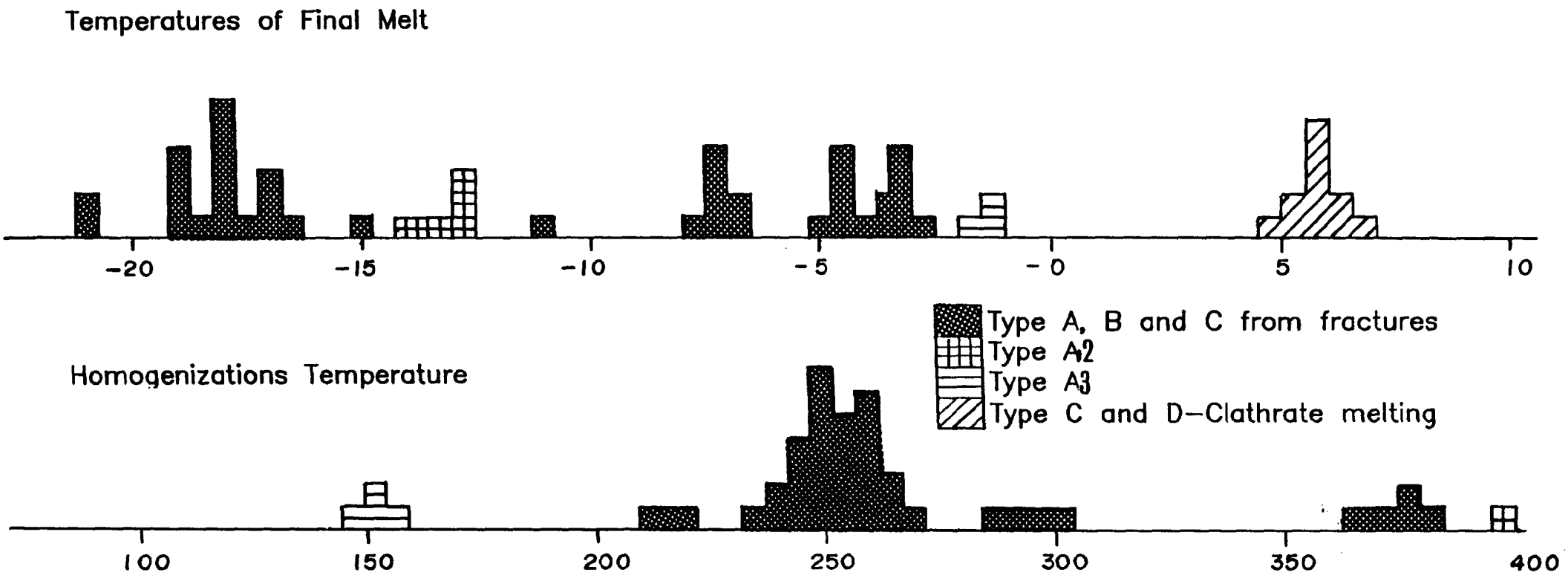


Figure 6.7. Histogram for the microthermometric data from fluid inclusions of the Minerva mine intrusion

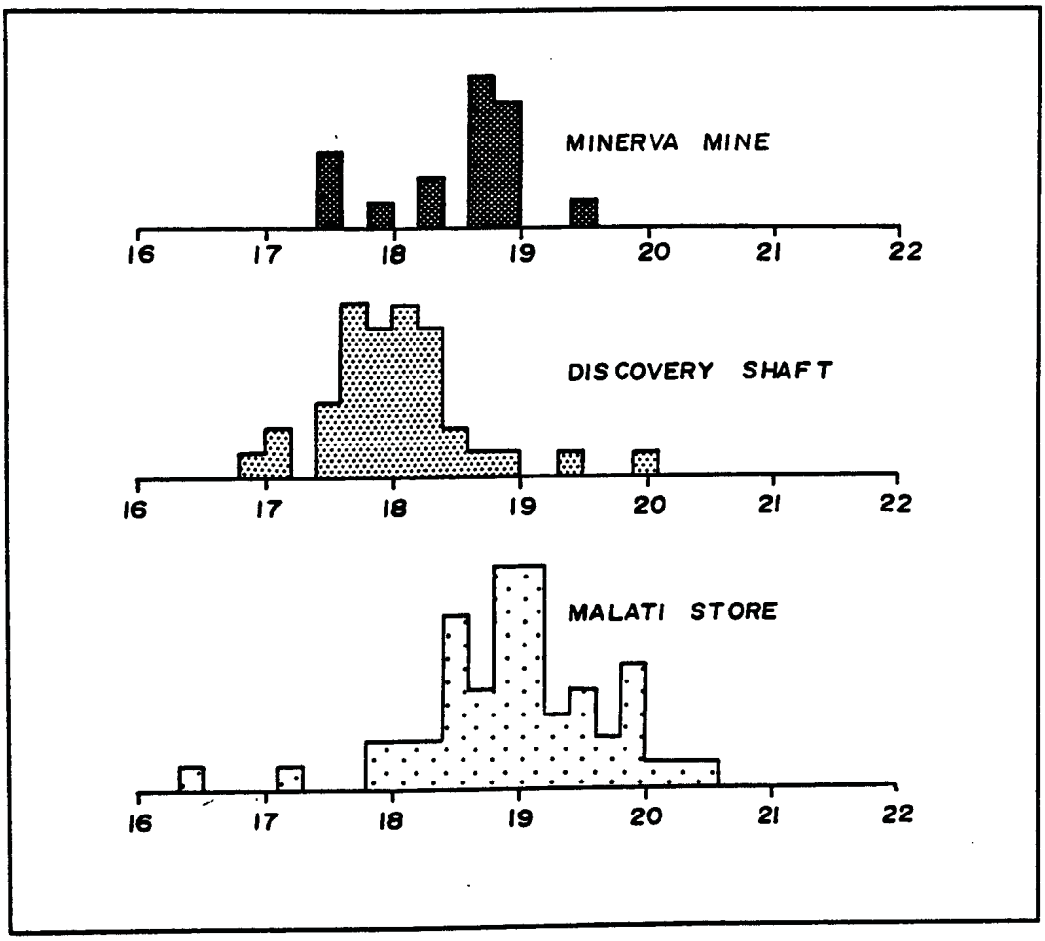


Figure 6.8. The CO_2 homogenization temperatures for the various intrusions examined.

Microscopic examination showed numerous intersecting secondary intersecting trails of inclusions, indicative of repeated microscopic scale fracturing and sealing under hydrothermal conditions. However, occasionally isolated, possibly primary, inclusions were also observed and were generally larger than the secondary inclusions. These commonly occurred in clusters and were apparently unrelated to fractures. The fluid inclusions present within the intrusions can be divided into four types:-

Type A. Predominantly aqueous, two phase (L+V) inclusions.

Type B. Predominantly aqueous, three phase inclusions containing a solid phase. These inclusions are saturated in salts (ie. > 21 wt% eNaCl) with some inclusions containing up to four different daughter minerals.

Type C. H_2O+CO_2 inclusions containing liquid H_2O, liquid CO_2 and a mixed vapour phase at room temperature. The CO_2 content of the inclusions is highly variable and range from less than 5 % to 80 %. These inclusions are generally of low salinity.

Type D. Two phase CO_2-rich inclusions. These inclusions were only occasionally observed. These inclusions are the CO_2 (> 90%) rich equivalent of type C. They have been separated for ease of description.

The temperatures of eutectic melting are similar for all the aqueous inclusions examined and indicate a complex fluid which may be possibly represented by the H_2O-NaCl-$CaCl_2$-$MgCl_2$ system. Observable eutectic melting was observed at -35 °C (Na_2O-NaCl-$MgCl_2$), -21 °C (H_2O-NaCl) and -50 °C (H_2O -$CaCl_2$), although the fluid is likely to be more highly complex.

6.5.1. Type A Inclusions

Type A inclusions exhibit three distinct populations of homogenization temperature (A1, A2, A3).

Type A1. The first (A1) is of variable size and occurs along fracture planes, commonly in close proximity to type B and C inclusions. These inclusions generally have a low salinity (<7 wt% ENaCl) and clathrate melting was occasionally observed, indicating the presence of small amounts of CO_2. Type A1 inclusions are considered to represent CO_2-poor inclusions of the type C inclusions. The homogenization temperatures and salinities of the type A1 and C inclusions were similar within a single intrusion.

Salinities of Type A1

Malati Store 4.1 - 6.4 wt% eNacl
Discovery Shaft 3.9 - 6.9 wt% eNaCl
Minerva Mine 4.5 - 6.7 wt% eNaCl

Homogenization Temperature of Type A1

Malati Store 198 - 294°C
Discovery Shaft 280 - 365°C
Minerva Mine 235 - 271°C

Type A2. Type A2 inclusion are commonly larger (± 15-20 μm) than all the other inclusions and have well developed negative crystal forms. They occasionally occur in clusters, although cross cutting trails were also observed. The general morphology of the inclusions suggests that they might represent primary inclusions. However, it must be remembered that the quartz samples examined contained many planes of secondary

inclusions, so there is a distinct probability that any primary inclusions were reopened and contaminated by later fluids. The A2 inclusions have the highest homogenization temperatures (> 350 °C) recorded within the intrusions. This temperature usually caused decrepitation in the majority of the other inclusion populations. The salinity of these inclusions is moderate and fairly constant both within and between intrusions.

Salinities of Type A2

Malati Store 14.5 to 16.1 wt% eNaCl
Discovery Shaft 12.4 to 13.7 wt% eNaCl
Minerva Mine ± 17 wt% eNaCl

Homogenization Temperatures of Type A2

Malati Store ± 350°C
Discovery Shaft ± 375°C
Minerva Store ± 400°C

Type A3. The third type (A3) is only rarely observed and occurs as large inclusions (20-30 μm) along irregular fractures. This inclusion population cross-cuts all other inclusions. The homogenization temperatures are low (< 150 °C) and they have low salinities of 1-3 wt% eNaCl. This phase is interpreted to represent late fluid infiltration of the intrusions along brittle micro fractures.

6.5.2. Type B Inclusions

The type B inclusions have similar homogenization temperatures to types A1 and C, but are characterised by high salinities, commonly as high as 35 wt% eNaCl. Certain inclusions were observed to contain up to five daughter minerals, occupying more than 70% of the inclusion volume. Identification of the daughter minerals is problematic, as often a single inclusion contains numerous small inclusions apparently of the same phase, predominantly NaCl. Although this is unlikely to occur within a single inclusion (Shepherd *et al.* 1985). Occasionally the inclusions contain such a large volume of solid that the latter probably do not represent true daughter crystals, but trapped mineral inclusions. The salinity of the inclusions was determined by the dissolution temperatures of the daughter crystals. However, certain daughter minerals failed to dissolve at temperatures of up to 450 °C, suggesting entrapment of foreign solid phases. Temperature Ts1 is the dissolution point of halite while Ts2 is the dissolution temperature of the unidentified daughter minerals, possibly a carbonate. On cooling

approximately one to two days later, the daughter minerals reappeared, usually as numerous small irregular crystals.

Homogenization of type B inclusions occurs within the same range as the type A and C inclusions within an a given intrusion.

Salinities of Type B

Malati Store 19 - > 35 wt% eNaCl
Discovery Shaft 22 - > 30 wt% eNaCl
Minerva Mine 20 - > 30 wt% eNaCl

Homogenization of Type B Inclusions

Malati Store 205 - 298°C
Discovery Shaft 295 - 352°C
Minerva mine 239 - 271°C

6.5.3. Type C Inclusions

The type C inclusions contain variable proportions of CO_2 and low salinity aqueous fluids. The CO_2 phase homogenized into the liquid and vapour phase at a temperature similar to that of the type D carbonic inclusions. Typically, those inclusions having a high CO_2:H_2O ratio were homogenized by the disappearance of the H_2O rich phase and *vice versa*. The aqueous phases homogenized into the liquid, although occasionally inclusions were observed to homogenize into the vapour phase, indicative of entrapment close to, or on the solvus.

Salinities of Type C

Malati Store 4.2 to 5.8 wt% eNaCl
Discovery Shaft 5.5 to 6.8 wt% eNaCl
Minerva Mine 4.5 to 6.4 wt% eNaCl

CO_2 Homogenization Temperatures of Type C

Malati Store 17.9 - 20.5°C
Discovery Shaft 16.9 - 19.2°C
Minerva Mine ± 19°C

Homogenization Temperatures of Type C

Malati Store 225 - 289°C

Discovery Shaft 285 - 352°C

Minerva Mine 233 - 264°C

6.5.4. Type D Inclusions

Type D inclusions are not common, but comprise CO_2-rich inclusions, with variable degrees of CO_2 vapour. They occur along fractures associated with type A1, A2, and C type inclusions. These inclusions are considered to represent the CO_2-rich portions of type C inclusions and are not considered to represent a different population, hence they are separated for convenience.

