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STUDY OF GEOLOGY AND FLUID INCLUSIONS IN THE FRANCOEUR AND LAC FORTUNE GOLD DEPOSITS, QUEBEC

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ABSTRACT

The Francoeur and Lac Fortune gold deposits are located in the Rouyn-Noranda area, Québec. The major host lithologies include volcanic rocks of the Blake River Group, sedimentary rocks of the Timiskaming and Cobalt groups, synvolcanic and late-tectonic intrusive rocks.

The Francoeur deposit occurs along the east-west striking Francoeur-Wasa shear zone, bordered to the north by gabbro-diorite stock. Hydrothermal alteration is well developed, and is commonly limited to the shear zone. The major products of alteration are zoned. A typical sequence of alteration zones from the orebody outward changes from the assemblage albite-pyrite, through carbonate-hematite, to muscovite-chlorite. Gold mineralization is related to hydrothermal wall rock alteration, especially to the formation of the albite-pyrite assemblage. The ore is mostly located in altered mylonites, in which gold is disseminated, closely associated with pyrite.

The Lac Fortune deposit occurs in a small shear zone parallel to the Francoeur-Wasa shear zone. It is characterized by the development of quartz-carbonate veins. Hydrothermal alteration is less well developed than in the Francoeur deposit. The alteration minerals mainly occur in the wall rock or near the contact zone between the wall rock and quartz-carbonate veins, with chlorite-carbonate-fuchsite being the principal assemblage. The minerals of the quartz-carbonate veins were formed mainly by open space filling or direct precipitation of ore material from hydrothermal fluids. Gold-bearing minerals, including coarse free gold and Pb-Bi tellurides, are scattered in the quartz-carbonate veins.

Three groups of fluid inclusions related to the gold mineralization of the Lac Fortune and Francoeur deposits are recognized. They are aqueous inclusions, CO_2-rich inclusions and H_2O-CO_2 inclusions. The aqueous inclusions are in the H_2O-NaCl system plus $CaCl_2$. Besides predominant CO_2, the CO_2-rich inclusions also contain minor amounts of H_2O and another gas, probably CH_4. The H_2O-CO_2 inclusions are in the H_2O-CO_2-NaCl system, with additional $CaCl_2$ and CH_4. Homogenization temperatures appear higher on average in the Francoeur deposit than in the Lac Fortune deposit. The homogenization temperatures range from 110°C to 360°C for the fluid inclusions from the Lac Fortune deposit, and from 150°C to 578°C for those from the Francoeur deposit. The salinity ranges from 5 to 9 wt% NaCl equivalent for the fluid inclusions from the Lac Fortune deposit, and from 2 to 9 wt% NaCl equivalent for those from the Francoeur deposit. The ore-forming fluids in both deposits are rich in CO_2 with low salinity.

In the Lac Fortune deposit, the fluid preserved in the H_2O-CO_2 inclusions represents the primary ore-forming hydrothermal fluid. This H_2O-CO_2 fluid with low salinity separated in the process of mineralization to form an aqueous fluid with relatively high salinity and a non-saline CO_2-rich fluid The temperature and pressure of the fluid range respectively from 110°-360°C and 3200-5100 Pa at the site of mineralization. Phase separation (unmixing) of the mineralized fluid is an important mechanism of gold deposition.

In the Francoeur deposit, the mineralized fluids are compositionally H_2O-CO_2-NaCl fluids. The minimum temperature and pressure are 150°-578°C and 4000-5000 Pa at the site of mineralization. Fluid-rock interaction played an important role in the gold precipitation.

The different mineralization mechanisms and styles may be caused by the difference of physicohemical conditions of the ore-forming fluids. Temperature of the mineralized fluid is the major controlling factor in both gold deposits. In the Lac Fortune gold deposit, because the mineralized fluid had a relatively low temperature, phase separation played an important role in the gold precipitation and an open-space filling type of gold deposit was formed. In the Francoeur deposit, however, the mineralized fluid, with relatively high temperature, resulted in an extensive alteration of wall-rock; fluid-rock interaction played an important role in the gold deposition and produced a replacement type gold deposit.

RÉSUMÉ

Les gîtes aurifères de Francoeur et du Lac Fortune sont situés dans le camp minier de Rouyn-Noranda au Québec. Ils sont associées aux roches volcaniques métamorphisées du Groupe de Blake River, aux roches sédimentaires des groupes de Timiskaming et de Cobalt ainsi qu'à des intrusions felsiques syn-volcaniques et tardi-tectoniques.

Le gîte Francoeur est localisé sur la faille de Francoeur-Wasa, laquelle est bordée au nord par une intrusion de gabbro-diorite. L'altération hydrothermale intense associée au dépôt est limitée à la zone cisaillée et présente une zonation marquée. Les faciès d'altération, de la masse minéralisée vers l'éponte, passent d'un assemblage à albite-pyrite, vers celui à carbonate-hématite, pour se terminer en une zone à muscovite-chlorite. L'or est lié à l'altération hydrothermale de l'éponte, plus spécifiquement au faciès à albite-pyrite. La minéralisation se retrouve dans des mylonites variablement altérées, contenant l'or disséminé dans la pyrite.

Le gîte du Lac Fortune est situé sur une petite zone de cisaillement parallèle à la faille de Francoeur-Wasa. Il est caractérisé par l'abondance des veines de quartz et carbonate. L'altération hydrothermale, moins intense qu'au gîte Francoeur, affecte la roche encaissante à la bordure des veines de quartz et carbonate. Elle est dominée par un assemblage à chlorite-carbonate-fuchsite. Les minéraux dans les veines ont été déposés dans des fractures ouvertes, ou précipités directement des fluides hydrothermaux. L'or natif et les tellurures de plomb-bismuth-or sont disséminés dans ces veines.

Trois groupes d'inclusions fluides sont reliées aux minéralisations aurifères des gîtes Francoeur et du Lac Fortune. Ce sont des inclusions aqueuses, des inclusions riches en CO_2 et des inclusions CO_2-H_2O. Les inclusions aqueuses appartiennent au système H_2O-NaCl, dans lequel du $CaCl_2$ a aussi été détecté. Outre le CO_2, les inclusions riches en CO_2 contiennent une certaine proportion d'eau et d'un autre gaz, probablement du méthane. Les inclusions de H_2O-CO_2 appartiennent au système H_2O-CO_2-NaCl, dans lesquelles du $CaCl_2$ et du CH_4 ont été détectés. Les températures d'homogénéisation sont plus élevées au gîte Francoeur (150-578°C) qu'à celui du Lac Fortune (110-360°C). La salinité y varie de 2% à 9% (pourcent poids) d'équivalent NaCl pour le gîte Francoeur, et de 5% à 9% pour le gîte du Lac Fortune. Le fluide minéralisant, dans les deux gîtes, est riche en CO_2 et peu salin.

Au gîte du Lac Fortune, les inclusions de H_2O-CO_2 ont trappé ce qui est interprété comme le fluide minéralisateur. Ce fluide, peu salin, a subséquemment été ségrégué en un fluide aqueux salin et en un second fluide carboné non-salin au cours du processus de minéralisation. Les températures et pressions enregistrées par ces fluides sont de l'ordre de 110°-360°C et 3200-5100 Pa au site de déposition de la minéralisation. La précipitation de l'or semble liée à la séparation des phases de ces fluides.

Au gîte Francoeur, le fluide minéralisant appartient au système H_2O-CO_2-NaCl. La température minimale et la pression du fluide sont de 150°-578°C et 4000-5000 Pa au site de

minéralisation. Le processus de précipitation de l'or semble contrôlé par l'interaction entre le fluide et la roche encaissante.

Les différents processus de déposition de la minéralisation entre les deux gîtes semblent liés aux différences des conditions physico-chimiques affectant le fluide minéralisateur. La température semble le facteur dominant dans les deux cas. Au Lac Fortune, la basse température du fluide a entraîné une ségrégation du fluide en phases carbonée et aqueuse, ce qui a joué un rôle crucial dans le processus de précipitation de l'or, et un gîte de type "remplissage de veine" a été formé. Inversement, au gîte Francoeur, le fluide minéralisateur a réagi intensement avec l'éponte rocheuse. Des réactions roche-fluide ont dominé le processus de précipitation de l'or, et un gîte de type "remplacement" a été formé.

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CHAPTER I

INTRODUCTION

1.1 Previous studies and problems

The Francoeur deposit and the Lac Fortune deposit are located approximately 15 km southwest of Rouyn-Noranda, Québec. It was shown (Couture and Pilote 1991) that they have a very similar geological context. They are both in the Abitibi greenstone belt terrain, and have an Archean age. They developed in shear zones that crosscut similar bounding rocks. There exist, however, some differences between these two deposits. According to the classification of Roberts (1989), the Francoeur deposit belongs to the Au-quartz veins type, while the Lac Fortune deposit belongs to the replacement type.

Previous geological investigations of the Francoeur and Lac Fortune deposits have been carried out by Bruce (1933), Bugnon (1982), Fritzsche (1934), Gelinas et al. (1983), Hogg (1984), Hinse (1985), Karpoff (1986), and Couture and Pilote (1991). Couture and Pilote (1991) have done a more detailed study of the alterations at the Francoeur deposit. These last authors studied the hydrothermal alteration and the S, C, O isotopic compositions of mineralized and unmineralized samples. It was considered that the Francoeur-Wasa shear zone remained relatively permeable through much of the hydrothermal process such that fluid flow operated under near constant hydrostatic gradient, preventing fluid pressure buildup, promoting fluid-rock chemical exchanges leading to an extensive alteration halo, and favouring gold deposition by fluid oxidation and wall rock sulfurization. In the Francoeur deposit, it was noticed that the orebodies are associated with albitite dikes, although not enough attention has been paid to the effect of albitite dikes on mineralization. The albitite dikes may have played a role in the gold mineralization process.

Despite these previous studies, a lot of problems remained to be solved. For example, the characteristics of the ore-forming fluids had not been reported, alteration and its role on gold mineralization need to be further precised. Comparison between the Francoeur and Lac Fortune deposits and their genesis also need to be further discussed.

1.2 Objectives

In order to deepen the understanding of the Francoeur and Lac Fortune gold deposits, this thesis aims at four principal objectives as follows:

1. To describe the regional and local geological features of both gold deposits on the basis of previous studies and present investigations;

2. To determine alteration mineral assemblages in both deposits;

3. To determine the physicochemical conditions and chemical compositions of the ore-forming hydrothermal fluids of both deposits using fluid inclusions techniques. This is the focus of this thesis;

4. To discuss the similarity and difference between these two deposits;

5. To establish a metallogenetic model for them.

1.3 Methodology

Field investigations consisted in recognition and description of host rocks structures, alterations, mineral assemblages, mineralization, and of the fundamental spatial and temporal relationships of all these characteristics with the host rocks. Samples were collected from 3 cross sections (36 samples) in the Francoeur deposit and from 1 cross section (12 samples) in the Lac Fortune deposit.

More precisely, field investigations were done in order to determine the spatial relationships between different types and/or different stages of alteration and mineralization. A relative time sequence between alteration and mineralization could then be constructed from the observation of the relationships between different veins and the various alteration textures and mineralogy. These are necessary to further understand the geology and geochemistry of the deposits.

The petrographic and mineralogical study focused on the recognition of mineral components and their relationships with the orebodies and the unaltered and altered host rocks. In association with field investigations, this work provides the basis for recognizing the space and time relationships between the structure, the different stages of alteration and mineralization. It also leads to the recognition of the mineral assemblages of alteration, an indication of the main ore-forming conditions and of the broad range of the content of the ore-forming fluids. For example, the fact that carbonate and albite dominate in the alteration zone of the Francoeur deposit may indicate that the alteration of this deposit should be dominated by carbonatization and albitization.

The fluid inclusions study is used to show that the solutions enclosed in fluid inclusions hosted in the ore minerals or veins are the remains of fossil ore-forming fluids. Their compositions are frequently considered to represent those of the ore-forming fluids at the time of capture (Roedder, 1984; Lu 1991). Therefore, fluid inclusions study is a significant method to develop constraints on P-T conditions and compositions of the ore-forming fluids.

1.4 Equipments used

A Nikon microscope with magnification up to 40X in the laboratory of UQAC.

The fluid inclusion laboratory at UQAC, including a U.S.G.S. Gas-flow heating and freezing system and a Chaixmeca heating and freezing stage (Nancy, France).

CHAPTER II

GEOLOGICAL SETTING

2.1 Regional geological setting

The Superior Province (Fig. 2.1) is the largest exposed Archean craton in the world and hosts many large gold deposits such as the Hollinger, Porcupine, and Dome gold deposits. It has yielded 170 million ounces of gold from hundreds of deposits (Hodgson and MacGeehan 1982), more than any other Archean cratons. The Rouyn-Noranda area, representing a typical sector of the Archean Abitibi greenstone-gneiss belt terrain, is in the eastern part of the Superior Province.

One prominent characteristic of all significant gold deposits in the Superior Province is their occurrence within or immediately adjacent to greenstone belts (Fig. 2.1). Another characteristic is their occurrence within major tectonic zones (Fig. 2.2) which comprise a series of shear zones (Colvine et al. 1988).

The Superior Province is divided into four major subprovince types (Card and Ciesielski 1986): volcano-plutonic, plutonic, metasedimentary, and high grade gneiss. The boundaries of these subprovinces are either major dextral, transcurrent, east-striking faults, or zones of structural and metamorphic transition.

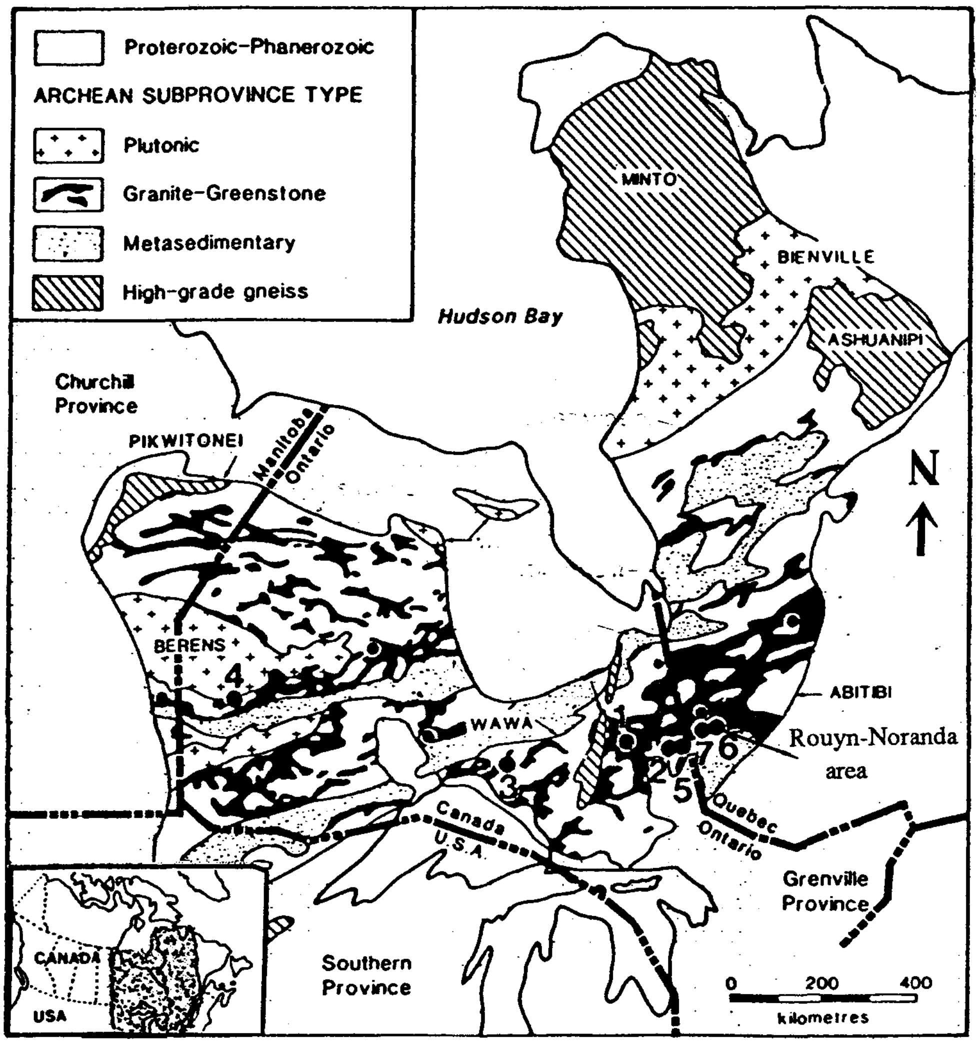


Fig. 2.1 Generalized geology of the Superior Province, showing subprovinces and the locations of major gold camps. Gold camps shown include: 1- Timmins/Porcupine, 2- Kirkland Lake, 3-Hemlo, 4-Red Lake, 5- Larder Lake, 6- Val d'Or, and 7- Malartic. Map modified from Card and Ciesielski (1986).

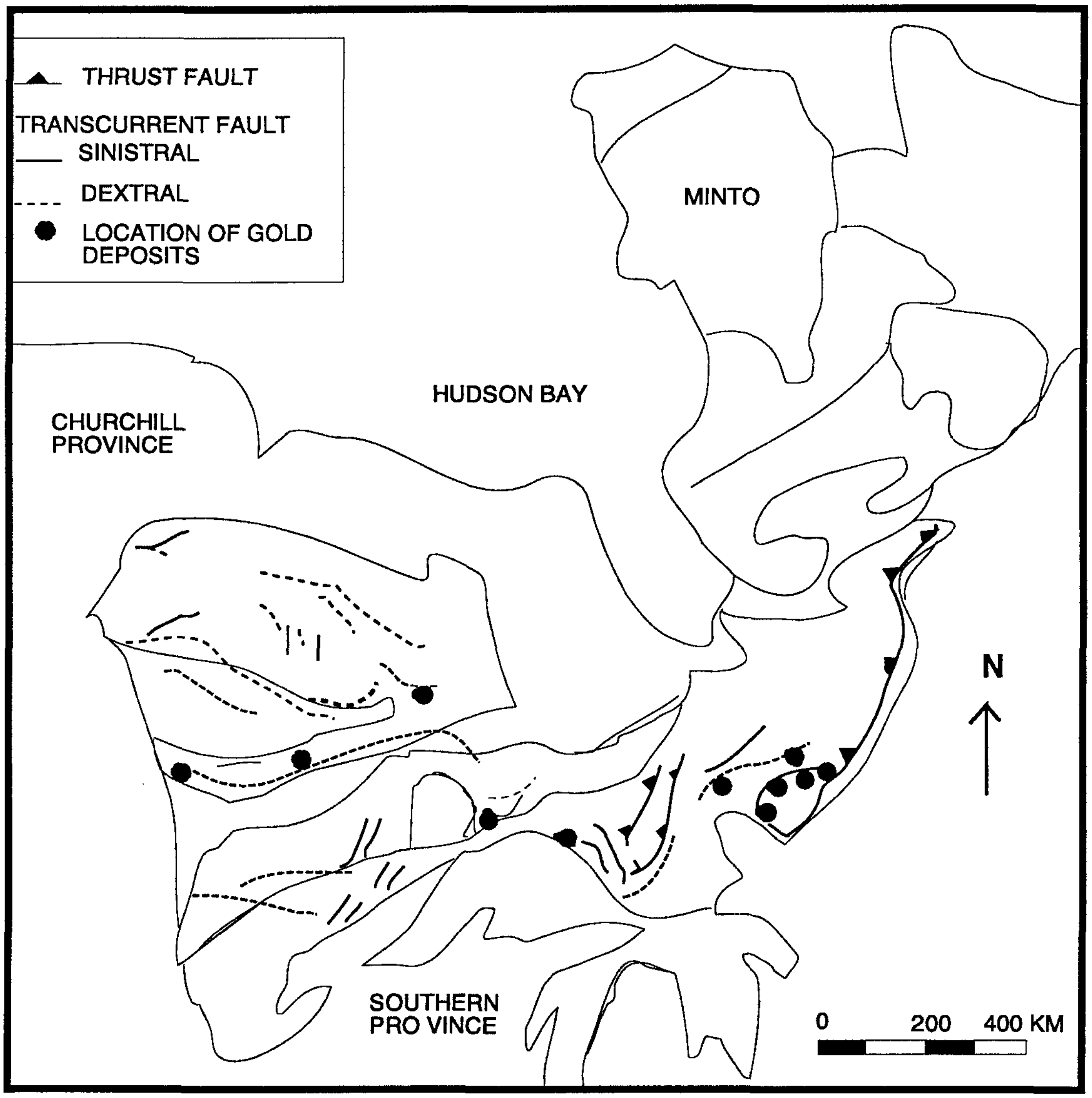


Figure. 2.2 Major faults of the Superior Province, with major gold deposits (modified from Card and Ciesielski 1986).

The greenstone belts which host the gold deposits occur as east-northeasterly-trending, ribbon or amoeboidal domains in the volcano-plutonic terrains (Fig. 2.1). They typically consist of mafic to ultramafic and felsic metavolcanics, interlayered with metasediments. The supracrustal rocks have been intruded by syn-volcanic plutons. Saturated and undersaturated felsic to mafic igneous rocks intruded into the greenstone belts in late Archean.

The metamorphic grade of the present erosional level of most greenstone terrains ranges from sub-greenschist to greenschist facies in the center, to lower amphibolite facies at the margin. Amphibolite facies contact metamorphic aureoles occur around intrusions into the greenstones (Jolly 1978, 1980).

2.2 Local geological setting

The Francoeur and Lac Fortune deposits are located in Arntfield (Fig. 2.3), approximately 15 km southwest of Rouyn-Noranda. The Rouyn-Noranda camp is principally known for its volcanogenic base metal deposits. Nonetheless, the Francoeur camp produced over 125 metric tons of gold ores from approximately 20 gold-only deposits. Excluding deposits of the Bousquet area, combined production and reserves are estimated at over 300 metric millions tons or close to 10 millions troy ounces of gold (Couture and Pilote 1991). Reserves of the Lac Fortune deposits are calculated at about 234,050 metric tons or approximately to 36,745 ounces of gold (Karpoff 1986).

The geology of the Rouyn-Noranda area has been well described by numerous authors (Dimroth et al. 1982, 1983a, 1983b; Gelinas et al. 1983; Gélinas et al. 1984; Leduc and

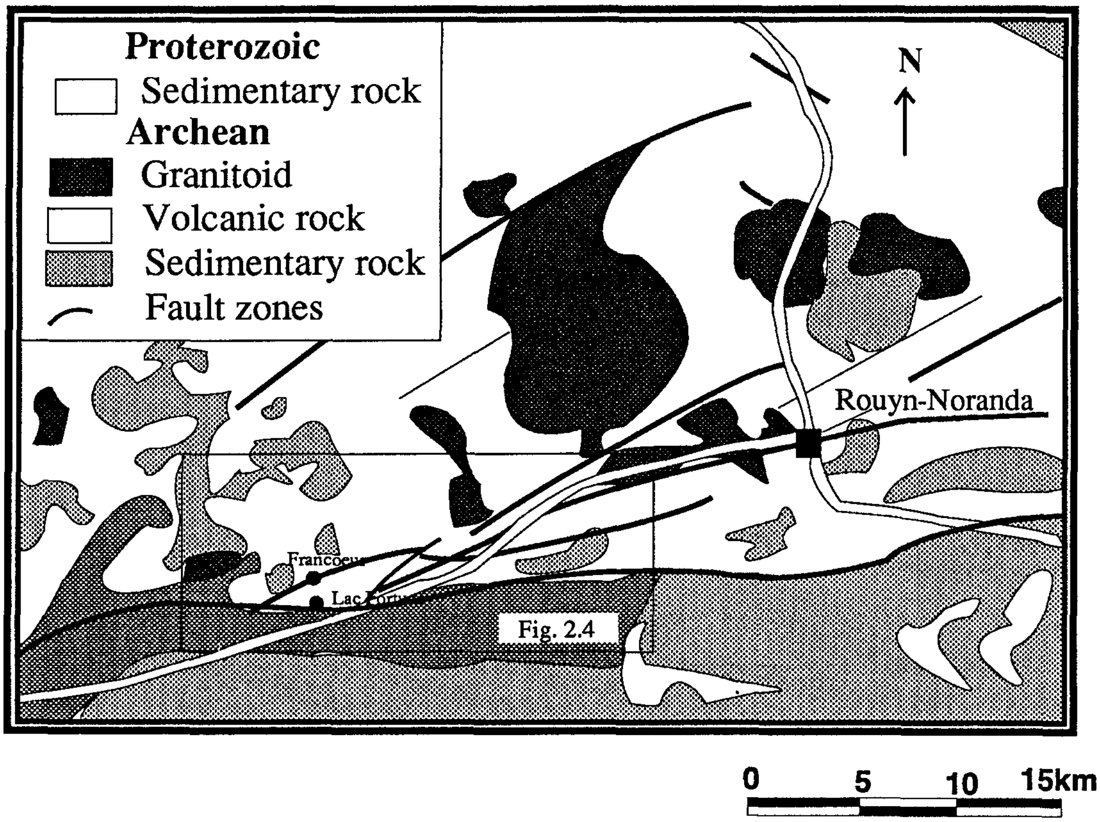


Fig 2.3 Simplified regional geological map of the Francoeur and Lac Fortune deposits(modified from Couture and Pilote, 1991).

Forest 1985; Péloquin et al. 1990; Couture and Pilote 1991). It provides a good basis for the present study.

There are four basic rock types in the studied area: volcanic rocks of the Blake River Group, sedimentary rocks of the Timiskaming and Cobalt groups, synvolcanic and late-tectonic intrusion rocks (Fig. 2.4). All rocks have been metamorphosed to greenschist facies.