CO_2 Homogenization Temperature of Type D

Malati Store 18.1 - 19.9°C

Discovery Shaft 17.3 - 18.5°C

Minerva Mine ± 19°C

Melting point of CO_2 = -56.7 - -57.3 °C

Figure 6.9 is a diagram showing fluid inclusions along a fracture from the Malati Store intrusion. The fracture contains numerous secondary inclusions, indicating the co-existence of type B and C inclusions. This co-existence of low salinity vapour rich, CO_2-bearing inclusions with variable H_2O:CO_2 ratios and a H_2O-rich, high salinity fluid which homogenizes at approximately the same temperature, is suggestive of phase separation due to immiscibility. The occurrence of the various inclusions along a single fracture suggests that the inclusions may have co-evolved. Figure 6.10 and 6.11 show similar examples from the Discovery Shaft and Minerva Mine intrusions.

Due to this phase separation, it is not possible to ascertain the initial H_2O:CO_2 ratio for the parental homogenous fluid. Since the inclusions homogenize into both the vapour and liquid phase, the fluid entrapment must have occurred close to the liquid-vapour solvus. Consequently, the homogenization temperatures are more or less equal to the trapping temperature and no pressure correction needs to be applied.

Figure 6.9. Fluid inclusion filled fracture from the Malati Store intrusion.

A. Low power magnification (X100) of quartz stockwork from the Malati Store intrusion, showing the complex array of fluid inclusions along micro fractures.
B. High power magnification (X360) of a single fracture plane. Note the extreme variation in salinity and CO_2 content of the inclusions. A high salinity (18 to ± 35 wt% eNaCl) and a low salinity (< 5 wt% eNaCl) population, containing CO_2, commonly occur along the same fracture. All the inclusions have similar homogenization temperatures into both liquid and vapour phases indicating phase separation.

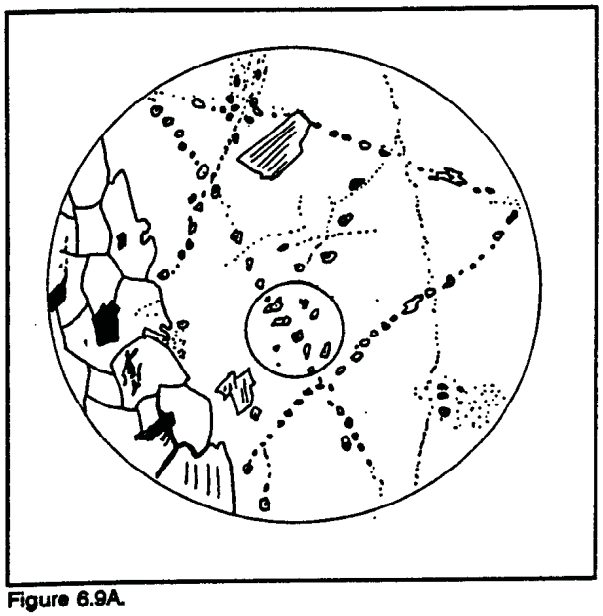


Figure 6.9A.

1. Th = 256 oC (L+V-L) wt% eNaCl = 7.3
   Tmcla = +6.1 oC Density H_2O = 1.02 g/cm^3
   $ThCO_2$ = 19.3 oC Density CO_2 = 0.78 g/cm^3

2. Tm = 258 oC (L+V-L) wt% eNaCl = > 28
   Tm = -21.5 oC Density H_2O = 1.2 g/cm^3
   Ts1 = 348 oC Density CO_2 = 0.68 g/cm^3
   Ts2 = 352 oC

3. Th = 255 oC (L+V-L) wt% eNaCl = 28
   Tm = -3.2 oC Density H_2O = 0.85 g/cm^3

4. Th = 259 oC wt% eNaCl = 5.2
   Tmcla = +7.2 oC Density H_2O = 1.02 g/cm^3
   $ThCO_2$ = 18.3 oC (L+V-V) Density CO_2 = 0.18g/cm^3

5. Th = 262 oC (L+V-V wt% eNaCl = 7.8
   Tm = -5.1 oC Density H_2O = 0.86 g/cm^3

6. Th = > 450 oC wt% eNaCl = 14.4
   Tm = -14.5 oC

7. Th = 255 °C (L+V-L) wt% eNaCl = 5.6
   Tm = -3.5 °C Density H_2O = 0.84 g/cm^3

8. Tm = 261 °C (L+V-L) wt% eNaCl = > 36
   Tm = -22.4 °C Density H_2O = 0.84 g/cm^3
   Ts = 305 °C

9. Th = 259 °C (L+V-V wt% eNaCl = 23.5
   Tm = -18.1 °C Density H_2O = 0.95 g/cm^3

10. Th = 255 °C (L+V-L) wt% eNaCl = 22.01
    Tm = -19.5 oC Density H_2O = 0.97 g/cm^3

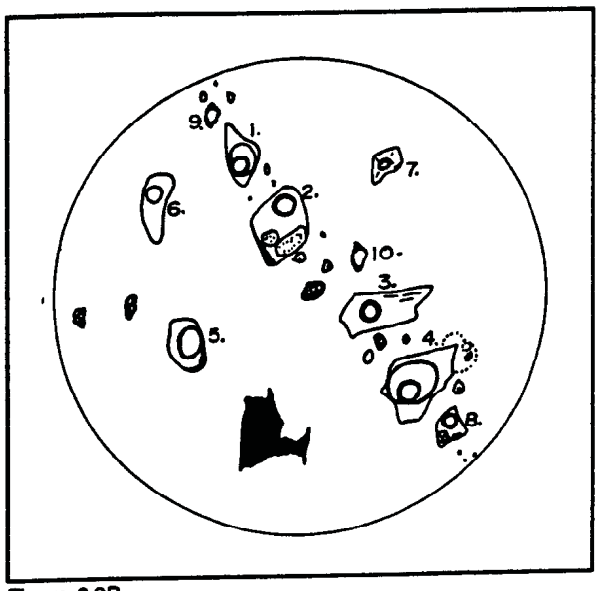


Figure 6.9B.

Figure 6.10. Example of a fluid inclusion fracture from the Discovery Shaft Intrusion.

1. Th = 325 °C (L+V-L) wt% NaCl = 20.3
   Tm = -17.2 °C Density H_2O = 0.908 g/cm^3

2. Th = 215 °C (L+V-L) wt% NaCl = 6.7
   Tm = -4.2 °C Density H_2O = 0.90 g/cm^3

3. Th = 321 °C (L+V-V) wt% NaCl = 4.4
   Tm = -2.7 °C Density H_2O = 0.75 g/cm^3

4. Th = 315 °C (L+V-L) wt% NaCl = 9.2
   Tmcla = +4.5 °C Density H_2O = 1.02 g/cm^3
   $ThCO_2$ = +18.2 °C Density CO_2 = 0.79 g/cm^3

5. Th = 328 °C (L+V-L) wt% NaCl = >32
   Tm = -21.2 °C Density H_2O = 1.2 g/cm^3
   Ts = 352 °C

6. Th = 325 °C (L+V-V) wt% NaCl = 5.0
   Tm = -3.1 °C Density H_2O = 0.74 g/cm^3

7. Th = 305 °C (L+V-L) wt% NaCl = 6.8
   Tmcla = +6.4 °C Density H_2O = 1.03 g/cm^3
   $ThCO_2$ = +17.2 °C Density CO_2 = 0.8 g/cm^3

8. Th = 122 °C (L+V-L) wt% NaCl = 3.4
   Tm = -2.1 °C Density H_2O = 0.90 g/cm^3

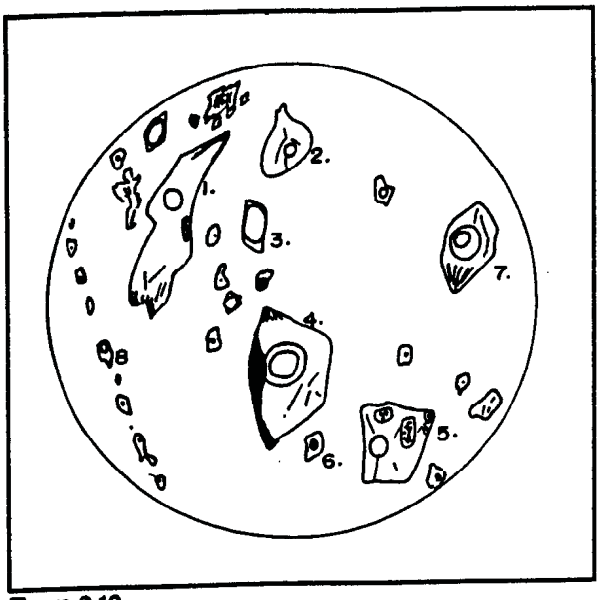


Figure 6.10.

Figure. 6.11. Example of a fluid inclusion fracture from the Minerva Mine Intrusion.

1. Th = 252 °C (L+V-L) wt% NaCl = 7.1
   Tmcla = +6.2 °C Density H_2O = 1.04 g/cm^3
   $ThCO_2$ = +18.9 °C Density CO_2 = 0.72 g/cm^3

2. Th = 248 °C (L+V-V) wt% NaCl = 5.1
   Tm = -3.2 °C Density H_2O = 0.84 g/cm^3

3. Th = 255 °C (L+V-L) wt% NaCl = >35
   Ts = 352 °C Density H_2O = 1.21 g/cm^3

4. Th = 395 °C (L+V-L)(Primary ?) wt% NaCl = 16.3
   Tm = -13.4 °C Density H_2O = 0.78 g/cm^3

5. Th = 253 °C (L+V-L) wt% NaCl = 7.1
   Tm = -4.1 °C Density H_2O = 0.82 g/cm^3

6. Th = 235 °C (L+V-V) wt% NaCl = 6.5
   Tm = -3.1 °C Density H_2O = 0.85 g/cm^3

7. Th = 252 °C (L+V-L) wt% NaCl = >38
   Ts = 422 °C Density H_2O = 1.23 g/cm^3

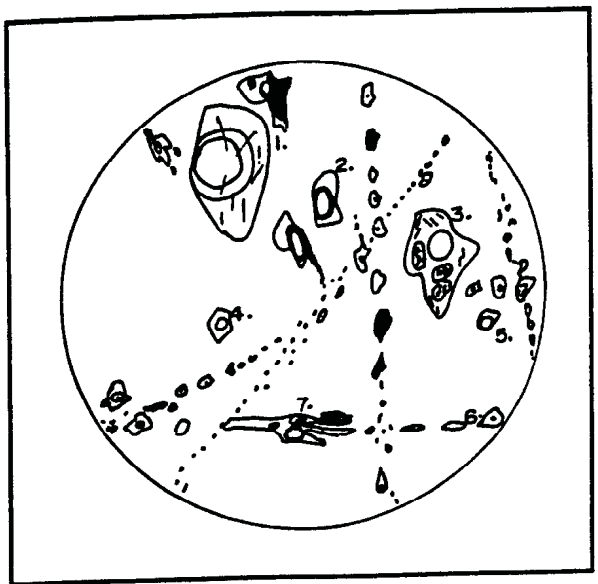


Figure 6.11

The melting point of CO_2 shows a slight depression (-56.6 - 57.4°C), indicative of the presence other volatile species (eg. CH_4, N_2, H_2S). When crushed, the quartz from all the intrusions produced a distinct smell of H_2S, indicating the presence of H_2S within the fluid inclusions. A melting event was occasionally observed at -86.4 to -89.7°C, especially in the Malati Store samples and since the melting point of H_2S is -85.5°C, this event is interpreted to be due to the presence of H_2S. A sample from the Malati Store mine contained a triple-bubble at room temperature. On heating, the inner bubble phase homogenized at 89.1°C, suggesting that this phase represents H_2S (Critical point of pure H_2S = +100.4°C)

6.6. Conclusions

The fluid characteristics of the three intrusions examined are similar. The data indicates that fluid immiscibility has occurred within the intrusions, resulting in the formation of a low density (± 0.75 g/cm^3), low salinity (< 7 wt% eNaCl), CO_2-rich fluid and a high density (± 1.1 g/cm^3), high salinity (> 18 wt% eNaCl), aqueous, CO_2-poor fluid. Due to this immiscibility, it is not possible to reconstruct the fluid salinity or the CO_2 content of the original homogeneous parental fluid phase.

The average homogenization temperatures for the Minerva Mine and Discovery Shaft intrusions are similar (± 250 °C), and are lower than that determined for the Discovery Shaft intrusion (± 300 °C). These temperatures compare favourably with the stable isotope data which also indicated that the Discovery Shaft intrusion had interacted with fluids at a higher temperature. Due to fluid entrapment close to the H_2O-CO_2 solvus, the homogenization temperature is approximately equal to the entrapment temperature.

The identification of H_2S in the intrusions is important with regard to gold transportation. The fluid immiscibility observed in the intrusions has implications for the process responsible for sulphide and gold precipitation. It is suggested that immiscibility resulted in the destabilization of gold-thiosulphide complexes, resulting in precipitation of auriferous pyrite. Thus unlike the auriferous schists, changes in the fO_2 were not responsible for a reduction in gold solubility and precipitation (as suggested by the stable isotope data) within the albitized cupola zones.

CHAPTER 7
Conclusions

Gold-antimony-molybdenite-tourmaline-beryl mineralization within the study area has been shown to be intimately related to intrusive granodiorites which have intruded along major structural discontinuities, including the Antimony Line. The present study has shown that the albitites of the Murchison schist belt occur as a result of varying degrees of pervasive sodium metasomatism (albitization) of the cupola zones of some of these granodiorite intrusions, due to the interaction of fluids of both deuteric and post-magmatic origin. The albitized intrusions contain disseminated gold-pyrite mineralization which have given rise to sub-economic levels of exploitation. The sodium alteration resulted in the replacement of primary quartz, oligoclase and microcline by albite (Ab_{95-98}) and irregularly distributed secondary quartz. Amphiboles and biotite within the granodiorite were replaced initially by chlorite and fine-grained epidote, with the precipitation of fine-grained, irregular rutile along cleavages. Increased degrees of metasomatism resulted in the replacement of chlorite by fine-grained, irregular albite and later laths of albite. The hydrothermal fluids were undersaturated with respect to silica during a period of the hydrothermal alteration, which resulted in desilicification of the intrusions. Late quartz-stockwork development occurred in the intrusions. Paragenetically late potassic alteration is present in the intrusions and is commonly developed along the wall rock contacts. Geochemically, the albitized intrusions are enriched in Na_2O (6-9 %) and depleted in potassium (< 1%), with comparison to the unaltered granodiorites. The Na_2O:K_2O ratio ranges between 10-80, depending on the degree of alteration. There is a continuous geochemical progression from unaltered granodiorites through to virtually monomineralic albitites comprising up to 80% normative albite. Hydrothermal alteration in the granodiorites involved the addition of Na, Ti, S, Au and Cu and the subsequent loss of K, Si, Rb, Sr, resulting in an approximately 10% increase in mass.

Gold within the intrusions occurs within pyrite as visible and sub-microscopic inclusions, suggestive of simultaneous precipitation of pyrite and gold. Hydrothermal rutile is a common constituent of the albitized zones, while magnetite, common in unaltered granodiorites, is not observed, suggesting replacement of pre-existing magnetite. Auriferous quartz-pyrite-tourmaline ± rutile veins occur within the albitized intrusions and extend out into the country schists, resulting in alteration and minor gold mineralization.

The rare earth element profiles of the albitites indicates distinct similarities to the unaltered granodiorites, confirming their genetic relationship to the granodiorites and excluding the idea of lateral secretion processes for their formation. REE analysis indicates that the HREE are enriched as the degree of albitization increases. The observed HREE enrichment may be due to the destabilization of HREE-CO_3^{-2} complexes during carbonate precipitation. This idea is reinforced by the presence of CO_2 in fluid inclusions and the predominance of carbonate minerals, especially ferroan-dolomite, within the albitized and mineralized zones. The albitized intrusions and albite pegmatites related to emerald mineralization have similar REE profiles to the spatially related Willie pluton, which suggest that the fluids responsible for albitization and pegmatite formation were ultimately derived from a granodiorite similar to the Willie pluton. The presence of beryl within the albitized intrusions and the albite pegmatites also indicates a genetic link between the two. The Willie pluton is also anomalously enriched in Au, relative to normal Archaean granodiorites.

Trace element analysis (Co, Ni, Cu, Au, Sb) of the pyrites from the albitized intrusions, albite pegmatites and Antimony Line indicates that similar fluids and physiochemical conditions prevailed during pyrite precipitation. The Antimony Line pyrite trace element content is distinctly different from that of exhalative deposits, including the Cu-Zn line. This feature excludes a volanogenic origin to the Antimony Line mineralization. The mineralized pyritic schists have reduced Ni:Co ratios, compared to the spatially related albitites, as a result of later remobilization of Ni into the pyrrhotite phases during shearing.

Fluid inclusion microthermometry indicates that the temperatures of alteration were at ± 250 °C in the Malati Store and Minerva Mine intrusions and ± 300 °C in the Discovery Shaft intrusion. Phase separation of the CO_2-H_2O fluid has occurred, indicating that the homogenization temperature is approximately that of the trapping temperature. Phase separation of the fluids within the intrusions is also proposed as a mechanism for destabilization of the gold-thiosulphide complex and precipitation of auriferous pyrite. Eutectic melting temperatures suggest complex fluids which may be represented by the NaCl-$CaCl_2$-$MgCl_2$-H_2O system. Phase separation has resulted in the formation of a saline aqueous phase and a CO_2-rich, low salinity phase. Thus it is not possible to unequivocally determine the characteristics of the pre-existing homogeneous fluid phase. However, a fluid of moderate salinity (8-10 wt% NaCl) and CO_2 content of 5-15 % with variable amounts of H_2S, is tentatively proposed. Fluid pressure at the time of trapping

is less well constrained but is estimated to be between 0.8 and 1.1 Kba (i.e. a depth of 2-3 km).

Stable isotope data indicate two distinct sources of carbon in carbonates from the Murchison schist belt. A regional sea water alteration product ($\delta^{13}C$ = -3 ± 1 $^0/_{00}$) and a magmatic (juvenile) source (δ13C = -7 ± 1 $^0/_{00}$), which was involved in the Au-Sb-beryl mineralization. The carbon isotopes of the mineralized albitized intrusions, regional quartz-lode deposits, albite pegmatites associated with emerald mineralization, and the Antimony Line, are statistically similar, suggesting that a regional, magmatic (juvenile) source was responsible for mineralization in the Murchison schist belt. The earliest carbonate reservoir is that associated with regional sea floor alteration. This carbonate cannot be the sole or even a major source of CO_2 in the mineralizing fluids of the Murchison schist belt since it has significantly more positive $\delta^{13}C$ values than the carbonates from ore deposits in the Murchison schist belt. This militates against both a metamorphic derivation of mineralizing fluids and an exhalative origin for the Antimony Line mineralization. Sulphur isotope data indicate that the sulphides associated with mineralization in the Murchison schist belt had a homogeneous $\delta^{34}S$ source (± +1 $^0/_{00}$), indicative of magmatic sulphur or leaching of pre-existing magmatic sulphur, transported as a reduced species. Local variations in the $\delta^{34}S$ values of the sulphides were due to variations in temperature and oxygen fugacity. Stable fluid conditions prevailed within the albitized intrusions with fO_2 values of approximately log 10^{-37} to 10^{-38} bars, a pH of neutral to slightly alkaline and temperatures of 250 °C to 350 °C. Gold solubility under these physiochemical conditions was at a maximum for gold-thio complexes allowing the transport of potentially ore-forming fluids. The stable isotope data from the spatially related pyritic schists and the Antimony Line indicate that redox reactions between the mineralizing fluids and possible iron-rich lithologies resulted in an increase in the fO_2, with a consequent drop in gold solubility, causing gold precipitation. There is also evidence that gold may have precipitated onto the surface of arsenic-rich pyrites, due to electrochemical processes in the Malati Store intrusion.

The calculated $\delta^{18}O$ value for the hydrothermal fluids responsible for albitization and mineralization within the intrusions is estimated to be +6 ± 1 $^0/_{00}$, which is also consistent with a magmatic origin. Mineral fractionation pairs indicate temperatures which are consistent with the fluid inclusion microthermometry. The feldspar-quartz $\delta^{18}O$ fractionation precludes low temperature sea water interaction with the granodiorite intrusions and, hence, argues against spilitization as a process related to albitization. The

isotopic data indicates that the mineralizing hydrothermal fluids were isotopically uniform and influenced large portions of the schist belt, suggestive of a large uniform source external to the schist belt and indicative of a magmatic source.

The $\delta^{18}O$ carbonate-quartz and carbonate-water fractionation does not represent equilibrium fractionation. This is probably due to late, low temperature effects during carbonate precipitation and possibly oxygen exchange with later fluids. The fluid inclusion data suggest the presence of a late, low temperature fluid which may have interacted with the carbonate and exchanged oxygen.

The distinctly spatial relationship between zones of sodium and potassium alteration suggest a zonal arrangement, where the potassium (derived from the albitized cupolas) migrated further into the country rocks resulting in zones of potassic alteration which are distant relative to the zones of sodic alteration. This study has shown that large quantities of potassium is removed from the albitized zones of the granodiorite intrusions.

The age of the granodiorite intrusions is not well constrained, but they are likely to have been generated in response to crustal thickening associated with the Limpopo Orogeny (2650-2750 Ma) (Van Reenen *et al.*, 1987; Barton and Van Reenen, 1987). Granodiorites in the Murchison schist belt are considered to have intruded along major structural discontinuities, including the Antimony Line, along with fluids derived from the crystallizing magmas (Figure 7.1). Partitioning of sulphur, gold, antimony and other elements into the fluid phases resulted in the formation of a mineralizing fluid which was concentrated within the cupola zones of the granodiorite intrusions and percolated upwards into the country rocks of the structural discontinuity. Fluid interaction with iron-rich lithologies, as well as possible phase separation of the fluid within and beyond the intrusions, resulted in the precipitation of economically viable mineralization. Although there is controversy regarding the source of hydrothermal fluids and ore components in Archaean gold deposits, the geochemical and stable isotope studies from the Murchison schist belt support the notion that, in this case a CO_2 bearing auriferous fluid was derived from the crystallizing granodiorite intrusions. Since magmatic fluids have been shown to produce economic concentrations, it is then significant that the presence of CO_2-bearing auriferous fluids in Archaean mesothermal gold deposits is not necessarily indicative of a metamorphic origin, as suggested by previous workers. The role of magmatic fluids in the formation of Au-Sb-Mo-As-Be ore bodies in the Murchison schist belt is significant in terms of exploration as it implies a direct link

between the altered, cupola zones of granitoid intrusions and the location of either endogenous or exogenous gold deposits.

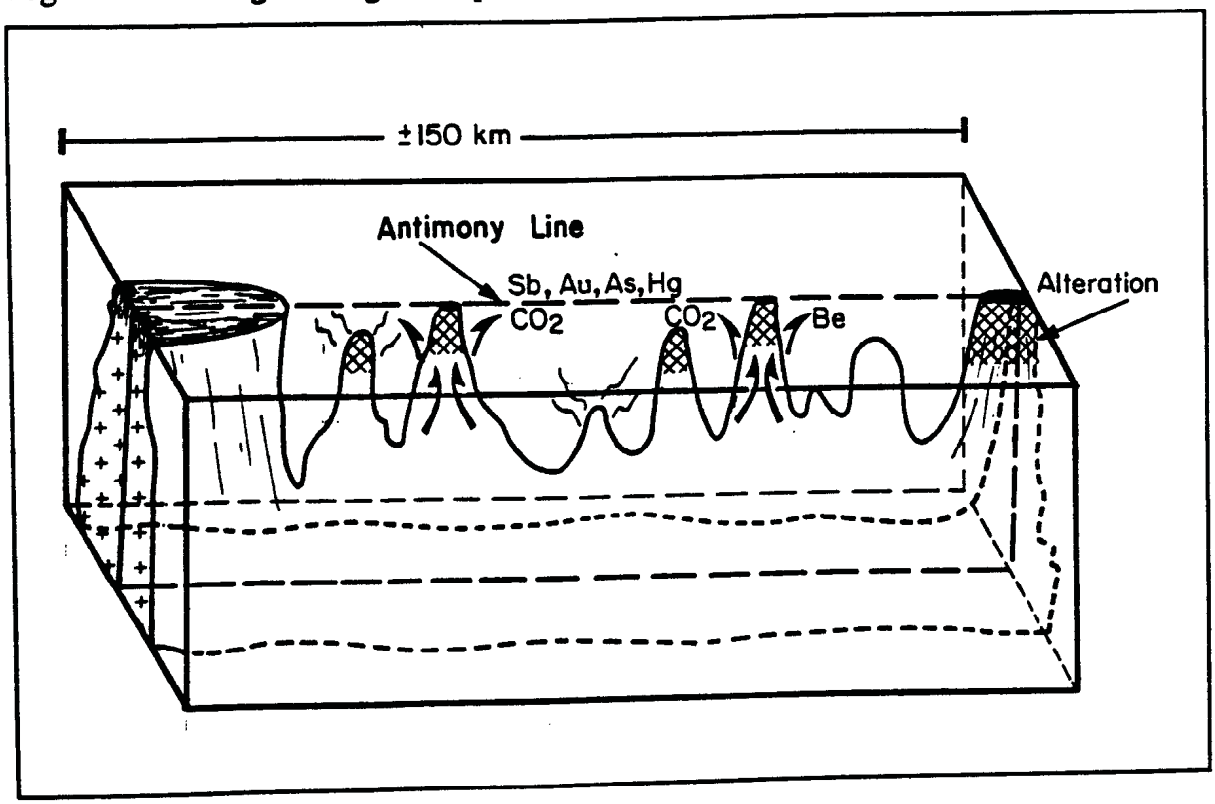


Figure 7.1. Schematic representation of the Antimony Line showing the intrusion of the granodiorite intrusion along the major structure.