In the Francoeur and Lac Fortune deposits area, all rock units face to the north (Fig. 2.5), and have variable strikes from west to west-north-west with generally moderate to steep dip (Bugnon 1982).

Volcanic rocks of the Blake River Group which host the gold deposits are the principal Archean rock-types exposed in the study area. Rocks of the Blake River Group are bounded to the north by the Porcupine-Destor-Parfouru fault system and to the south by the Cadillac Fault. The Blake River Group is the youngest volcanic sequence in the Superior Province and forms a central volcanic complex which is characterized by cyclic bimodal andesite-rhyolite units of calc-alkaline and theoleiitic affinity (Peloquin et al. 1990). These units are underlain by the sedimentary rocks of the Timiskaming Group, which are themselves overlain by little deformed Proterozoic sedimentary rocks of the Cobalt Group along the south boundary (Fig.2.5). The volcanic rocks are intruded by two major intrusive rocks, mafic gabbro-diorite sills and stocks that are either synvolcanic or clearly post-tectonic. All lithologies, except for the syenites, are folded and metamorphosed.

Below the Proterozoic Cobalt sediments, about 1 kilometer south of the Lac Fortune deposit, the Cadillac Fault cuts the Archean rocks and separates the rocks of the Blake River Group to the north with the sedimentary rocks of the Timiskaming Group to the south. Besides this major structure, the Archean rocks are also affected by two families of very

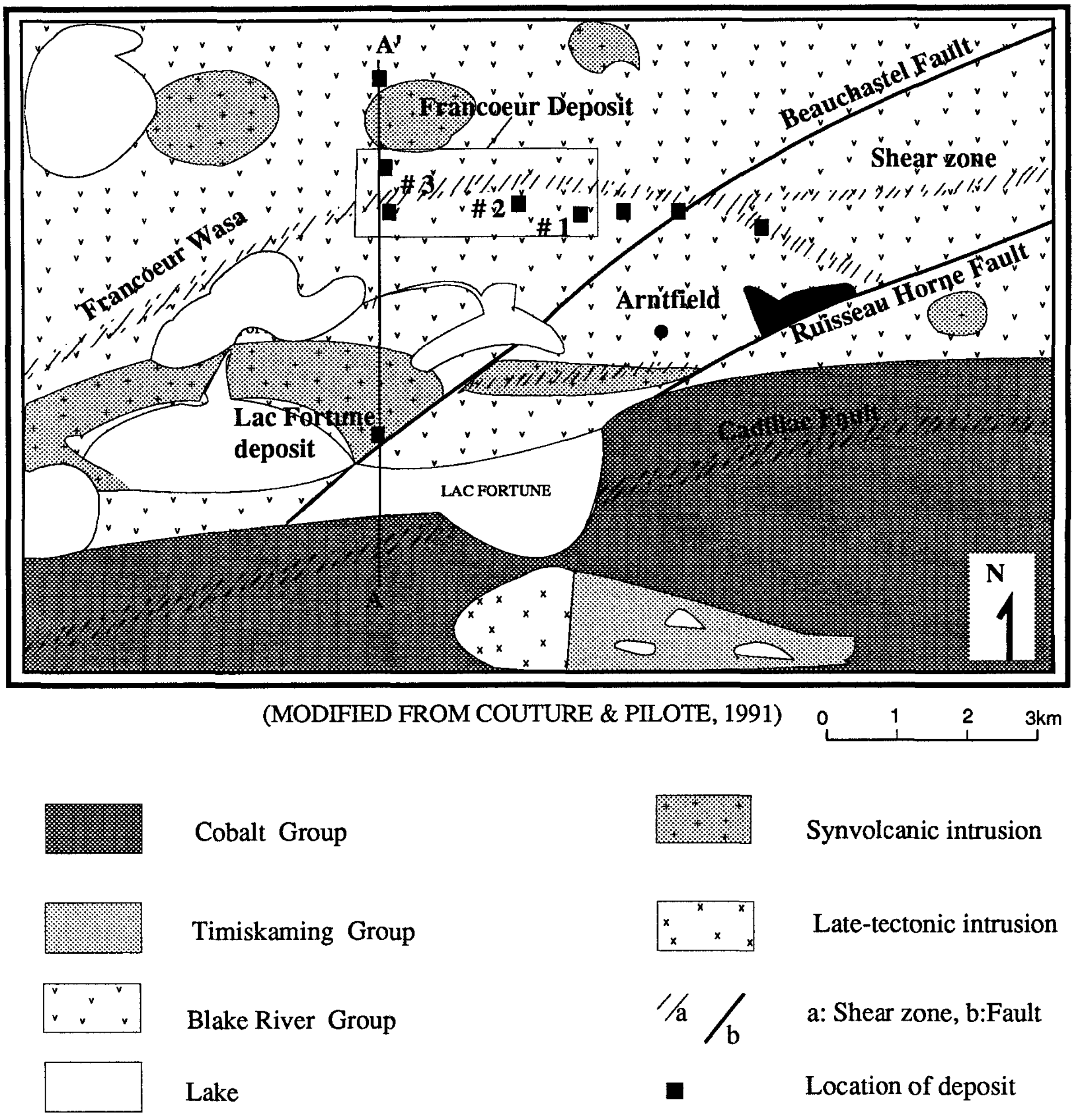


Fig. 2.4 Geological map of the Arntfield region

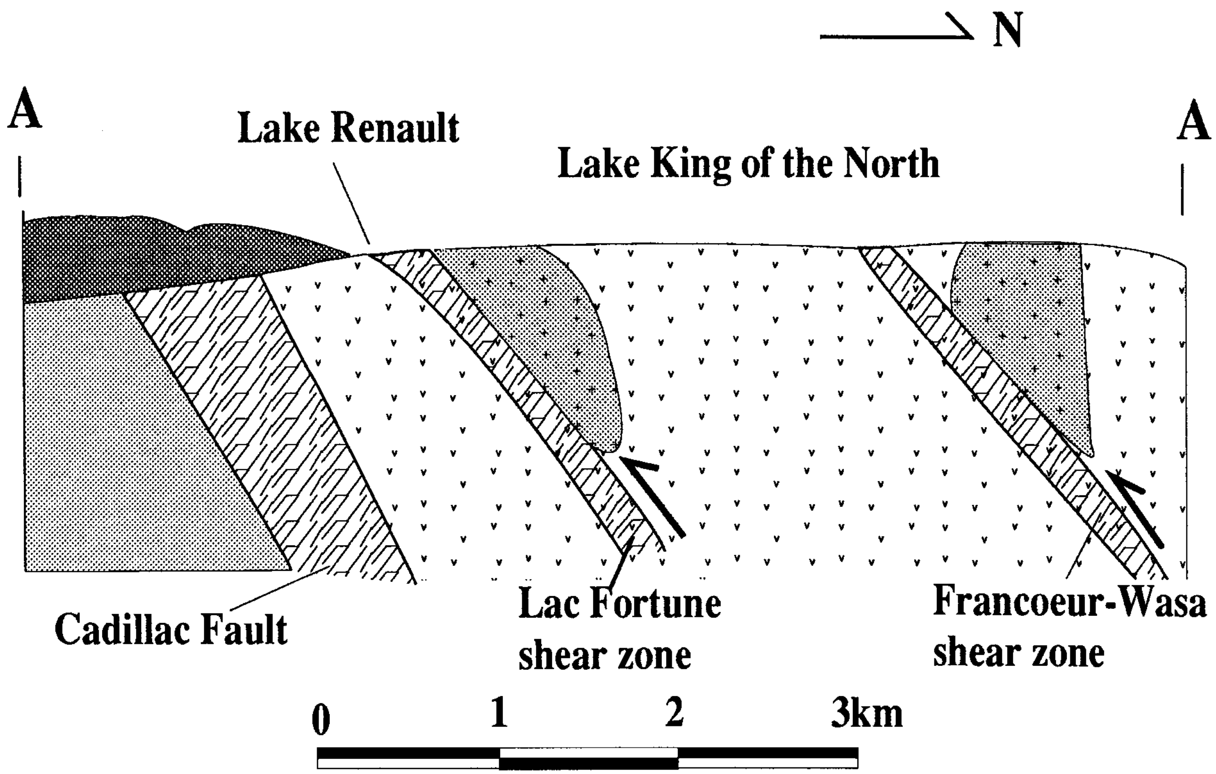


Fig. 2.5 Cross-section of the Francoeur#3 and Lac Fortune deposits

(MODIFIED FROM COUTURE AND PILOTE, 1991) different faults, one of which is related to the zones of Lac Fortune and Francoeur-Wasa shears, and the other to the Beauchastel and Ruisseau Horne faults. Like regional structures, these faults and shear zones have near E-W striking. The Lac Fortune and Francoeur-Wasa shear zones are composed of a series of reverse faults with moderate dip to north and are strongly hydrothermally altered.

CHAPTER III

GEOLOGY OF THE MINE AREA

3.1 The Francoeur deposit

The Francoeur deposits include the Francoeur #1, #2 and #3 deposits. They occur along the Francoeur-Wasa shear zone (Fig. 3.1) together with the Arntfield #1, #2, and #3 deposits, the Wasamac mine and the Wingate deposit from west to east. Although local host rocks vary, all these deposits are very similar to one another in both geological aspect and type of mineralization. The Francoeur #3 is the largest one of them, and it will be selected for a detailed study in this thesis.

The Francoeur #3 deposit is hosted in the metavolcanic rocks of the Blake River Group. Gold mineralization mainly developed in the Francoeur-Wasa ductile shear zone, and is in contact with the southern margin of a gabbro-diorite stock (Fig. 3.2). The mineralized zone extends for at least 1200 meters down dip from surface to beyond the 17th level where it crosses over the property boundary. It is a composite orebody consisting of four distinct ore zones (Couture and Pouliot 1991), three of which occur within the Francoeur-Wasa shear zone. These are: (1) the south or principal zone extending from surface to the 13th level along the footwall of the shear zone; (2) the north zone extending along the hanging wall of the shear zone, from level 11 downwards across the property boundary; and (3) the 11-20 zone which is restricted from level 9 to 12 along the north contact of a less deformed slivers of

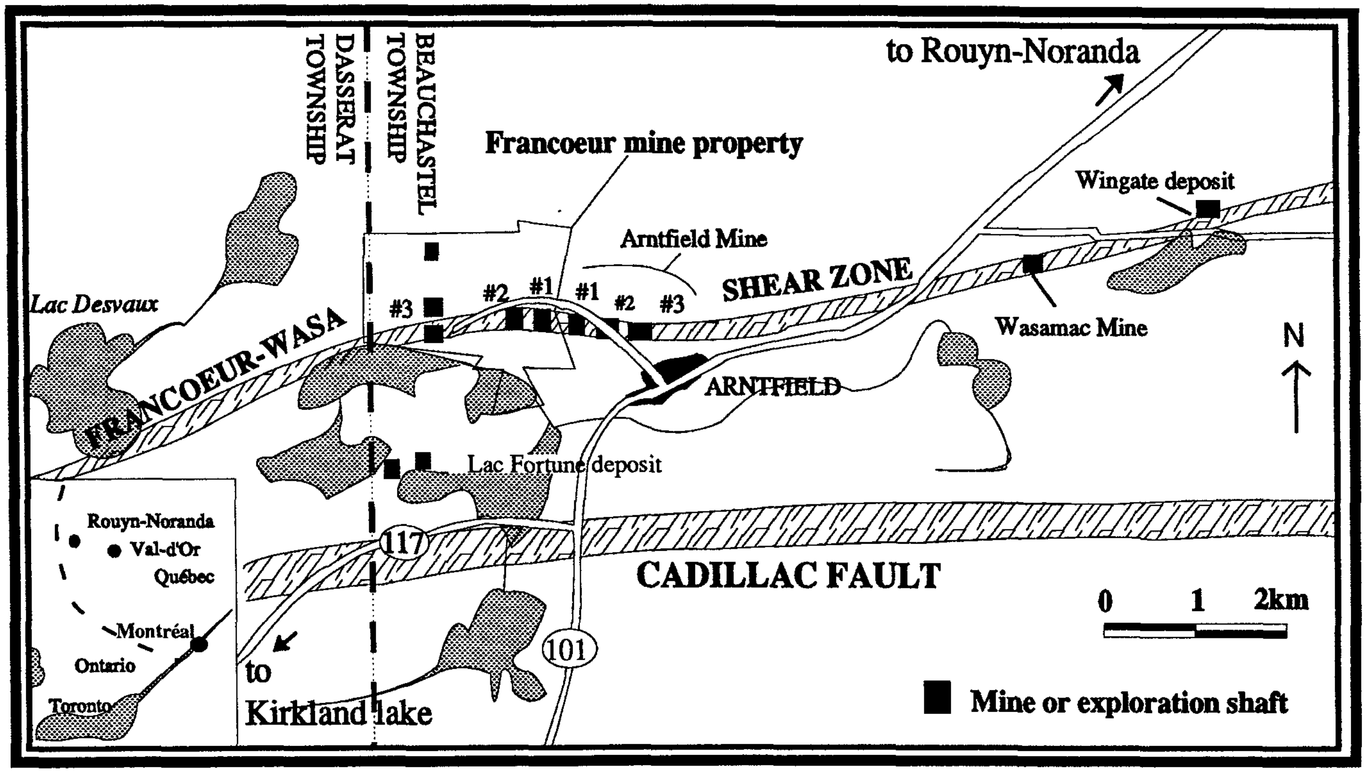


Fig. 3.1 Location of the principal gold deposits along the Francoeur-Wasa shear zone in the Arntfield area

(MODIFIED AFTER COUTURE AND POULIOT 1991).