This study has shown that the hydrothermal activity and mineralization within the Murchison schist belt, including the Antimony Line is inextricably linked to the intrusive granodiorites.

REFERENCES

Alderton, D.H.M., Pearce, J.A., and Potts, P.J. 1980. Rare earth element mobility during granite alteration: evidence from southwest England. Earth Planet. Sci. Lett. 49. p.149-165

Aleksiyev, E. K., 1970. Genetic significance of REE in the younger granites of Northern Nigeria and the Cameroons. Geochem. Int. p.127-132.

Allegre, C.J., Javoy, M. and Michard, G., 1968. Study of the distribution and abundance of the transition elements in the earths crust compared to those of the rare earths. (In French). *In* Ahrens, L.H., Ed Origin and the Distribution of the elements, Pergamon Press, London. 1179p

Allegre, C.J. and Michard, G. 1974. Introduction to geochemistry. Geophys. Astrophys. Monogr., 10. D. Reidel Publ. Co. Boston. 142p

Andrews, A.J., Hugon, H., Durocher, M., Corfu, F., and Lavigne, M.J., 1986. The anatomy of gold bearing greenstone belt: Red Lake, northwestern Ontario, Canada.*In* Macdonald, A.J., ed., Proceeding of Gold '86: Toronto, Ontario, Geological Association of Canada, p.2-22

Anhaeusser, C.R. 1976. Archaean Metallogeny in southern Africa. Econ. Geol., 71. p.5-43

Anhaeusser, C.R. 1983. The granitic-gneiss greenstone shield: South Africa. *In* Precambrian of the Southern Hemisphere. D. Hunter (ed) p.423-453. Elevier Science. New York.

Anhaeusser, C.R., Mason, R., Viljoen, M.J. and Viljoen, R.P. 1969. A reappraisal of some aspects of Precambrian shield geology. Geol. Soc. America Bull. 80. p.2175-2200.

Baertschi, P., and Silverman, S.R. 1951. The determination of relative abundances of the oxygen isotopes in silicate rocks. Geo. Chem. Acta. 1. p.317-328

Bains, T., 1877. Gold regions of south eastern Africa. Edward Stanford, Charing Cross, London, 240pp.

Bancroft, G.M., and Jean, G. 1982. Gold deposition at low temperature on sulphide minerals. Nature, 298. p.730-731

Barton, J.M., Jr. 1984. Timing of ore emplacement and deformation, Murchison and Sutherland greenstone belts, Kaapvaal Craton. *In* Proc. Symp. Gold, 82 Geol. Surv. Zimbabwe, Spec. Pub. 1, A.A. Blakema, Rotterdam, Netherlands

Barton, J.M. Jr. 1985. Isotopic and trace element studies of the origin, emplacement and depth of Archaean mineral deposits in the granite-greenstone terrane of the Kaapvaal Craton. Final Report, National Geosciences Programme, Open File. Geol. Surv. S. Africa.

Barton, J.M., and Van Reenen, D.D. 1987. 2650 Ma magmatism in the northern Kaapvaal craton, southern Africa. Geol. Assoc. Can. Prog. Astr. 12. p.23

Barton, J.M., and Klemd, R., Byron, C.L., and Beattie, M. 1991. Albitization and the gold-bearing Roodepoort Pluton. Pietersburg Granite-Greenstone Terrane, South Africa. Geol. Soc. S. Africa. 93. p.776-784.

Batchelor, R.A., and Bowden, P. 1985. Petrogenetic interpretation of granitoid rock series using multicationic parameters. Chem. Geol. 48. p.43-55

Battener, P. and Bird, G.W. 1974. Oxygen isotope fractionation between quartz and K-spar at 600 °C. Earth Plant. Sci. Letters. 23. p.21-27

Bajwah, Z.U., Seccombe. P.K. and Offler, R. 1987. Trace element distribution, Co:Ni ratios and genesis of the Big Canadia iron ore deposit, New South Wales, Australia. Mineral. Deposita. 22. p.292-300.

Beattie, M. 1991. Alteration and gold mineralization in the Roodepoort Goldfields, Pietersburg granite-greenstone terrane. M.Sc. thesis unpubl. Rand Afrikaans Univ. (in prep)

Bickel, M.J. Martin, J., Nisbet, E.G. 1975. Basaltic and peridotitic komatiities and stromatolites above the basal unconformatity in the Belingwe greenstone belt, Rhodesia. Earth Planet. Sci. Lett. 27. p.155-162.

Bodart, D.E., 1968. On the paragenesis of albitites. Norsk. Geologsk Tidsskrift, 48. p.269-280.

Boese, R. 1964. Die Antimonglanzgaenge von Gravelotte in der Murchison Range in nordost-Transvaal, Sud Afrika. Unpublished Ph.D. thesis. University of Hamburg 85pp.

Boocock, C.N. 1984. Ore genesis along the Antimony Line, Murchison Range, northeastern Transvaal. Unpubl. M.Sc. thesis University of the Witwatersrand, Johannesburg. 193pp

Boocock, C.N., Cheshire, P.E. Killick, A.M., Maiden, K.J. and Vearncombe, J.R. 1988. Antimony-gold mineralization at Monarch antimony mine, Murchison greenstone belt, Transvaal. Trans. Geol. Soc. S. Africa. 87. p.315-325.

Boocock, C.N. Cheshire, P.E. and Vearncombe, J.R. 1984. The structural geology of the Gravelotte shaft quarry and the Monarch antimony Mine, Murchison schist belt, Transvaal. Trans. Geol. S. Africa. 87. p.315-325.

Borthwick, J., and Harmon, R.S. 1982. A note regarding ClF_3 as an alternative to BrF_5 for oxygen isotope analysis. Geo. Chem. Acta. 46. p.1665-1668

Both, R.A., Rafter, T.A., Solomon, M., and Jenson, M.L. 1969. Sulphur isotopes and zoning of the Zeehan Mineral Field, Tasmania. Econ. Geol. 64. p.618-628

Botinelly, T., Seims, D.F., and Sanzolone, R.F. 1985. Trace elements in disseminated sulphides, magnetite, and massive sulphides, west Shasta-District, California. Econ. Geol. 80. p.2196-2205

Bowers, T.S., and Helgeson, H.C. 1983. Calculation of the thermodynamic and geochemical consequences of non-ideal mixing in the system H_2O-CO_2-NaCl on phase relations in geologic systems. metamorphic equilibria at high pressure and temperature. Am. Mineralogist. 68. p.1059-1975.

Bowles, M., Swart, M. and Hammerbeck, E.C.I. 1982. Review of tungsten mineralization in greenstone belts in the eastern and north-eastern Transvaal. Geol. Surv. S. Africa. 1. 53.pp

Boyle, R.W., 1979, The geochemistry of gold and its deposits: Geological Survey of Canada Bulletin. 280. 584pp.

Bralia, A., Sabatini, G., and Troja, F. (1979). A revaluation of the Co:Ni ration as a geochemical tool in ore genesis problems. Mineral. Deposita. 14. p.353-374.

Brown, P.E. 1989. FLINCOR: a fluid inclusion data reduction and exploration program (abstr). Second Biennial Pan-American Conf. on Research on Fluid Inclusion Prog. with Abstr. 14

Brown, P.E. and Lamb, W.M. 1989. P-V-T properties of fluids in the system H_2O-CO_2-NaCl: New graphical representation and implications for fluid inclusion studies. Geochim. Cosmochim. Acta. 53. p. 1356-1359

Browning, P., Groves, D.I., Brockley, J.G., and Rosman, K.J.R., 1987. Lead isotope constraints on the age and source of gold mineralization in the Archean Yilgarn Block, Western Australia. Econ. Geol. 82. p.971-986.

Burger, A.J. and Walraven, F. 1975/1976. Summary of age determinations carried out during the period April 1975 to March 1976. Annals Geol. Surv. S. Africa. 11. p.323-329

Burnham, C.W., 1969. Magmas and hydrothermal fluids. *In* Barnes, H.L., ed. Geochemistry of hydrothermal ore deposits. New York, Wiley Intersci. p.76-136

Burnham, C.W. and Ohmoto, H. 1980. Late-stage processes of felsic magmatism. *In* Granitic magmatism and related mineralization. Ishihara, S. and Takenouchi, S. (eds). Soc. Min. Geol. Japan. 8. p.1-11

Burrows, D.R. and Spooner, E.T.C. 1986. The McIntyre Cu-Au deposit, Timmins Ontario, Canada. *In* Gold '86. A.J. Macdonald (ed) Konsult International Inc. Toronto. p.23-39.

Burrows, D.R., and Spooner, T.C., 1987. Generation of a magmatic H_2O-CO_2 fluid enriched in Mo, Au, and W within an Archean sodic granodiorite stock, Mink Lake, Northwestern Ontario. Econ. Geol. 82. p.1931-1957.

Burrows, D.R., Wood, P.C., and Spooner, E.T.C. 1986. Carbon isotope evidence for a magmatic origin of Archean Au-quartz vein ore deposits: Nature. 321. p.851-854.

Button, A. 1973. The depositional history of the Wolkberg proto-basin, Transvaal. Trans. Geol. Soc. S. Africa. 76. p.15-25

Callan, N.J. and Spooner, E.T.C. 1989. Archean Au-quartz vein mineralization hosted in a tonalite-trondhjemite terrane, Renabie mine area, Wawa North Ontario, Canada. Econ. Geol. Monograph 6. p.9-18.

Cameron, E.M. and Hattori, K. 1987. Archean mineralization and oxidized hydrothermal fluids. Econ. Geol. 82. p.1177-1191

Carroll, M.R., and Rutherford, M.J., 1985. Sulphide and sulphate saturation in hydrous silicate melts. Jour. Geophysics Res. 90. p.C601-C612

Cathelineau, M. 1986. The hydrothermal alkali metasomatism effects on granitic rocks: Quartz dissolution and related subsolidus changes. Jour. Petrol. 27. p.945-965.

Chatterjee, A.K., and Strong, D.F., 1984. Rare-earth and other element variations in greisens and granites associated with East Kemptville tin deposits, Nova Scotia, Canada. Trans. Inst. Min. Metall. 93. p.b59-b70

Cherry, M.E., 1983. Association of gold and felsic intrusives - Examples from the Abitibi Belt. *In* The geology of gold on Ontario. Ontario Geological Survey, Miscellaneous Paper 110. p.48-55. 278p.

Claoue, J.C., King, R.W., and Kerrich, R., 1990. SHRIMP ion probe dating of the Camlfo deposit, Abitii belt. Earth Planet. Sci. Letters. 98. p.109-128

Clayton, R.N., O'Neill, J.R. and Mayeda, T.K. 1972. Oxygen isotope exchange between quartz and water. Journ. Geophy. Research. 77. p.3057-3067.

Cobra Emerald Mines Limited. 1986. Annual Reports June 30, 1986, June 30 , 1985. 23pp.

Collins, P.L.F., 1979. Gas hydrates in CO_2 bearing fluid inclusions and the use of freezing data for estimation of salinity. Econ. Geol. 74. p.1435-1444.

Colman, M.L., and Moore, M.P., 1978. A method for direct reduction of sulphates to sulphur dioxide for isotopic analysis. Analyt. Chem. 50. p.1594-1595

Colvine, A.C., Andrews, A.J., Cherry, M.E., Durocher, M.E., Fyon, A.J., Lavigne, M.J., Macdonald, A.J., Marmon, T.S., Poulsen K.H., Springer J.S., and Troop, D.G., 1984. An integrated model for the origin of Archean gold deposits. Ontario Geological Survey, Open File Report 534. 98pp.

Colvine, A.C., Fyon, K.B., Heather, S.M., Smith., P.M. Troop, D.G., 1988. Archean lode gold deposits in Ontario. Ontario Geological Survey, Miscellaneous Paper 139. 131pp

Colvine, A.C., Corfu, F., Davis, D.W., and Scott, G.M., 1985. Archaean gold mineralization and metamorphism timing and constraints from precise U-Pb dating. Geol. Soc. America. Abstract with Program. 17. p.551.