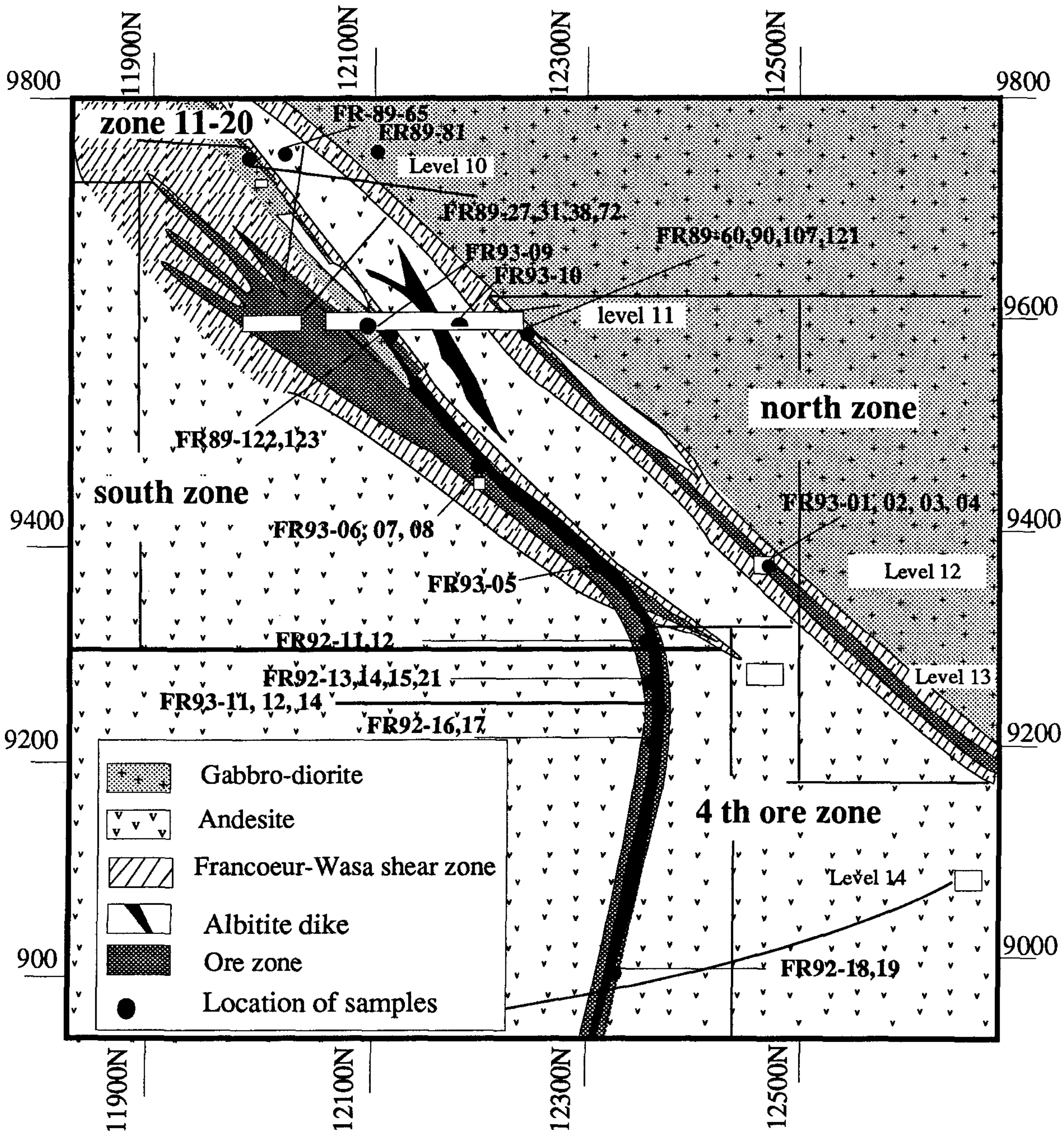


Fig. 3.2 Detailed composite cross section of the three ore zones and the distribution of albitite dykes at the Francoeur #3 deposit plus location of samples (Modified from Couture and Pouliot, 1991).

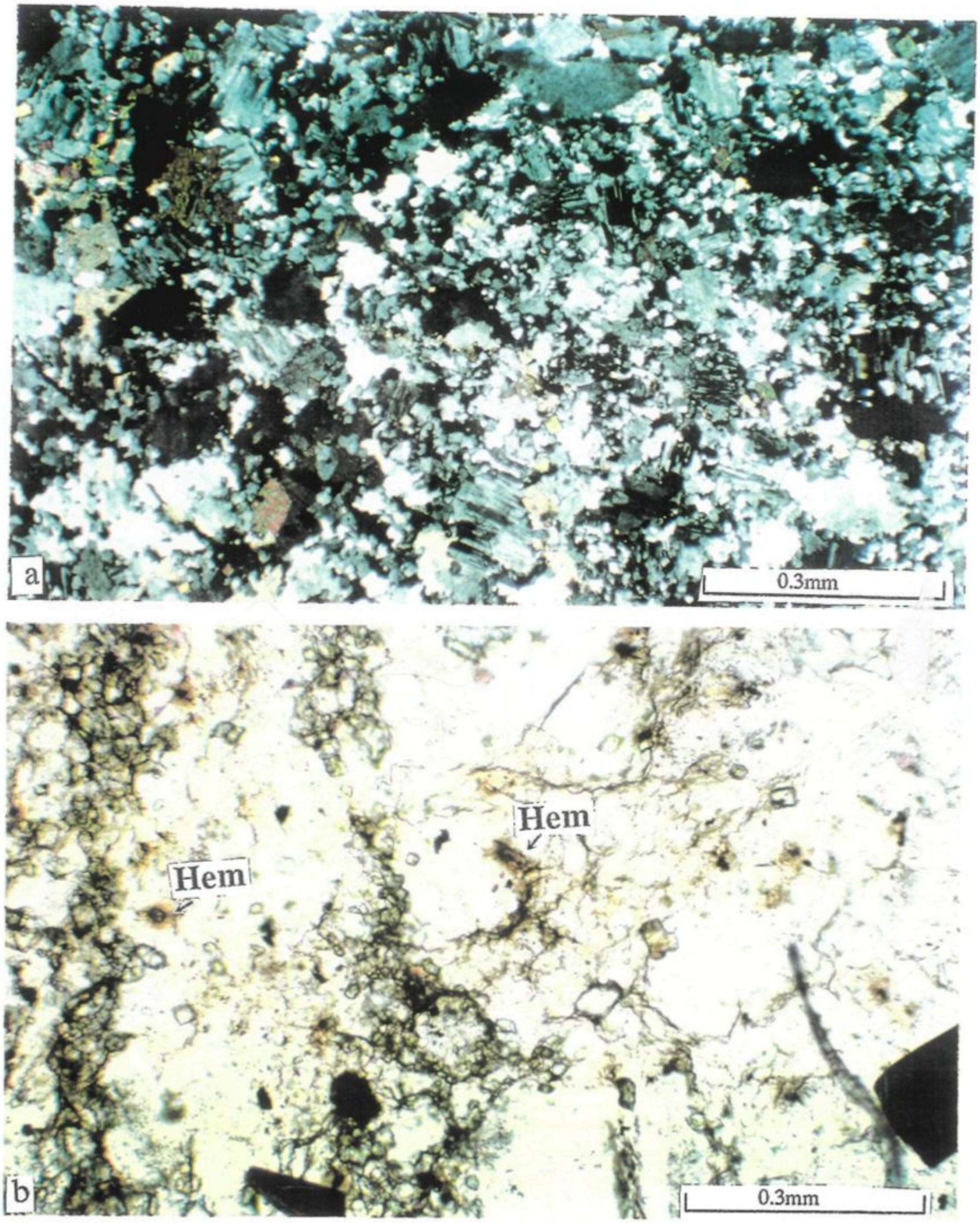
gabbro located in the shear zone. The fourth ore zone (the South-south zone) is not located in the Francoeur-Wasa shear zone, but it is noted that this ore zone is spatially associated with a large albitite dike (Fig. 3.2).

3.1.1 Mine lithologies

Much basic work in Francoeur has been done by Couture and Pilote (1991), who provided quite detailed descriptions of the geology of this deposit. The present research is the continuation of previous works, and in many cases the field investigations of the present research are consistent with the observations made by Couture and Pilote (1991).

It is observed that three principal lithologic series occur in the Francoeur #3 deposit. The major lithologic series consists of calc-alkaline andesite flows and tuffs intercalated with minor volcaniclastic horizons. Between the 8th and 13th levels, the hanging wall of the mineralized structure is composed of a gabbro-diorite rock, which forms the second major lithologic series. The albitite dikes are the third major lithology. They strike on average east-west but dip more abruptly than the mylonitized zone. The dikes exist in all ore zones even in the wall-rocks. The observations under microscope show that the albitite dikes are principally composed of albite and minor amount of quartz, carbonate, hematite and pyrite. The albitite dikes have been carbonatized, especially in their margin. In general, however, the center retains their original intergranular texture (Plate Ia). Some albitite dikes present a red color, which is probably caused by finely disseminated hematite along albite twin planes, cleavages and grain boundaries (Plate Ib). The contact between albitites and orebody is usually quite sharp. The fourth ore zone at depth was discovered outside the shear zone, but in close spatial association to such an albitite dike (Fig. 3.2). The examinations of field and laboratory work indicate that the position and structure of these albitite dikes are similar with those of the

Plate I



a: Intergranular texture in the center of an albitite dike; b: Finely hematite disseminated in an albitite dike.

quartz veins in many other Archean gold deposits. The albitite dikes may have played an important role in hydrothermal alteration related to mineralization. They may have provided a channel for the circulation of hydrothermal fluids.

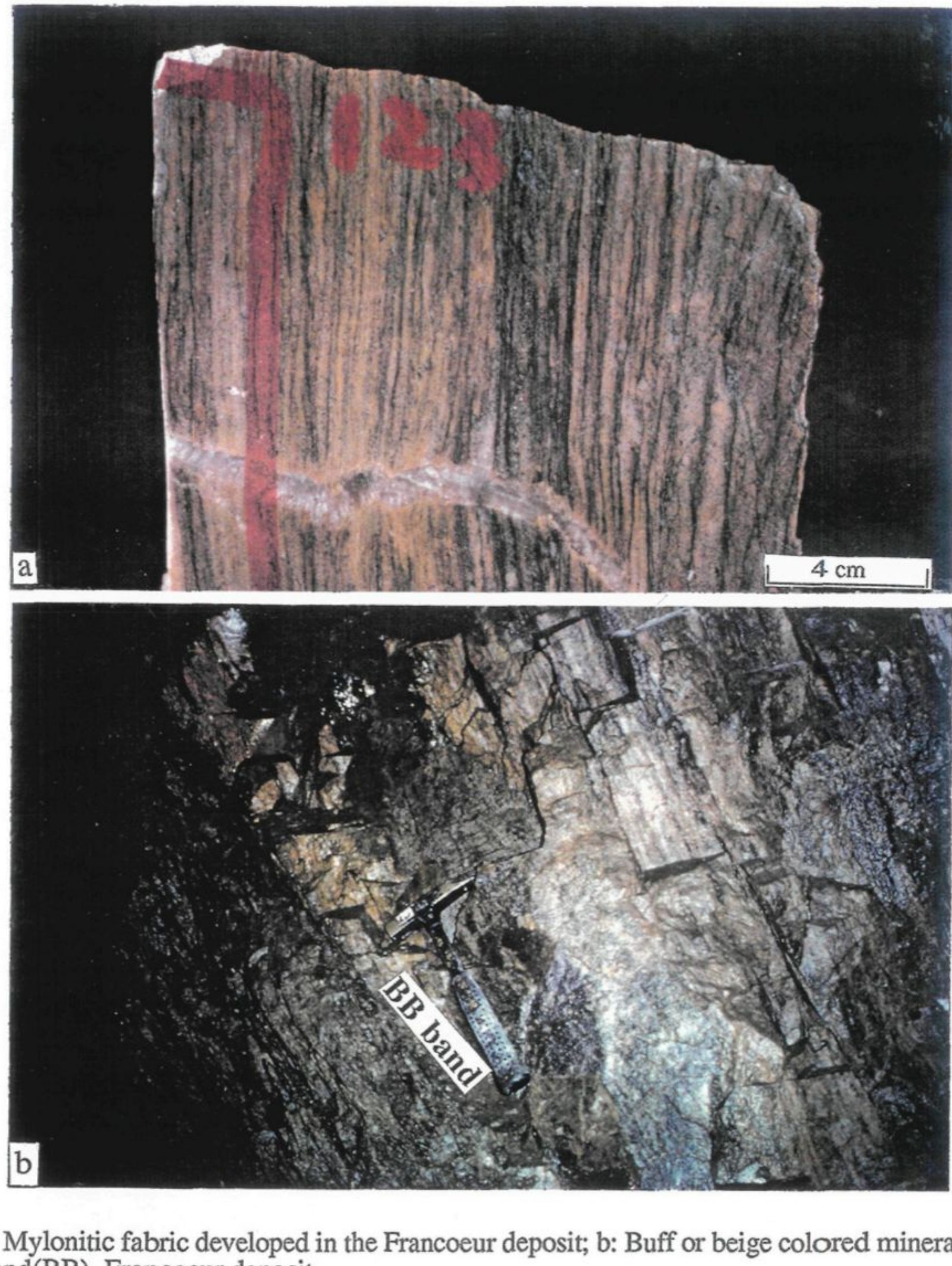
3.1.2 Structure

The Francoeur-Wasa shear zone is the main structure in the Francoeur #3 mine. It strikes east-west and dips approximately 45° to the north. The Francoeur shear zone consists of a series of inverse faults. The width of the shear zone is between 50 and 80 metres. In the mine workings the shear zone thickness varies from about 20 m near surface to over 80 m at depth (Couture and Pilote 1991). This shear zone is characterized by the development of a strong mylonitic fabric (Plate IIa) and an intense hydrothermal alteration which totally destroys the primary structures and textures of the initial rocks.