Condie, K.C. and Hunter, D.R. 1976. Trace element geochemistry of Archaean granitic rocks from the Barberton region, South Africa. Earth Planet. Sc. Lett., 29. p.389-400

Corfu, F. and Andrews, A.J. 1987. Geochronological constraints on the timing of magmatism , deformation and gold mineralization in the Red Lake greenstone belt, Northwestern Ontario. Canadian. J. Earth Sci. 24. p.1302-1320.

Corfu, F. and Wood, J. 1986. U-Pb zircon ages for late magmatism and regional deformation in the Shabandowan belt, Superior Province, Canada. Canadian Journal of Earth Science. 23. No.7. p.967-977.

Coryell, C.G., Chase, J.W and Winchester, J.W., 1963. A procedure for geochemical interpretation of terrestrial rare-earth abundance patterns. J Geophys. Res., 68. p.559-566

Cotton, F.A. and Wilkinson, G. 1966. Advanced inorganic chemistry: a comprehensive text. New York. Interscience Publ. 1136pp.

Coward, M.P, and Fairhead, J.D. 1980. Gravity and structural evidence for the deep structure of the Limpopo belt, southern Africa. Tectonophysics. 68. p.31-44.

Craig, H., 1957. Isotopic standards for carbon and oxygen and correction factors for mass spectrometric analysis of carbon dioxide. Geochim. et Cosmochim Acta. 12. p.133-149

Craig, H., 1961. Standard for reporting concentrations of deuterium and oxygen 18 in natural waters. Science. 133. 3467. p.1833-1834.

Diagneault, R., Perralut, G., and Berdard, P., 1983. Geologie et geochimie de la mine Lamaque, Val d'Or, Quebec: Canadian Institute of Mining Bulletin. 76. p.111-127.

Davies, J.F., Whitehead, R.E.S., Cameron, R.A., and Duff, D. 1982. Regional and local patterns of CO_2-K-Rb-As alteration: A guide to gold in the Timmins area. *In* Hodder, R.W. and Petruk, W., eds., Geology of the Canadian gold deposits: Canadian Institute of Mining and Metallurgy. Spec. Vol. 24. p.130-143

Davis, D.R., Paterson, D.B. and Griffiths, D.H.C. 1986. Antimony in South Africa. Mineral Resources of the Republic of South Africa (5th edition). p.107-110.

De Beer, J.H., Stettler, E.H., Duvenhage, A.W.A, Joubert, S.J. and Raath, C.J.De W. 1984. Gravity and geochemical studies of the Murchison greenstone belt, South Africa. Trans. Geol. Soc. S. Africa. 87. p.347-359.

De Beer, J.H. 1985. A geophysical study of the deep structure of the Barberton and Murchison greenstone belts. Final Report National Geoscience Programme. Open File. Geol. Survey. S. Africa.

De la Roche, H., 1964. Surl,expression graphique des relations entre la composition chimique et la composition mineralogique quantitative des roches cristallines - Presentation d'un diagramme destine a l'etude chimico-mineralogique des massifs granitique et granodioritiques - Application aux Vosges cristallines. Sci. Terre. 9. p.293-337

De la Roche, H. and Leterrier, J., 1973. Transposition du tetraedre mineralogique de Yoder et Tilly dans un diagramme chimique de classification des roches basaltiques. C.R. Acad. Sci. Paris, Ser. D. 276. p.3115-3118

De la Roche, H., Leterrier, J., Granclaude, P. and Marchal, M. 1980. A classification of volcanic and plutonic rocks using R1R2-diagram and major element analysis - its relationship with current nomenclature. Chem. Geol. 29. p.183-210.

de Ronde, C.E.J., Spooner, E.T.C., Bray, C.J. and de Wit, M.J. 1991. Mafic-ultramafic hosted, shear zone related, Au-quartz vein deposits in the Barberton greenstone belt, South Africa: structural style, fluid properties and light stable isotope geochemistry. Brazil Gold '91. E.A. Ladeira (ed) Balkema. Rotterdam. p.279-286.

Deins, P. and Gold, D. P. 1973. The isotopic composition of carbonatites and kimberlite carbonates and their bearing on the isotopic composition of deep-seated carbon. Geochimica et Acta. 37. p.1709-1733.

Donnelly, T.H., Lambert, B., Oehler, D.Z., Hallberg, J.A., Hudson, D.R., Smith, J.W., Bavinton, O.A., and Golding, L., 1977. A reconnaissance study of stable isotope ratios in Archaean rocks from the Yilgarn Block, Western Australia. Geol. Soc. Aust. 24. p.409-420.

Eggler, D.H. 1974. Application of a portion of the system $CaAl_2Si_2O_8$-$NaAlSi_3O8$-SiO_2-MgO-FeO_2-H_2O-CO_2 to the genesis of the calc-alkaline suite; American. Joun. Science. 274. p.297-315

Foster, R.P. 1982. Gold and silver in Zimbabwe. *In* Foster, R.P., ed. Gold '82. Rotterdam, A.A. Balema Pub. p.39-54.

Foster, R.P. 1980. The controls of gold deposition in Archean gold deposits. Mining and Engineering (Zimbabwe) p.21-23.

Franklin, J.M., Roscoe, S.M., Loveridge, .D., and Sangster, D.F., 1983. Lead isotope studies Superior and Southern Provinces. Geol. Surv. Canada. 351. 60p.

Friend, C.R.L. 1985. Evidence of fluid pathways through Archaean crust and the generation of the Closepet Granite, Karnataka, South India. Precam. Res. 27. p.239-250

Fripp, R.E.P. 1976. Stratabound gold deposits in Archaean banded iron-formations, Rhodesia. Econ. geol. 71. p.68-75.

Fripp, R.E.P., Van Neirop, D.A, Callow, M.J., Lilly, P.A. and du Plessis, L.U. 1980. Deformation in part of the Archaean Kaapvaal Craton, South Africa. Precambrian Research. 13. p.241-251

Fritz, P., Drimmie, R.J., and Nowicki, V.K., 1974. Preparation of sulphur dioxide for mass spectrometer analysis by combustion of sulphides with copper oxide. Analytical Chemistry. 47. p.1179-1181.

Freyer, B.J., Kerrich, R., Hutchinson, R.W., Peirce, M.G. and Rogers, D.S. 1979. Archaean precious-metal hydrothermal systems, Dome Mine, Abitibi greenstone belt. I. Patterns of alteration and metal distribution, Canadian Journal of Earth Sciences. 16. p.421-439

Frost, B.R. and Frost, C.D. 1987. CO_2, melts and granulite metamorphism. Nature. 327. p.503-506

Fyfe, W.S. and Henley, R.W. 1973. Some thoughts on chemical transport processes with particular references to gold. Mineral Science and Engineering. 5. p.295-303

Fyfe, W.S., and Kerrich, R., 1984. Gold: Natural concentration processes. *In* Foster, R.P., ed. Gold '82: Rotterdam, A.A. Balema Pub. p.99-127.

Fyon, J.A. 1986. Field and stable isotopic characteristics of carbonate alteration zones. Timmins area. Unpubl. PhD. thesis. McMaster University, Hamilton, Ontario, 399pp

Fyon, J.A., Crocket, J.H., and Schwarcz, H.P., 1983. Application of stable isotope studies to gold metallogeny in the Timmins-Porcupine camp. Ontario Geological Survey, Open File Report, 5464. 1832pp

Fyon, J.A., and Crocket, J.H. 1982. Gold exploration in the Timmins District using field and lithogeochemical characteristics of carbonate alteration zones. *In* Geology of Canadian Gold deposits. Canadian Institute of Min. and Met. 24. p.113-129

Fyon, J.A. Scvhwarcz, H.P., Crocket, J.H. and Knf, M. 1982. Gold exploration potential using oxygen, carbon and hydrogen stable isotope systematics of carbonated rock and quartz veins, Timmins area. In Geoscience Research grant programme. Ontario Geological Survey. Miscellaneous paper 103. 219p.

Fyon, A.J., Schwarcz, H.P., and Crocket, J.H., 1984. Carbonatization and gold mineralization in the Timmins area, Abitibi greenstone belt: Genetic links with Archean mantle CO_2 degassing and lower crustal granulitization (abs.): Geol. Assoc. Canada-Mineral. Assoc Canada Ann. Program with abstracts. 9. p.65.

Gallagher, D., 1940. Albite and gold. Econ. Geol. 35. p.698-736.

Gary, M., McAfee, R.,Jr., and Wolf, C. L., eds., 1974. Glossary of Geology. Washington. D.C., Am. Geol. Inst. 860pp

Ghosh-Dastidar, P., Pajari, G.E and Trembath, L.T. 1970. Factors affecting the trace element partition coefficients between coexisting sulphides. Econ. Geol. 65. p.815-837.

Glickson, A.Y. 1976. Trace element geochemistry and origin of early Precambrian acid igneous series, Barberton mountain land. Geochim. Cosmo. Acta. 40. p.1261-1280.

Golden Dumps Research. Felsic intrusions of GEM. Unpubl. company report.

Golding, S.D. 1982. An isotopic and geochemical study of gold mineralization in the Kalgoorlie-Norseman region. Unpubl. Ph.D. Brisbane. Australia. Univer. Queensland. 353pp

Golding, S.D., Groves, D.I., McNaughton, N.J., Barley, M.E., and Rock , N.M.S. 1987. Carbon isotopic composition of carbonates from contrasting alteration styles in supercrustal rocks of the Horseman-Wiluna Belt, Yilgarn Block, Western Australia; Their significance to the source of Archaean auriferous fluids. *In* Recent understanding of Precambrian Gold Deposits. Editor S.E. Ho. U.W.A. No. 11. p.215-238

Golding, S.D., and Wilson, A.F., 1983. Geochemical and stable isotope studies of the No. 4 lobe, Kalgoorlie, Western Australia. Econ. Geol. 178. p.438-450.

Goldschmidt, V.M., 1954. Geochemistry. Muir, A., Ed. Oxford Univ. Press. London, 730pp

Goodwin, A.M. 1965. Volcanism and gold deposition in the Birch Uchi Lakes area. Canadian Institute of Mining and Metallurgy. 68. p.91-104

Graf, J.L., 1977. Rare earth elements as hydrothermal traces during the formation of massive sulphide deposits in volcanic rocks. Econ. Geol. 72. p.527-548.

Graham, R.H. 1974. A structural investigation of the southern part of the Limpopo belt and the Kaapvaal craton. Report research Institute Africa geology. University Leeds. 18. p.63-69.

Grant, J. A., 1986. The isocon diagram - A simple solution to Gresens' equation for metasomatic alteration. Econ. Geol. 81. p.1976-1982.

Gresens, R.L., 1967. Composition - volume relationships of metasomatism. Chem. Geol. 2. p.47-55.

Grinenko, V.A. and Grinenko, L.N. 1976. Fractionation of sulphur isotopes in high temperature decomposition of sulphides by water vapour. Geochem. Intern. 4. p.843-845

Groves, D.I., Golding, S.D., Rock, N.M.S., Barley, M.E., and McNaughton, N.J., 1988. Archaean carbon reservoirs and their relevance to the fluid source for gold deposits. Nature, 331. p.254-257.

Groves, D.I., and Phillips, G.N., 1987. The genesis and tectonic controls on Archean gold deposits of the western Australia shield - a metamorphic replacement model. Ore Geology Reviews. 2. p.287-322.

Groves, P.I., Phillips, G.N. Ho, S.E., Henderson, C.A, Clark, M.E. and Wood, G.M., 1984. Controls on distribution of Archaean hydrothermal gold deposits in Western Australia. *In* Foster, R.P., ed. Gold '82: Rotterdam, A.A. Balema Pub.,

Groves, P.I., Phillips, G.N. Ho, S.E., and Houston, S.M. 1985. The nature, genesis and regional controls of gold mineralization in Archaean greenstone belts of Western Australian shield: A brief review. Geol. Soc. S. Africa. 88. p.135-148

Grundmann, G., and Morteani, G. 1989. Emerald mineralization during regional metamorphism: The Habachtal (Austria) and Leysdorp (Transvaal, South Africa) deposits. Econ. Geol. 84. p.1835-1849.

Hall, A.L., 1912. The geology of the Murchison Range and Zoutpansberg district. Mem. Geol. Surv. S. Afr. 6. 186pp.

Hall, D.L, Sterner, S.M. and Bodnar, R.J. 1988. Freezing point depression of NaCl-KCl-H_2O solutions. Econ. Geol. 83. p.197-202.

Harker, A.A., 1909. The Natural History of Igneous Rocks. Methuen, London. 384pp

Harris, M., 1980. Hydrothermal alteration at Salave gold prospect, northern Spain. Trans. Inst. Min. Metall. 89. p.B5-B15.