3.1.3 Mineralization

The ore zones of the Francoeur #3 deposit are generally made up of distinct lenticular and tabular bodies up to 1 m in thickness, and form buff or beige colored bands, called BB bands (Plate IIb). All the BB bands are principally composed of carbonate, albite, pyrite and minor amounts of quartz and rutile, with trace amounts of sericite and gold. There is no evidence of stratigraphic control on the gold deposition in the Francoeur mine. Instead, the gold emplacement apparently developed in the shear zone and is partially related to albitite dikes (Fig. 3.2). A similar lack of stratigraphic control was noted by Hutchinson and

Plate II



a: Mylonitic fabric developed in the Francoeur deposit; b: Buff or beige colored mineralized band(BB), Francoeur deposit.

Burlington (1984) for deposits adjacent to the Cadillac break in the Noranda district of Quebec. The nature of the contacts of gold ore bodies with enclosing mylonitic schist is quite variable. There are two types of basic contacts. One of them is faulted, while the other may be sharp or gradational. The BB bands display a wide variety of textures, ranging from a foliated microbreccia (Plate IIIa), to more common fine grained and very well laminated rock (Plate IIIb). They contain on average 20 to 40 g/t Au and the grade can reach 50g/t locally. The gold is commonly in its native form and is very fine-grained. Gold grains are usually associated with small pyrite crystals, but a proportion is also disseminated in the finely recrystallized carbonate-albite matrix.

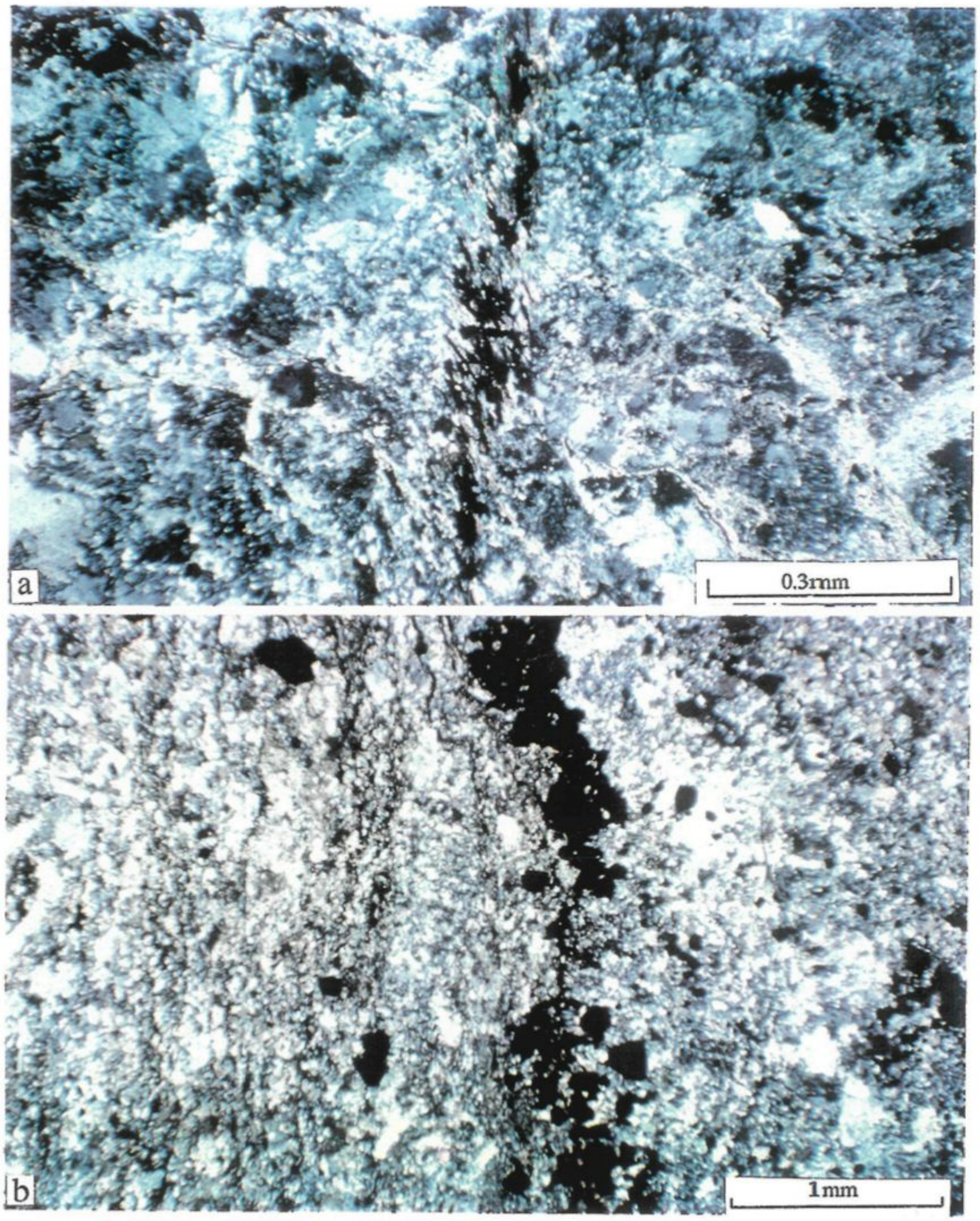
3.2 The Lac Fortune deposit

3.2.1 Mine geology

The geology of the Lac Fortune mine area has been described by the geological staff of the mine in several reports (Fritzsche 1934; Bruce 1933; Karpoff 1986). More recently, genesis of the deposit has been studied by Couture and Pouliot (1993).

The Lac Fortune mine is situated about 2 km farther to the south of the Francoeur #3 deposit and 3 km farther to the west of Arntfield. This deposit is comprised in quartz-carbonate veins, and belongs to the quartz vein type gold deposit. This deposit developed in a small shear zone parallel to the Francoeur-Wasa shear zone (Fig. 3.3). It is located near a contact between a gabbro-diorite stock and mafic volcanic rocks. The shear zone also consists of a series of inverse faults and is approximately 25 metres wide. Two types of intrusive

Plate III



a: Foliated microbreccia in BB band, Francoeur deposit; b: Fine grained and well-laminated texture in the BB band rock, Francoeur deposit.

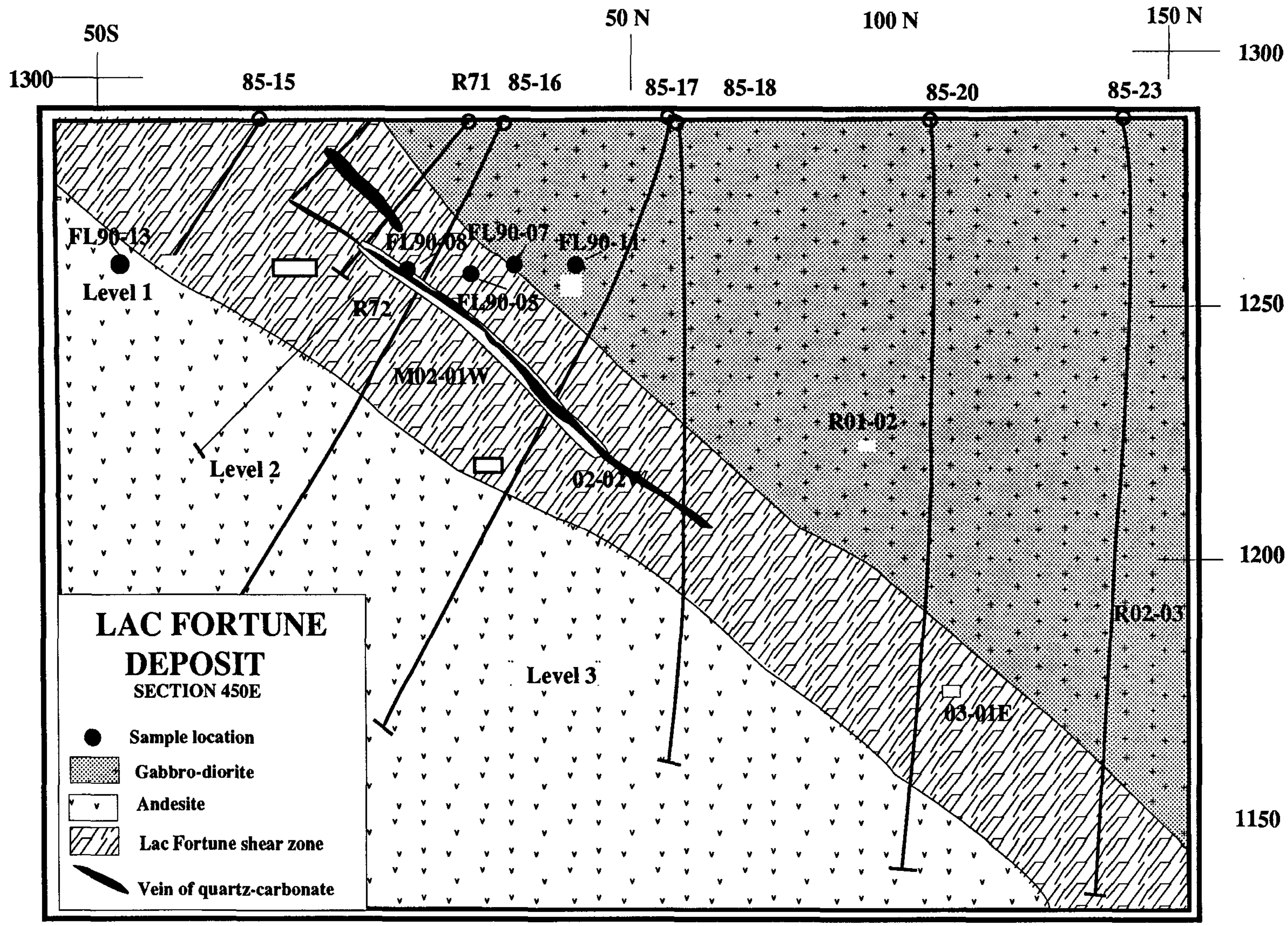


Fig. 3.3 General cross section of the Lac Fortune deposit and location of samples

(Modified from Couture and Pouliot 1991).

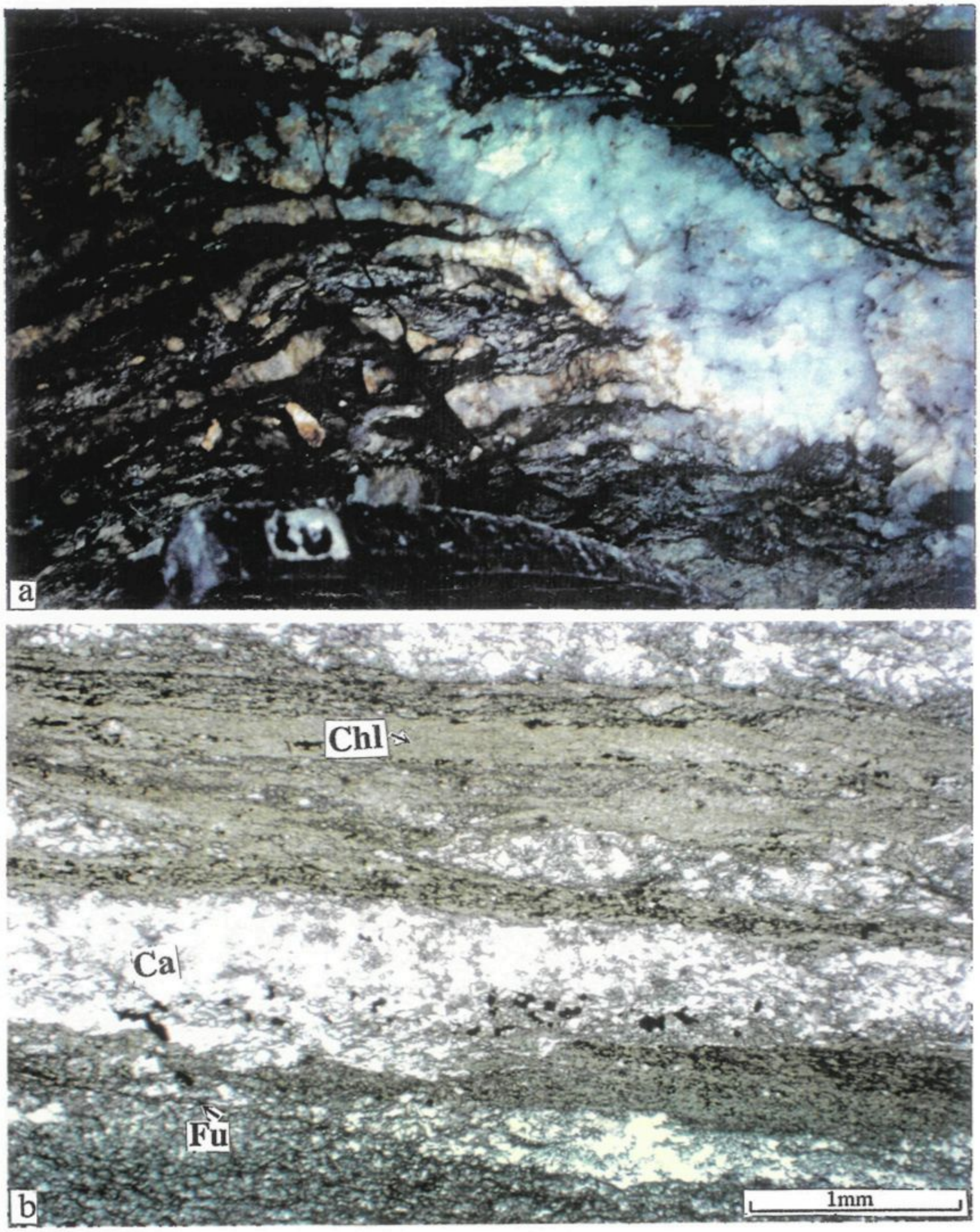
rocks have been observed in the Lac Fortune area: one is a diorite, and the other is a porphyry.

3.2.2 Mineralized veins

The mineralized veins are chiefly composed of quartz and carbonate, with smaller amounts of chlorite, fuchsite, pyrite, gold and various Pb-Bi tellurides. Two types of quartz veins occur within the mine: 1) large and extensive veins (Plate IVa), which occur parallel to the shear zone, and 2) narrower veins, which crosscut the sheared fabric and trend to the N-NE with a small dip.

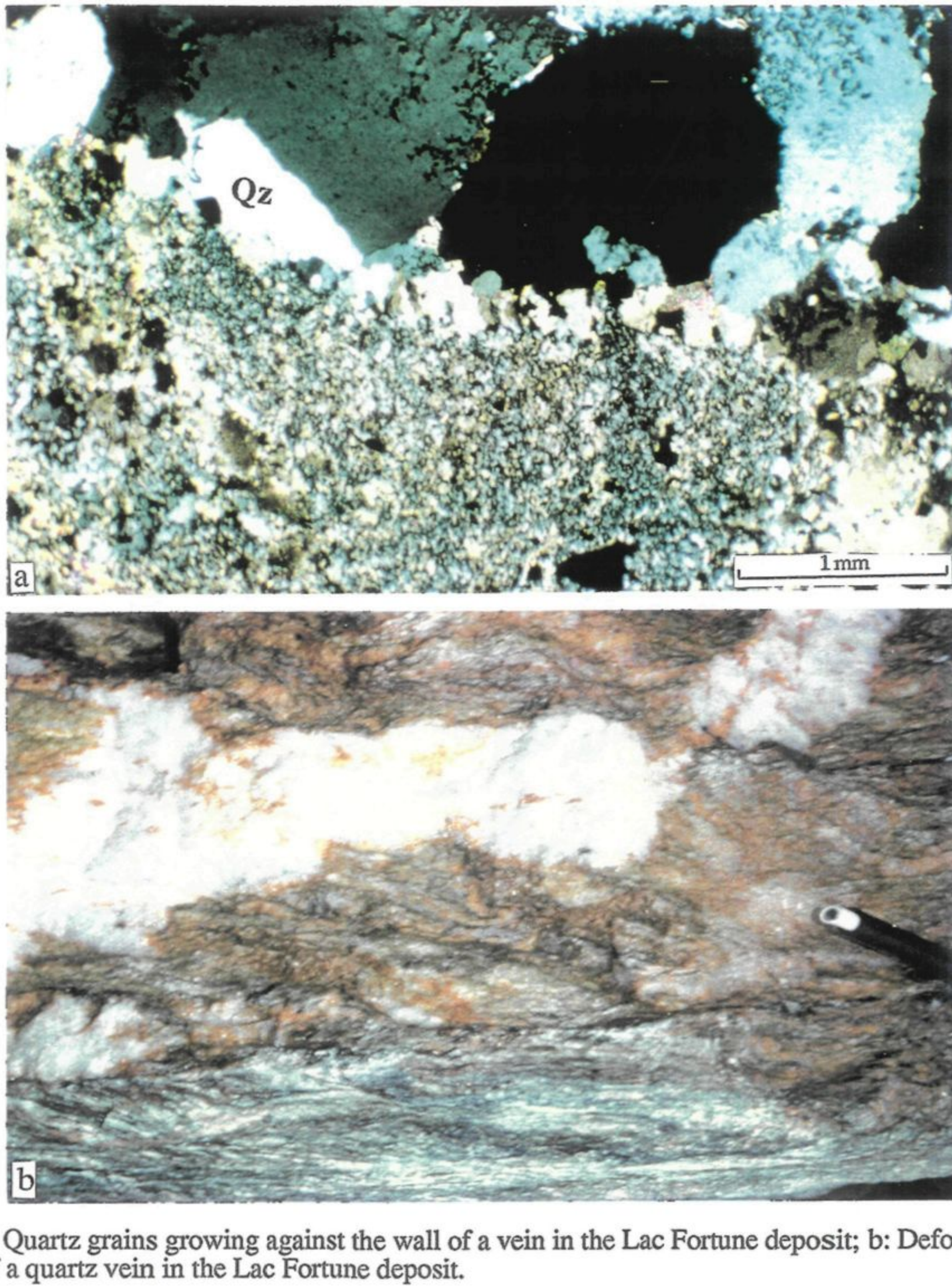
The constituents of the quartz veins are mainly quartz and minor amount of plagioclase, carbonate, white mica, pyrite, tourmaline and pyrrhotite. The wall rock is an altered mylonitic rock. The principal alteration minerals are chlorite, carbonate, and green fuchsite (Plate IVb). Most of these veins are composite, or display crack-sealed textures, with laminated or crustiform layering parallel to the vein walls. Quartz and carbonate in the veins have grown against the wall (Plate Va). These textures indicate that the veins formed as open space fillings, under oscillating, high fluid pressures (Sibson et al. 1975). Grains of quartz and carbonate display various microstructures, including undulatory extinction and deformation lamellae, indicating ductile strain. Those textures also occur in subgrains and newly crystallized grains , indicating recovery and incipient recrystallization, respectively. These microstructures suggest an episode of ductile deformation of quartz and carbonate postdating the filling of the veins (Robert and Brown 1986). This deformation of quartz-carbonate veins can be observed in petrographic work (Plate Vb). Such deformation of the vein minerals is attributed to the emplacement of the veins in a dynamic tectonic

Plate IV



a: A large and extensive quartz vein occurring in the Lac Fortune deposit; b: Altered mylonitic wall-rocks consisting of chlorite, carbonate and fuchsite, Lac Fortune deposit.

Plate V



a: Quartz grains growing against the wall of a vein in the Lac Fortune deposit; b: Deformation of a quartz vein in the Lac Fortune deposit.

environment (Robert and Brown, 1986; Roberts, 1989), i.e., deformation and veining are parts of a concurrent and continuous process.

The gold mineralization is entirely hosted by quartz veins in the shear zone and consists of coarse free gold and Pb-Bi tellurides. This is typical quartz veins type gold deposit.

CHAPTER IV

HYDROTHERMAL ALTERATION

4.1 Introduction

It is widely accepted that Archean lode gold deposits are derived from the flow of large volumes of hydrothermal solutions, with gold precipitating in structurally controlled conduits (Fyfe and Henley 1973; Kerrich 1985; Neall and Phillips 1987; Kishida and Kerrich 1987; Colvine et al 1988). Many such gold deposits are surrounded by a pronounced alteration halo induced by the action of hydrothermal fluids on the contiguous wall rocks (Boyle 1979; MacGeehan et al. 1982; Kerrich 1985; Smith et al. 1984; Robert and Brown 1986). Information from alteration halos can provide certain insight into the conditions of metal mineralization (Phillips 1986; Kishida and Kerrich 1987; Couture and Pilote 1991).

Hydrothermal alteration means significant changes in the mineralogic and/or chemical composition of a rock brought by the action of hydrothermal solutions (Bates and Jackson 1987). Hydrothermal alteration is common in the Francoeur and Lac Fortune deposits (Couture and Pilote 1991), especially in the Francoeur deposit. It is interesting to note that the mineralization is closely associated with the hydrothermal alteration in the Francoeur mine. In the Lac Fortune mine, however, hydrothermal alteration is relatively simple and does not appear to be related to mineralization. Knowledge of hydrothermal alteration for the Francoeur and Lac Fortune deposits is therefore helpful to understand the process of mineralization of these two mines. Two important aspects are addressed in this chapter: (1) the types of alteration observed (2) the relationship of mineralization to the hydrothermally altered mineral assemblages.

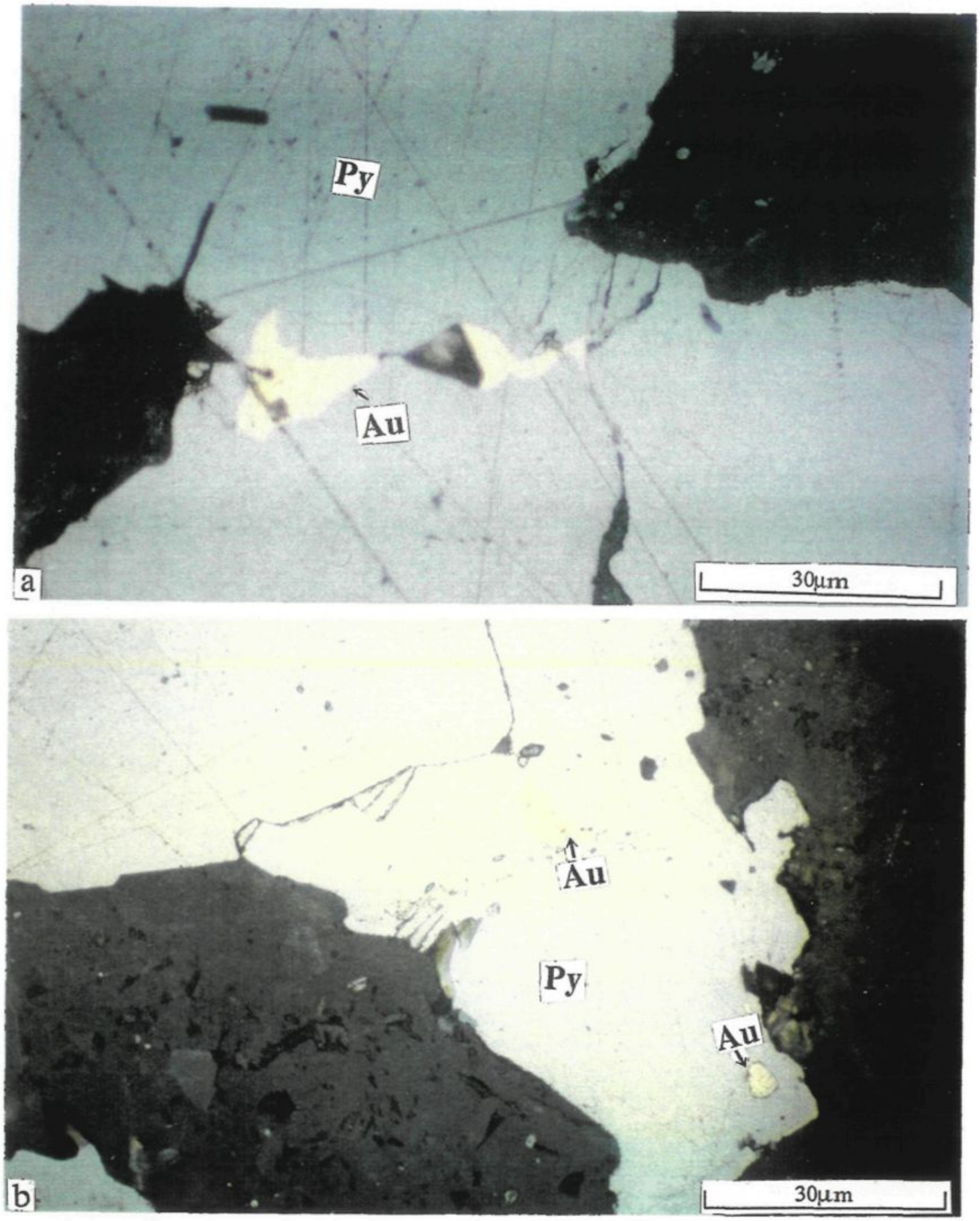
4.2 The Francoeur deposit

A series of samples were systematically collected from the orebody to the wall-rock along three sections in the Francoeur mine in order to investigate the change of hydrothermal alteration from the mineralized center to the wall-rock (Fig. 3.2 and Appendix I). Of the collected samples, 23 thin sections were made and studied under microscope.