Haskin, L. A., Frey, F.A., Schmitt, R. A., and Smith, R.A. 1966. Meteoric, solar and terrestrial rare earth distributions. *In* Physics and Chemistry of the earth. 7. New York, Pergaman Press, p.167-321

Haskin, L.A., Haskin, M.A., Frey, F.A. and Wildeman, T.R., 1968. Relative and absolute abundances of rare earths. *In*: L.H. Ahrens (Editor), Origin and distribution of the elements, 1. Pergamon, Oxford. 353pp.

Hattori, K., 1987. Magmatic felsic intrusions associated with Canadian Archean gold deposits. Geology, 15. p.1107-1111.

Hausmann, S.G., 1959. A mineralogical investigation of the Letaba copper-zinc ores and the Monarch cinnabar deposits located on the Murchison Range of the eastern Transvaal. M.Sc. thesis (unpub) University of the Witwatersrand. 149pp

Hayashi, K., and Ohmoto, H. 1991. Solubility of gold in NaCl- and H_2S bearing aqueous solutions at 250-350°C. Geochim. Cosmochim. Acta. 55. p.2111-2126

Heinrich, E.W., 1965. Microscopic identification of minerals. McGraw-Hill book company. New York. p.360-361

Henley, R.W. 1973. Solubility of gold hydrothermal chloride solutions. Chem. Geol. 11. p.73-87

Henley, R.W. 1985. The geothermal frame work of epithermal deposits. *In* Geology and geochemistry of epithermal systems. Bergr, B.R. and Bethke, P.M. (eds) Reviews in economic geology. Soc. Econ. Geol. 2.

Herrmann, A.G., 1970. Yittrium and lanthanides. *In* Wedepohl, K.H., Ed., Handbook of geochemistry, Vol.II Springer-Verlag, Berlin. 39. p.57-71.

Ho, S.E., 1987. Fluid inclusions: their potential as an exploration tool for Archaean gold deposits. *In* Recent Advances in understanding Precambrian Gold Deposits. Ho, S.E. and Groves, D.I. (Eds.). University of Western Australia. 88. p.239-263

Ho, S.E., Groves, D.I., and Phillips, G.N. 1985. Fluid inclusions as indicators of the nature and source of source fluids and ore depositional conditions for the Archaean gold deposits of the Yilgarn block, Western Australia. Geol. Soc. South Africa. 88. p.149-158

Hodgson, C.J., 1983. The structure and geological development of the porcupine Camp - A re-evaluation. p.211-225. *In* Geology of Gold in Ontario. A.C. Colvine (Ed), Ontario Geological Survey, Miscellaneous Papers 110. 278p.

Hoefs, J. 1980. Stable isotope geochemistry. 2nd Edition. Sringer Verlag. New York. 208pp

Holloway, J.R. 1976. Fluids in the evolution of granitic magmas: Consequences of finite solubility. Geol. Soc. America. Bull. 87. p.1513-1518.

Holloway, J.R. and Lewis, C.F. 1974. CO_2 solubility in hydrous albite liquid at 5 kbar (abstract). EOS. Trans. American Geophy. Union. 55. p.483

Ileri, M. 1973. Genesis and fabric study of stibnite ores at the Murchison Range, South Africa. Ph.D. thesis (unpubl.), Columbia Univ. New York.

Jackson, N.J., 1975. "Carbonas"- a review: Proc. Usher Society. 3. part 2. p.218-219.

Jacobson, R.R.E., Macleod, W.N., and Black, R., 1958. Ring complexes in the younger granite province of northern Nigeria. Geol. Soc. London, Memoir No.1.

Jenson, M.L., 1967. Sulphur isotopes and mineral genesis. *In* Barnes, H.L., (Ed) Geochemistry of hydrothermal ore deposits. New York. p.143-165

Jensen, M.L. and Nakai, N. 1963. Sulphur isotope meteorite standards, results and recommendations. *In* bio-geochemistry of sulphur isotopes. Nat. Sci. Foundation Sym. 3. p.143-165

Jemielita, R.A., Davis, D.W., and Krogh, T.E. and Spooner, E.T.C. 1989. Chronological constraints on the origin of Archaean lode gold deposits in the southern Superior Province from U-Pb isotopic analysis of hydrothermal rutile and titanite. Geol. Soc. America. Abstracts. 21. A351.

Jeppe, F. 1893. The Zoutpansberg Goldfield in the South African Republic. Geographical Journal (September). p.213-237.

Kaplan,I.R., Smith, J.W., and Ruth, E., 1970. Carbon and sulphur concentrations and isotopic compositions on Apollo II Lunar samples. Geochim. Cosmochim. Acta. 28. p.1787-1816.

Karauti, G. 1941. Synthetic study of gold-containing pyrite. Chem. Abstracts. 35. p.3563.

Katsurs, T., and Nagashima, S., 1974. Solubility of sulphur in some magmas at 1 atmosphere. Geochim. et Cosmochim. Acta. 38. p.517-531.

Kerrich, R. 1983. Geochemistry of gold deposits in the Abitibi greenstone belt. Canadian Institute of Min. and Met. 27. 75pp

Kerrich, R. 1986. Fluid transport in lineaments. Royal Society of London Philosophical Transactions. A. 317. p.219-251

Kerrich, R. 1987. The stable isotope geochemistry of Au-Ag vein deposits in metamorphic rocks. Min. Assoc. Canada. Short Course Handbook. 13. p.287-336.

Kerrich, R. 1989. Archean gold: Relation to granulite formation or felsic intrusions? Geology. p.1011-1015

Kerrich, R., and Fryer, B.J. 1979. Archaean precious metal hydrothermal systems, Dome Mine, Abitibi Greenstone Belt. II. REE and oxygen isotope relations. Canadian Journal of Earth Sciences. 16. p.440-458.

Kerrich, R., and Fyfe, W.S., 1981. The gold-carbonate association: Source of CO_2, and CO_2 fixation reactions in Archean lobe deposits. Chem. Geology. 33. p.265-295.

Kerrich, R., Fryer, B.J., King, R.W., Willmore, L.M., and van Hees, E. 1987. Crustal outgassing and LILE enrichment in major lithosphere structures, Archean Abitibi greenstone belt: evidence on the source reservoir from strontium and carbon isotope traces. Contrib. Miner. Pet. 97. p.156-168.

Kilinc, I. A., and Burnham, C.W. 1972. Partitioning of chloride between a silicate melt and coexisting aqueous phases from 2 to 8 kilobars. Econ. Geol. 67. p.231-235

Knipe, S.W. and Foster, R.P. 1991. Hydrothermal precipitation of precious metals on sulphide substrates. *In* Brazil Gold '91. Ladeira, E.A. (ed.) Balkema. Rotterdam. p.431-435.

Kosterin, A.V. 1959. The possible modes of transport of the rare earths by hydrothermal solutions. Geochemistry International (U.S.S.R) (English translation) 1. p.381-386.

Kullerud, G. and Yoder, H.S. 1964. Sulphide silicate relations. Carn. Inst. Washington, Ann. Report. 64. p.162-193.

Lafitte, M. and Maury, R. 1983. The stoichiometry of sulphides and its evolution: a chemical study of pyrites, chalcopyrites and sphalerites from terrestrial and oceanic environments. Earth Planet. Sci. Lett. 64. p.145-152.

Larsen, Jr., E.S, 1938. Some new variation diagrams for groups of igneous rocks. J. Geol., 46. p.505-520

Lambert, I.B., Donnelly, T.H., Dunlop, J.S.R., and Groves. 1978. Stable isotopic compositions of early Archean sulphate deposits of probable evaporitic and volcanogenic origins. Nature. 276. p.808-811

Lambert, I.B., Phillips, G.N., and Groves, D.L., 1984. Sulphur isotope compositions and genesis of Archean gold mineralization, Australia and Zimbabwe. *In* Foster, R.P., ed. Gold '82: Rotterdam, A.A. Balema Pub., p.373-387.

Lavigne, M.J.Jr., 1983. Geological, geochemical and sulphur isotopic investigations of gold mineralization and sulphide facies banded ironstone formations at the Dickenson and Campbell Red Lake Mines, Red Lake, Ontario. M.Sc. McMaster University (unpubl.), 324p

Light, M.P.R. 1982. The Limpopo mobile belt: A result of continental collision. Tectonics. 1. p.325-342

Loftus-Hills, G and Soloman, M. 1967. Cobalt, nickel and selenium in sulfides as indicators of ore genesis. Mineral Deposita. 2. p.228-242.

Lowell, J.D. and Guilbert, J.M. 1970. Lateral and vertical alteration - mineralization zoning in porphyry ore-deposits. Econ. Geol. 65. p.373-408.

Macdonald, A.J. and Fyon, J.A. 1986. Sulphidation - The key to gold mineralization in banded iron formation. *In* Foster, R.P., ed. Gold '82: Rotterdam, A.A. Balema Pub. p.96-97.

Macdonald, A.J., and Ray, G.E. 1984. Fluids responsible for lode gold deposition in the Cordillera and Superior Province: Implication for cost-effective exploration technique. Cordillera Section GAB Symposium. Vancouver. p.21.

Maiden, K.J. 1984. Metamorphic features of the Maranta J copper-zinc deposit, Murchison greenstone, belt, Transvaal. Trans. Geol. Soc. S Africa. 87. p.335-345.

Martini, J.E.J. 1980. On some occurrences associated with emerald deposits in the Gravelotte area, eastern Transvaal. Geol. Surv. S. Africa. 87. p.327-333.

Mason, R. and Melnik, N. 1986. The anatomy of an Archean gold system - The McIntyre-Hollinger complex at Timmins, Ontario, Canada. Gold '86. A.J. Macdonald (ed) Konsult International Inc. Toronto. p.40-55.

Masuda, A., 1962. Regularities in variation of relative abundances of lathanides elements and an attempt to analyses separate-index patterns of some minerals. J.Earth Sci. Nagoya Univ. 10. p.173-187.

Mathez, E.A. 1984. Influence of degassing on oxidation states of basaltic magmas. Nature. 310. p.371-375.

Maufe, H.B. 1913. The association of gold deposits with acid igneous rocks in Southern Rhodesia. Geol. Surv. of Rhodesia. 2

McNeil, A. M. and Kerrich, R. 1985. Archaean lamprophyric dykes and gold mineralization, Matheson, Ontario: the conjunction of LIL-enriched mafic magma, deep crustal structures and Au concentration. Can. J. Earth Science (in press).

McCourt, S., and Vearncombe, J.R. 1987a. Shear zones bounding the central zone of the Limpopo mobile belt. J. Struct. Geol. 9. p.127-137.

McCourt, S., and Vearncombe, J.R. 1987b. Crustal-scale shear zones in the Limpopo belt, southern Africa. Geol. Assoc. Can. Prog. Abstr. 12.

McNaughton, N.J. Cassidy, K.F., Dahl, N, J.R., De Laeter, S.D., Golding, S.D., Groves, D.I., Ho, S.E., Mueller, A.G., Perring, C.S., and Sang, J.H. 1990. The source of ore components in lode-gold deposits of the Yilgarn Block, Western Australia. *In* Third Inter. Archaean Symp. Extend. Abstracts. Geoconferences (W.A.) Inc. Perth.

Meinert, L.D. 1989. Gold skarn deposits - geology and exploration criteria. Econ. Geol. Monograph 6. p.537-552.

Mellor, E.T. 1906. The geology of the District about Haenertsburg, Leydsdorp, and the Murchison Range. Report Geol. Surv. Trans. p.23-52.

Meneyev, D.A., 1963. Geochemical differentiation of the rare-earths. Geochem. (U.S.S.R). 12. p.1129-1149.

Mendelssohn, H. 1905. The gold deposits of the central Murchison Range in the north-eastern Transvaal. Trans. Geol. Soc. S. Africa. 8. p.42-46

Meyer, F.M., Robb, L.J., Oberthur, T., Saager, R., and Stupp, H.D. 1990. Cobalt, nickel, and gold in pyrite from primary gold deposits and Witwatersrand reefs. S. Afr. J. Geol. 93. p.70-82

Meyer, F.M., Oberthur, Th., Robb, L.J., Saager, R., and Stupp, H.D. 1985. Ni, Co, and Au contents of pyrites from the Archaean granite-greenstone terranes and early Proterozoic sedimentary deposits in southern Africa. Inf. Cir. Econ. Geol. Res. Unit. Univ. Witwatersrand, 176.

Meyer, F.M., Robb, L.J. and Anhaeusser, C.R. 1987. Uranium and thorium distribution in late-stage granite plutons from the Barberton Mountainland, South Africa. ISGAM Extended Abstracts. (Salvador, Bahia, Brazil). p.271-274.