According to field observations, hydrothermal alteration is restricted to the shear zone and to the south ore zone where it is closely associated with the albitite dikes. All of four ore zones are associated with disseminated pyrite and hydrothermal alteration, but the type and degree of hydrothermal alteration are different. Alteration minerals have been identified under the microscope. They mainly include albite, carbonate, quartz, pyrite and a minor amount of muscovite, chlorite , hematite, and magnetite. Gold generally occurs in fractures of pyrite (Plate VIa), as small inclusions in pyrite (Plate VIb), or disseminated in the finely recrystallized carbonate-albite matrix (Couture and Pilote 1991).

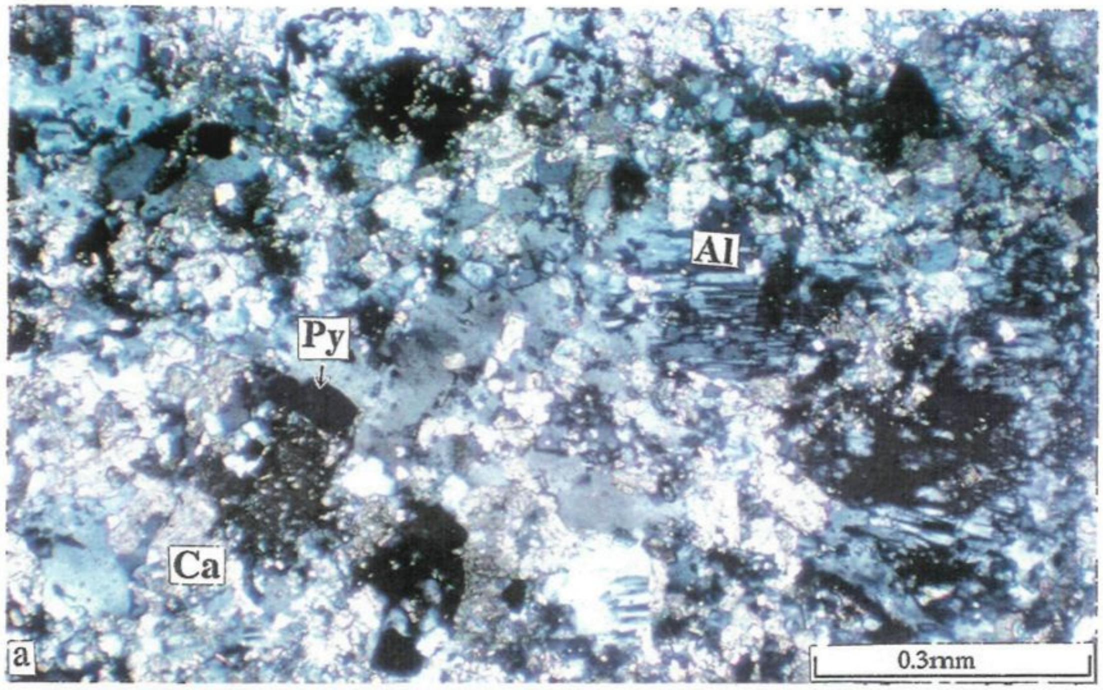
The alteration mineral assemblages display a distinct zonation which occurs around not only giant deposits but also smaller ones. From the orebody to outside, commonly, the sequence of alteration in mineralogical distinct bands changes from albite-pyrite, through carbonate-hematite, to muscovite-chlorite. Typical zonation is well shown in Plates VIIa-VIIIa. The zone of albte-pyrite is the main mineralization zone. It is principally hosted in

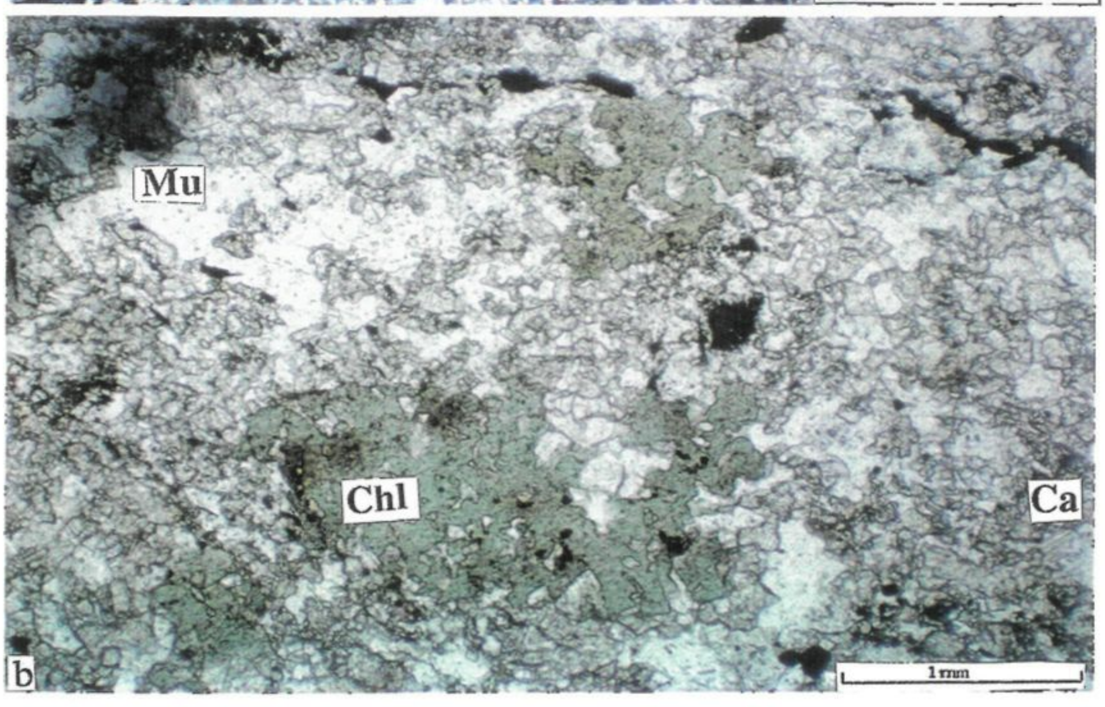
Plate VI



a: Gold occurring in the fractures of pyrite, Francoeur deposit; b: Gold occurring in pyrite, Francoeur deposit.

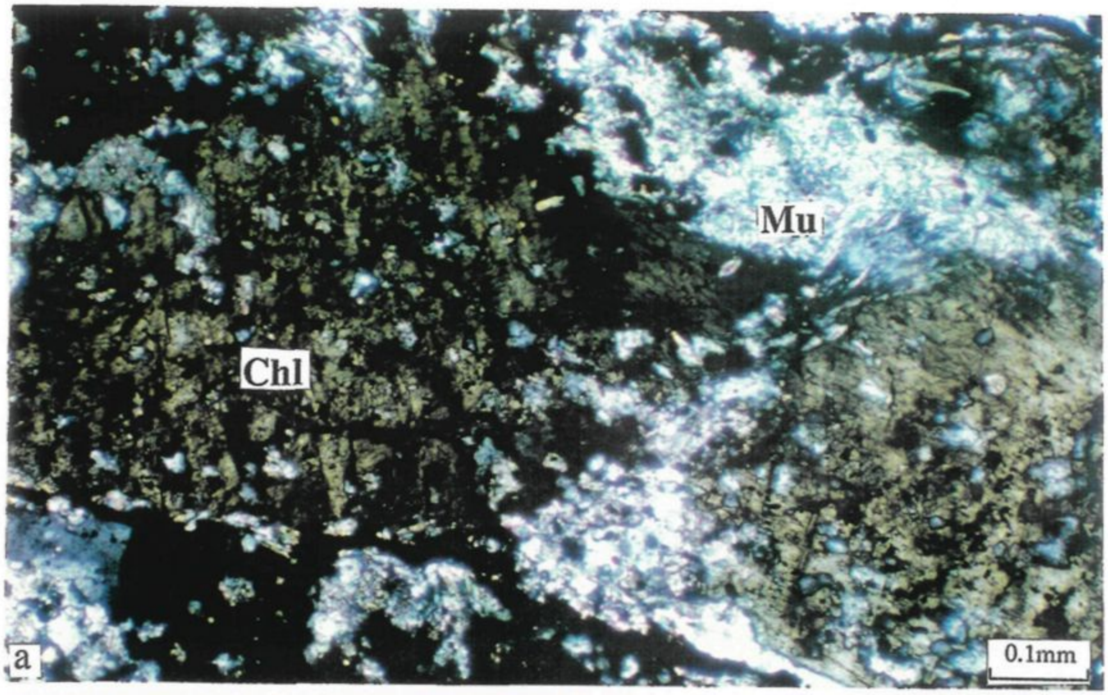
Plate VII

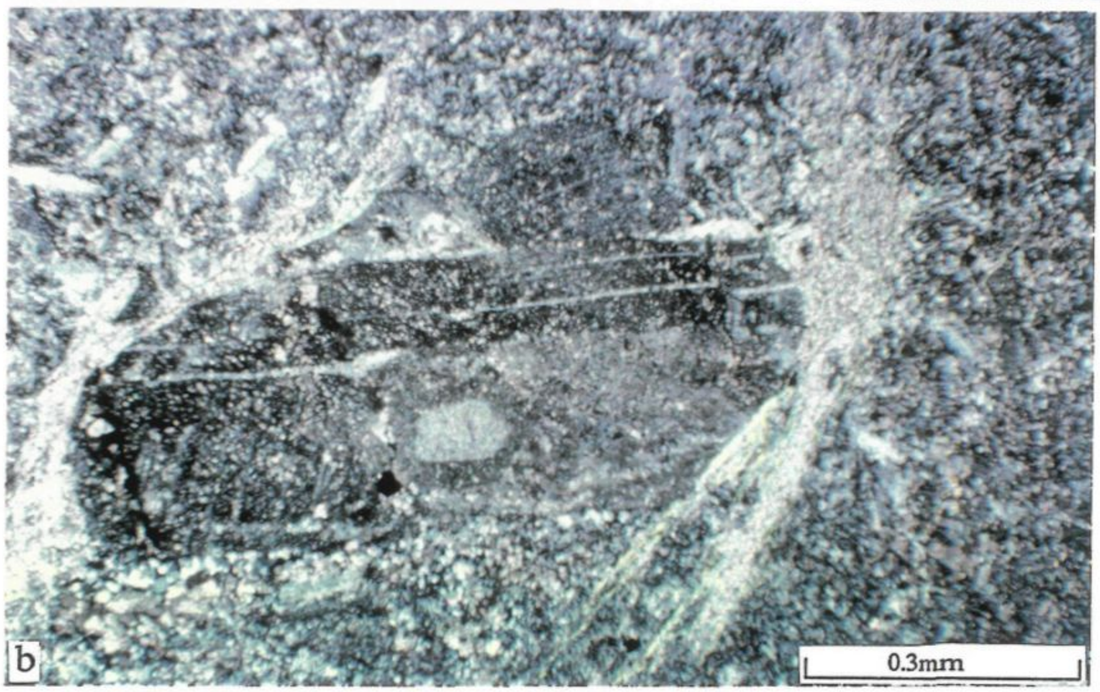




a: Albite-pyrite alteration mineral assemblage, Francoeur deposit; b: Carbonate-hematite alteration mineral assemblage, Francoeur deposit.

Plate VIII





a: Muscovite-chlorite alteration mineral assemblage, Francoeur deposit; b: Relict volcanic texture-pseudophenocryst texture, Francoeur deposit.