Meyer, F.M., and Saager, R., 1985, The gold content of some Archean rocks and their possible relation to epigenetic gold-quartz vein deposits: Mineral deposita. 20. p.284-289

Mitchel, R.A. 1968. A semi-quantitative study of trace elements in pyrite by spark source spectrometry. Norsk. Geol. Tiddsskrift. 48. p.65-80

Mineyev, D.A., 1963. Geochemical differentiation of the Rare-Earths. Geochemistry. 12. p.1129-1149

Minnitt, R.C.A., 1975. The geology of the eastern portion of the Murchison Range between the Quagga Camp area and the Kruger National Park. M.Sc. thesis (unpubl.), Univ. Witwatersrand, Johannesburg.

Minronov, A.G., Zhmodik, S.M., and Maksimova, E.A. 1981. An experimental investigation of the sorption of gold by pyrite with different thermoelectric properties. Geochem. International. 18. No.2. p.153-160

Moller, P., Morteani, G., Hoefs, J. and Parekh, P.P., 1979. The origin of the ore-bearing solutions in the Pb-Zn veins of the Western Harz, Germany, as deduced from rare-earth element and isotope distributions in calcite. Chem. Geol. 26., p.197-215

Muff, R. 1976. The antimony deposits in the Murchison Range of the northern Transvaal. Republic of South Africa. Min. Deposits. 16. 90p

Muff, R. and Saager, R. 1979. Metallogenic interpretations from a mineralgraphic and geostatistic study of the antimony ores of the Murchison greenstone belt, South Africa. Spec. Publ. geol. S. Afr. 5. p.167-179.

Murad, E. 1974. Hydrothermal alteration of granitic rocks and its possible bearing on the genesis of mineral deposits in the southern Black Forest, Germany. Econ. Geol. 69. p.532-544

Murowchick, A.N., and Barnes, H.L. 1987. Pyrite morphology. Amer. Min. 72. p.1241-1250.

Munha, J., Fyfe, W.S., and Kerrich, R. 1980. Adularia, the characteristic mineral of felsic spillites. Contrib. Min. and Pet. 75. p.15-19

Mysen, B.O. 1976. The role of volatiles in silicate melts: solubility of carbon dioxide and water in feldspar, pyroxene, and feldspathoid melts to 30 Kb and 1625°. American Jour. of Science. 276. p.969-996

Nagasawa, H. and Schnetzler, C.C. 1971. Partitioning of rare earth, alkali, and alkaline earth elements between phenocrysts and acidic igneous magma. Geochim. et Cosm. Acta. 35. p.953-968

Nash, J.T. 1976. Fluid inclusion petrology - data from porphyry copper deposits and applications to exploration. United States Geol. Survey. 907-D. 16pp

Nakai, N. and Jenson, M.L. 1964. The kinetic isotope effects in the bacterial reduction and oxidation of sulphur. Geochim. Cosmochim. Acta 28. p.1893-912

Nesbitt, B.E., Murowchick, J.B., and Muuehlenbachs, K. 1986. Dual origins of lode gold deposits in the Canadian Cordillera. Geology. 14. p.506-509

Neuerburg, G.J. 1975. A procedure using hydrofluoric acid for quantitative mineral separation from silicate rocks. U.S. Geol. Surv. Journ. Res. 3. p.377-378.

Nothop, D.A. and Clayton, R.N. 1966. Oxygen-isotope fractionation in systems containing dolomite. Jour. Geology. 74. p.174-196

Nutt, T., McCourt, S., and Vearncombe, J.R. 1988. Structure of some gold and antimony-gold deposits from Zimbabwe cratons. Geology Dept. and Univ. Extension, Univ. of Western Australia Publication. 12. p.63-80

Nwe, Y.Y. and Morteani, G. Fluid evolution in the H_2O-CH_4-CO_2-NaCl system during emerald mineralization at the Gravelotte, Murchison Greenstone Belt, N.E. Transvaal, South Africa. In Press.

Ohmoto, H. 1972. Systematic of sulphur and carbon isotopes in hydrothermal ore deposits. Econ. Geol. 72. p.551-578.

Ohmoto, H. 1986. Stable isotope geochemistry of ore deposits. Rev. Mineralogy. 16. p.491-567

Ohmoto, H., and Rye, R.O. 1979. Isotopes of sulphur and carbon, *In* Barnes, H.L., ed., Geochemistry of hydrothermal ore deposits: New York, Wiley-Intersci. p.509-567.

O'Neil, J.R., Clayton, R.N., and Mayeda, T.K. 1969. Oxygen isotope fractionation in divalent metal carbonates. Journ. Chem. Physics. 51. p.5547-5558

O'Neil, J.R., and Taylor, H.P., Jr. 1967. The oxygen isotope and cation exchange chemistry of feldspars. Am. Min. 52. p.1414-1437

Pearce, T.H., 1969. A contribution to the theory of variation diagrams. Contrib. Mineral. Petrol., 19. p.142-157

Pearton, T.N., 1978. The geology and geochemistry of the Monarch ore body and environs, Murchison Range, north-eastern Transvaal. *In* Verwoerd, W.J. ed. Mineralization in metamorphic terrains. Spec. Publ. Geol. Soc. S Africa. 4. p.77-86.

Pearton, T.N. 1979. A geochemical investigation of the carbonate and associated rocks of the Monarch antimony mine, Murchison Range, north-eastern Transvaal. Spec. Publ. Geol. Soc. S. Africa. 5. p.159-166

Pearton, T.N. 1980. The geochemistry of the carbonate and related rocks of the antimony line, Murchison greenstone belt, with particular reference to their genesis and to the origin of stibnite mineralization. Ph.D. thesis (unpub.), Univ. Witwatersrand, Johannesburg.

Pearton, T.N. 1982. Gold and antimony mineralization in altered komatiites of the Murchison greenstone belt. South Africa. *In*: Anhaeusser, C.R. and Maske, S. eds. Mineral deposits of Southern Africa. Geol. Soc. S. Africa. p.293-320.

Pearton, T.N., and Viljoen, M.J. 1986. Antimony mineralization in the Murchison greenstone belt - an overview. *In*. Anhaeusser, C.R. and Maske, S eds. Mineral Deposits of Southern Africa. Geol. Soc. S. Africa. p.293-320.

Peppard, D.F., Mason, G.W., and Hucher, I. 1962. Stability constants of certain lanthanide (III) and actinide (III) chloride and nitrate complexes. Jour. Inorganic Nuclear Chemistry. 24. p.881-888

Peterman, Z.E., 1979. Strontium isotope geochemistry of late Archaean to Cretacious tonalities and trondhejemites. *In* Barker, F.J., ed. Trondhejemites, dacites and related rocks. Amsterdam, Elsevier. p.133-148

Perring, C.S., Groves, D.I, and Ho, S.E. 1987. Constraints on the source of auriferous fluids for Archaean gold deposits. *In* Recent understanding of Precambrian Gold Deposits. Editor S.E. Ho. U.W.A.No. 11. p.287-306.

Perring, C.S., Groves, D.I, Shellabear, J.N., and Hallberg, J.A. 1991. Precambrian Research. 51. p.85-113.

Phillips, G.N. 1986. Geology and alteration in the Golden Mile, Kalgoorlie. Econ. Geol, 81. p.779-808

Phillips, G.N. and Groves, D.I. 1984. Fluid access and fluid-wallrock interaction in the genesis of Archaean gold-quartz vein deposits at Hunt mine, Kambalda, Western Australia. *In* Gold '82. Foster, R.P. (ed). Balkema, Rotterdam. p.689-712.

Pitcher, W.S. 1979. Comments on the geological environments of granites. *In* M.P. Atherton and J. Tarney (Eds.). Origin of Granite Batholiths - Geochemical Evidence. Shive, Orpington. p.1-8

Price, B.G. 1972. Minor elements in pyrites from the Smithers Map area, B.C. and exploration applications of minor elements studies. Unpubl. Ph.D thesis Univ. British Columbia. 270pp.

Prider, R.T. 1940. A note on the age relations of the basic porphyries and albite porphyries of the Golden Mine, Kalgoorlie, Western Australia. Journ. Royal Soc. W.A. 31. p.99-101

Robb, L.J., and Robb, V.M., 1986. Archean pegmatite deposits in the NE Transvaal. *In* Mineral Deposits of South Africa. Vol. 1. Anhauesser, C.R and Maske, S. (Eds.). Geol. Soc. S. Afr. Johannesburg.

Robert, F. and Kelly, W.C. 1987. Ore-forming fluids in Archean gold bearing veins at the Sigma Mine, Abitibi greenstone belt, Quebec, Canada. Econ. Geol. 82. p.1464-1482.

Roberts, R.G. 1987. Ore deposit models, Number 11: Archaean lode gold deposits. Geoscience Canada. 14. p.37-52

Robinson, B.W., and Kusakabe, M., 1975. Quantitative interpretation of sulphur dioxide, for $^{34}S/^{32}S$ analyses, from sulphides by combustion with cuprous oxide. Analytical Chemistry. 47 p.1179-1181.

Rock, N.M.S., and Groves D.I. 1988a. Can Lamprophyres resolve the genetic controversy over mesothermal gold deposits? Geology. 16. p.538-541

Rock, N.M.S., and Groves D.I. 1988b. Do lamprophyres carry gold as well as diamonds? Nature. 332. p. 253-255

Rock, N.M.S., Duller, P., Haszeldine, R.S., and Groves, D.I. 1987. Lamprophyres as a potential gold exploration targets. Univ. Western Australia. Geol. Department and Extension Publications. 11. p. 271-286

Roeder, E., 1984. Fluid inclusion evidence bearing on the environment of gold deposition. in Proc. Symp. Gold 82, Geol. Soc. Zimbabwe, Spec. Pub. 1, A.A. Balkema, Rotterdam, The Netherlands.

Roeder, E,. 1984b. Fluid inclusions. Min. Soc. Am. Reviews in Mineralogy. 12. 644 p.

Roeder, E., 1979. Fluid inclusions as samples of ore fluids. *In* H.L., Barnes (ed.). Geochemistry of hydrothermal ore deposits. 2nd edn. Wiley Interscience, New York. p.684-737

Romberger, S.B. 1986. Ore deposits #9. Disseminated gold deposits: Geoscience Canada. 13. p.23-31

Roth, E., Groves, D., Anderson, G., Daley, L, and Staley, R. 1991. Primary mineralization at the Boddington gold mine, Western Australia: An Archaean porphyry Cu-Au-Mo deposit. *In* Brazil Gold '91. E.A. Ladeira (ed.). Balkema, Rotterdam. p.481-488.

Saager, R., and Koppel, V., 1976. Lead isotopes and trace elements from sulphides of Archaean greenstone belts in South Africa - A contribution to the oldest known mineralization. Econ. Geol. 71. p.44-57

Saager, R., and Koppel, V., 1983. Gold distribution in Archaean granitoids and supercrustal rocks from southern Africa: a comparison. *In* Foster, R.P. Ed. Gold '82. Balkema Publ. Rotterdam. p.53-70.

SACS. South African Committee for Stratigraphy. 1980. Stratigraphy of South Africa. Part 1. Lithostratography of the republic of South Africa, South West Africa/Namibia and the Republics of Boputhatswana, Transkei and Venda. Handbook Geol. Surv. S. Africa. 8

Sakai, H., 1968. Isotopic properties of sulphur compounds in nature. Geochimica et Cosmochimica Acta. 12. p.150-169.

Sakai, H., 1969. Isotopic properties of sulphur compounds in hydrothermal processes. Geochem. Jour. 2. p.29-49.

Schidlowski, M., Eichmann, R. and Junge, C.E. 1975. Precambrian sedimentary carbonates. C and O isotope geochemistry and implications for the terrestrial oxygen budget. Precamb. Res. 2. p.1-69

Schwarcz, H.P. and Rees, C.E. 1985. Sulphur isotope studies of Archaean gold deposits. *In* Geoscience Research Grant Program, Summary of Research 1984-1985. Ontario Geological Survey, Miscellaneous Paper 127. 24p.

Scott, K.M. 1986. Sulphide geochemistry and wall rock alteration as a guide to mineralization., Mammoth area NW Queensland, Australia. J. Geochem. Expl. 25. p.338-308.

Seward, T.M. 1983. Thio-complexes of gold and the transport of gold in hydrothermal ore solutions. Geochimica et Cosmochimica Acta. 37. p.379-399.

Seward, T.M. 1984. The transport and deposition of gold in hydrothermal systems. *In* Foster, R.P. Ed. Gold '82. Balkema Publ. Rotterdam. p.53-70.

Shenberger, D.M. and Barnes, H.L. 1989. Solubility of gold in aqueous sulphide solutions from 150 to 350°C. Geochim. Cosmochim. Acta. 53. p.26-278.

Sheppard, S.M.F. and Dawson, J.B. 1973. $^{13}C/^{12}C$ and D/H isotope variation in "primary" igneous carbonates. Fortschritte Der Mineralogie, 50. p.128-331.

Sheppard, S.M.F. and Schwarcz, H.P. 1970. Fractionation of carbon and oxygen isotopes and Mg between coexisting metamorphic calcite and dolomite. Contrib. Min. and Pet. 20. p.161-198

Sheppard, T.J., Rankin, A.A., and Alderton, D.H.M. 1985. A practical guide to fluid inclusion studies. Blackie and Son, Glasglow. 239pp.

Siems. P.L. 1984. Hydrothermal alteration for mineral exploration workshop. Dep. Geology. University of the Witwatersrand.

Sillitoe, R.H. and Bonham, H.F., Jr. 1990. Sediment-hosted gold deposits: distal products of magmatic-hydrothermal systems. Geology 18. p.157-161

Sinkankas, J. 1981. Emeralds and other beryles. Cilton Book Company. Pennsylvania, p.491-499

Smirnov, V.I., 1976. Geology of mineral deposits: Moscow, MIR Publications. 520p.

Smith, F.G. 1942. Variation in the properties of pyrite. American Min. 27. p.1-19

Smith, H.S. 1986. Evidence from $\delta^{13}C$ and $\delta^{18}O$ isotopes in carbonate minerals for the origin of fluids in Archaean greenstone belt metamorphic and mineralization processes. Geocongress '86, Extended Abstracts, Geol. Soc. S. Afr. p.341-344

Smith, T.J., Cloke, P.L., and Kesler, S.E., 1984. Geochemistry of fluid inclusions from the McIntyre-Hollinger gold deposit, Timmins, Ontario (abs). Geol. Soc. America Abstracts with Programs, 16. p.661

Smith, J.P., Spooner, E.T.C., Broughton, D.W. and Ploeger, F.R. 1990. The Kerr Addison - Chesterville Archaean gold - quartz system, Virginia town: time sequence and associated mafic "albitite" dike swarm. Ontario. Geol. Surv. Misc. Paper 150. p.175-199.

Solomon, M. 1990. Subduction, arc reversal, and the origin of porphyry copper - gold deposits in island arcs. Geology 18. p.630-633

Spooner, E.T.C. 1990. Archaean intrusion - hosted, stockwork Au - quartz mineralization, Lamaque mine, Val d'Or, Quebec: Part II, Light stable isotope (H,O,C and S) characteristics and enriched calc-alkaline/shonkonite igneous geochemistry. NUNA Research Conference on Greenstone Gold and Crustal Evolution, Val d'Or, Quebec, Abstract Vol. p.88-90.

Spooner, E.T.C. 1991. The magmatic model for the origin of Archaean Au-quartz vein ore systems: An assessment of the evidence. Brazil Gold '91. E.A. Ladeira (ed). Balkeme, Rotterdam. p.313-318.

Spooner, E.T.C., Wood, P.C., Burrows, D.R., Thomas, A.V., and Nobel, S.R. 1985. Geological, fluid inclusion, and isotopic (Carbon and sulphur) studies of Au-quartz-carbonate- pyrite-scheelite vein mineralization and intrusion hosted Cu-(Au-Mo) mineralization in the Hollinger-McIntyre system. Timmins., Ontario. *In* Geoscience Research Grant Program, Summary of Research 1984-1985. Ontario Geological Survey, Miscellaneous Paper 127. 246 p.

Spooner, E.T.C., Burrows, D.R., Callan, N.J., De Ronde, C.E.J., and Wood, P.C. 1987. High hydrothermal fluid pressures, hydraulic fracturing, and fluid pressure dilation of shear zones in Archean Au-quartz vein systems. *In* programmes with Abstracts, Geol. Assoc. Canada, Summmer field meeting. Yellowknife.

Springer, J.S. 1985. Active carbon in Archaean rocks of the Abitibi belt, (Ontario-Quebec) and its relation to gold distribution. Canadian Jour. Earth Sci. 22. p.1945-1951

Stacy, J.S. and Kramers, J.D., 1975. Approximation of terrestrial lead isotope evolution by a two stage model. Earth Planet. Sci. Lett. 26. p.207-221.

Stern, C.R., Huang, W.L., and Wyllie, P.J. 1975. Basalt-andesite-rhyolite-H_2O crystallization intervals with excess H_2O and H_2O-undersaturated liquidus surfaces to 35 kilobars, with implications for magma genesis. Earth and Planetary Science Letters. 28. p.189-196.

Steuart, D.S.S. 1899. The mineral wealth of the Zoutpansberg: The Murchison Range gold-belt. Trans. Inst. Min. Eng. 17. p.388-426

Surorova, V.A., 1974. Temperature dependence of the distribution coefficient of sulphur isotopes between equilibrium sulphides. Nat. Symp. on Stable Isotope Geochemistry. 5th Moscow, Program-1. p.128. (In Russian)

Symons, P., Anderson, G., Beard, T., Hamilton, L., Staley, R., Roth, E. and Ho, S. 1990. The structural and host rock settings of primary gold mineralization at the Boddington Gold Mine. *In* Gondwana: Terranes and Resources, Geol. Soc. Australia. Abst. 25. p.56-61

Taylor, H.P., 1979. Oxygen and hydrogen isotope relationships in hydrothermal mineral deposits. *In* Barnes, H.L., ed., Geochemistry of hydrothermal ore deposits: New York, Wiley-Intersci. p.236-277.

Taylor, R.S. 1981. Volcanogenic copper-zinc sulphide deposits of the Murchison greenstone belt, northeastern Transvaal, South Africa. Ph.D thesis, University of Durham. 316pp

Taylor, R.P., and Fryer B.J. 1982. Rare earth element geochemistry as an aid to interpreting hydrothermal ore deposits. *In* Evans, A.M., Ed., Metallization associated with acid magmatism. New York, Wiley Sons Ltd. p.357-365.

Taylor, R.P., and Fryer B.J. 1983. Rare element lithogeochemistry of granitoid mineral deposits. CIM Bull., 76. p.74-84

Taylor, S.R., McLennan S.M. 1985. *In* The continental crust: its composition and evolution. Blackwell Publ. Oxford London

Thompson, A.B. 1971. PCO_2 in low grade metamorphism; zeolite, carbonates, clay minerals and relations in the system $CaO-Al_2O_3-SiO_2$. Contrib. Min. and Pet. 33. p.145-161

Touret, J. 1981. Fluid inclusions in high grade metamorphic rocks. *In* Short course in Fluid inclusions: Applications to Petrology, edited by L.S. Hollister and M.L. Crawford, Mineralogical Association of Canada. 6, 304p

Troger, W.E. 1935. Spezielle petrographie de erupyivgestein. Deutsh. Min. Ges. e V

Trompsdorff, V. and Skippen, G. 1986. Vapour loss ("boiling") as a mechanism for fluid evolution in metamorphic rocks. Contrib. Min. Pet. 94. p.317-322.

Truesdell, A.H. 1974. Oxygen isotope activities and concentration in aqueous salt solutions at elevated temperatures - consequences for isotope geochemistry. Earth Planetary Sci. Letters. 23. p.387-396

Tyrell, T.N. 1926. *In* Principles of petrography; an introduction to the science of rocks. London. New York. Methuen. E.P. Dutton

Van Eeden, O.R., Partridge, F.C., Kent, L.R. and Brandt, J.W. 1939. The mineral deposits of the Murchison Range, east of Leydsdorp. Mem. geol. Surv. S. Afr., 26. 172p.

Van Reenen, D.D., Barton, J.M. Jr, Roering, C, Smit, C.A. and van Schalkwyk, J.F. 1987. Deep crustal response to continental collision: The Limpopo belt of southern Africa. Geology. 15. p.11-14.

Vearncombe, J.R., and van Reenen, D.D. 1986. Structures of the Archaean schist belt, Kaapvaal Craton. Final Report, Open File. Geol. Surv. South Africa.

Vearncombe, J.R., Cheshire, P.E., and de Beer, J.H., Killick, A.M., Mallinson, W.S., McCourt, S. and Stettler, E.H. 1988. Structures related to the Antimony Line, Murchison Schist belt, Kaapvaal craton, South Africa. Tectonophysics. 154. p.285-308

Vearncombe, J.R., Walsh, K.L. and Barton, J.M. Jr. 1986. Geology of the Rooiwater igneous complex, Murchison greenstone succession, Kaapvaal craton (extended abstract). *In* Geocongress '86, Abstract Volume. Geol. Soc. S. Africa. p.397-400.

Vearncombe, J.R., Barton, J.M. and Walsh, K.L. 1987. The Rooiwater complex and associated rocks, Murchison granitoid-greenstone terrain, Kaapvaal craton. In preparation.

Vearncombe, J.R. 1988. Structures and metamorphism of the Archaean Murchison schist belt, Kaapvaal Craton, South Africa. Tectonics. 7. p.761-774

Vearncombe, J.R., Barton, J.M. Jr., Cheshire, P.E., de Beer, J.H. and Stettler, E.H. Geology, geophysics and mineralization of the Archaean Murchison schist belt, Transvaal. Explanation to accompany 1:50 000 sheets: 2330CC (Tzaneen), 2430AA (The Downs), 2330CD (Letsitele), 2330DC (Gravelotte), 2330DD (Mulati), 2330DB (Ka-Makhuva), 2331CC (Phalaborwa) and 2331CA (Mahlangeni). Mem. Geol. Surv. S. Africa. In press

Viljoen, M.J. and Viljoen, R.P. 1961. An introduction to the geology of the Barberton granite-greenstone terrane. Geol. Soc. S. Africa. Spec. Publ. 2. p.9-28.

Viljoen, M.J. and Viljoen, R.P. 1969. The geochemical evolution of the granitic rocks of the Barberton region. Spec. Publ. geol. Soc. S. Afr., 2. p.245-274.

Viljoen, M.J., Van Vuuren, C.J.J., Pearton, T.N., Minnitt, R.C.A., Muff, R. and Cilliers, P. 1978. The regional geological setting of the mineralization in the Murchison Range with particular reference to Antimony. Spec. Publ. Geol. Soc. S Africa. 4. p.55-76

Viljoen, M.J., 1979. The geology and geochemistry of the "Antimony Line" in the united Jack Complex, Murchison Range. Spec. Publ. geol. Soc. S. Afr. 5, 133-158.

Walsh, J.F., Cloke, P. L., and Kesler, S.E. 1984. Fluid (CO_2 + H_2O), immiscibility and fO_2 as factors in gold deposition. Pamour No.1 mine, Timmins, Ontario. (Abs). Geol. Soc. America abstract with programs. 16 p.686

Walsh, J.L., and Solomon, M. 1981. An investigation into the environment of formation of the volcanic hosted Mt. Lyell copper deposit using geology, mineralogy, stable isotopes, and six-component chlorite solid solution model. Econ. Geol. 76. p.246-284

Wanless, R.K., Boyle, R.W. and Lowdon, J.A. 1960. Sulphur isotope investigations of the gold-quartz deposits of the Yellowknife District. Econ. Geol. 55. p.1591-1621

Ward,H.J., 1958. Albite porphyries as a guide to gold ore. Econ. Geol. 53. p.754-756.

Wellington, J.H. 1955. Southern Africa: a geographical study. Vol.1. Cambridge Univ. Press. London. 528pp

Whitney, J.A. 1975. Vapour generation in a quartz monzonite magma: A synthetic model with applications to porphyry copper deposits. Econ. Geol. 70. p.346-358.

Whitney, J.A. 1978. Experimental studies pertaining to the origin of granitic magma and their role in orogenesis. ISGAM Extended Abstracts (Bahia, Brazil). p.19-21.

Wilson, N.W. 1945. Geology of the Monarch cinnabar mine, Transvaal, South Africa. Inst. Min. Met. London.

Wilson-Moore, C. 1896. The economic importance of the Murchison Range. Trans. Geol. Soc. S. Africa. 1. p.51-60.

Wood, P.C., Thomas, A.V., Burrows, D.R., Macdonald, A.J., Noble, S.R. and Spooner, E.T.C. 1984. CO_2-bearing low salinity fluids in Archean gold-quartz-carbonate- (W-Mo) vein deposits and magmatically derived Mo, W, Ta, and Sn mineralization. (abstract). *In* Abstracts with programs. Geol. Soc. America. 16. p.700.

Wood, P.C., Burrows, D.R., Thomas, A. V., and Spooner, E.T.C., 1986. The Hollinger-McIntyre Au-quartz vein system, Timmins Ontario, Canada. Geologic characteristics, fluid properties and light stable isotope geochemistry. *In* Gold '86. Konsult International Inc., Toronto, 517p.

Wyman, D., and Kerrich, R., 1988. Alkaline magmatism, major structures and gold deposits: implicationsrf greenstone belt gold metallogeny. Econ . Geol. 83. p.454-461