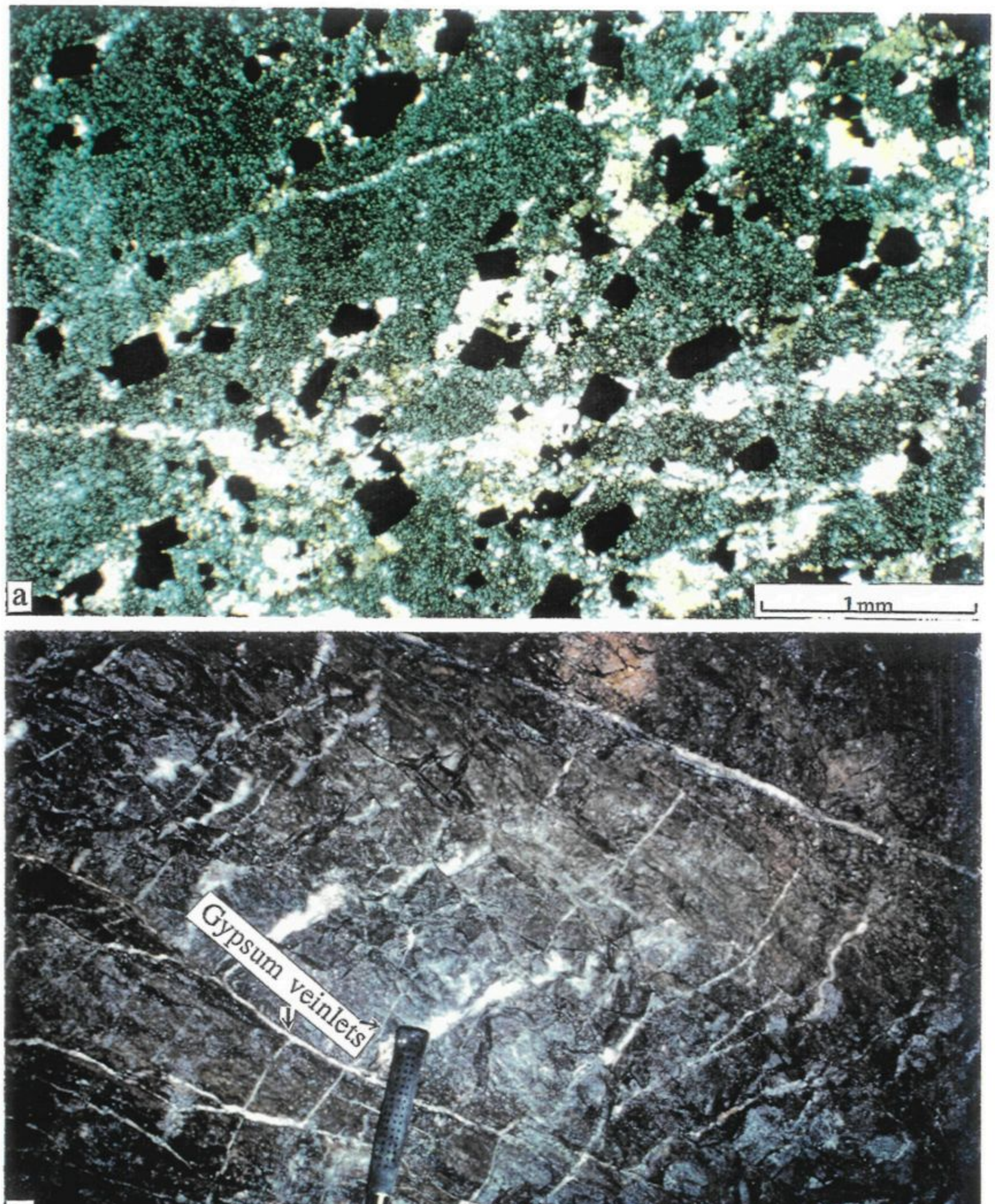
shear zones. The muscovite-chlorite zone is commonly situated in the wall-rock away from the shear zone, and the carbonate-muscovite-chlorite-hematite zone in transitional zone from the orebody to the wall rock. The muscovite-chlorite may be absent in some places. It is possible that the muscovite-chlorite zone has been completely replaced by later alteration mineral assemblage such as albite-pyrite. The content of hematite and magnetite gradually increase from the orebody to the wall-rock. Relict volcanic texture, such as pseudophenocryst texture, can be observed in wall-rock and BB band rock (Plate VIIIb).

The grain size of the alteration minerals is variable. In some cases, quartz and albite are too small to distinguish them under microscope; but in other cases, the albite grains are, up to 1 x 2 mm^2, and exhibit good albite twinning (Plate VIIa). Early carbonate is very small, existing mainly in fine aggregates. Late carbonate is relatively larger, with its size up to 2 x 3 mm^2, and they show well developed cleavages.

Pyrite is commonly euhedral, with section of 1 x 1 mm^2 in size. Muscovite occurs as minute shreds, some of which resulted apparently from the alteration of feldspar. A lot of altered veinlets are observed in the orebody and wall-rock (Plate IXa),and indicate the penetration of hydrothermal fluid along fractures. The albitite dikes associated with mineralization have been altered. The degree of alteration is obviously more extensive at the margin than in the center.

Observations show that the hydrothermal fluid associated with gold mineralization might have circulated along the shear zone and then penetrated to the wall-rock. The zonation of alteration indicates an evolution sequence of fluid-rock interactions with time and space. The significance of albitite dike to gold mineralization probably lies on that it provides a penetrative channel for the flow of hydrothermal fluids.

Plate IX



a: Altered veinlets occurring in orebody, Francoeur deposit; b: Gypsum veinlets of post-alteration in the Francoeur deposit.

4.2.1 Alteration mineral associations

In a manner similar to that of Kishida and Kerrich (1987) at Kerr Addison, alteration types can be classified on the basis of coexisting diagnostic minerals and their textural relationships. With respect to the temporal and spatial relationship with the Au mineralization and alteration, alteration minerals may be grouped into three assemblages: the metamorphic assemblage, the hydrothermal alteration mineral assemblages, and the post-hydrothermal alteration mineral assemblage. They are shown in the Table 4.1.

4.2.1.1 Metamorphic assemblage

The metamorphic assemblage is seldom observed in the Francoeur mine area, except in slivers of wall-rock within the shear zone (Couture and Pilote 1991). Relict volcanic textures are locally preserved in the mine area. Actinolite, chlorite, muscovite are diagnostic minerals of the metamorphic assemblage. Minor amount of quartz, epidote, and feldspar also exist.

Both the protolith and gabbro are typically composed of actinolite, chlorite, muscovite, feldspar and epidote with minor amount of quartz, magnetite, hematite, and calcite. In the present study, the samples collected have been intensely altered, not much actinolite was found in the thin sections examined. Generally, actinolite has an aligned fabric, and it is the same as chlorite and muscovite.

Table 4.1 Mineral assemblages of altered rocks, Francoeur deposit

AITERATION STAGE	ALTERATION TYPE	Ac	Chl	Mu	Hem	Ca	Py	Al	Gy	Ca'
Pre-alteration	Metamorphic assemblage	+	+	+						
Alteration stages	Muscovite-chlorite		+	+						
	Carbonate-hematite		+	+	+	+				
	Albite-pyrite				+	+	+	+		
Post-alteration	Gypsum-hematite								+	+

Ac=Actinolite; Chl=Chlorite; Mu=Muscovite; Hem=Hematite; Ca=Carbonate;

Py=Pyrite; Al=Albite; Gy=Gypsum; Ca'=Late carbonate.

4.2.1.2 Alteration stage assemblages

The alteration stage assemblages include three alteration types based on the occurrence of alteration minerals. They are mainly the alteration products of metavolcanic rocks in the mine area during the alteration stage. These three alteration types are characterized by the muscovite-chlorite assemblage, the carbonate-hematite assemblage, and the albite-pyrite assemblage.

Muscovite-chlorite assemblage: The diagnostic minerals of the muscovite-chlorite assemblage are muscovite and chlorite, which together make up 80% of the the minerals of this assemblage. Carbonate, quartz, magnetite also exist in this alteration mineral assemblage. Relict texture of actinolite can been examined. Chlorite exhibits black green colour. The chlorite occurs either as large crystalline blocks or as randomly oriented fine-grained aggregates. Generally, muscovite occurs as fine grains (Plate VIIIa).

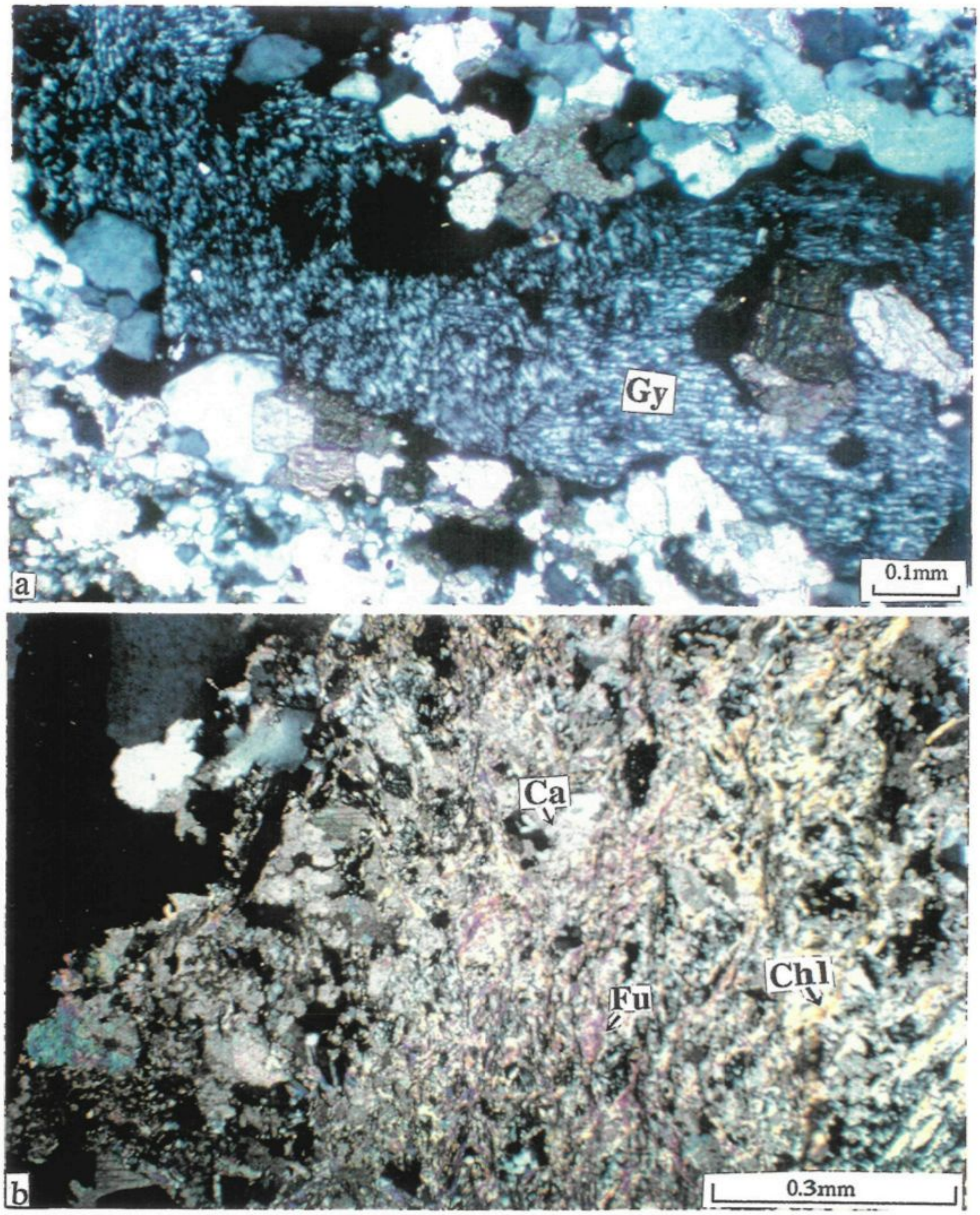
Carbonate-hematite assemblage: The diagnostic minerals of this assemblage are carbonate and hematite, which together make up 80% of the the minerals of this assemblage. Muscovite and chlorite often occur in relict texture (Plate VIIb). Other significant minerals include quartz, albite and magnetite. It is interesting to note that hematite, chlorite and muscovite are aligned along the structural lineation, indicating that the alteration is probably syn-tectonic. Carbonate, which replaced the muscovite-chlorite mineral assemblage and/or the regional metamorphic assemblage, usually occurs as fine-grained assemblage. The abundance of this mineral assemblage decreases rapidly with increasing intensity of alteration. Rocks affected by this type of alteration have anomalous gold values but usually do not make ore grades (Couture and Pilote, 1991).

Albite-pyrite assemblage: The diagnostic minerals in this mineral assemblage are albite and pyrite, coexisting with quartz, carbonate and relict chlorite. The grains of carbonate and albite are bigger than those of the carbonate-hematite assemblage. The content of carbonate plus albite is more than 85% (Plate. VIIa) of this assemblage. This mineral assemblage is characterized by: 1)the coexistence of pyrite, carbonate and albite, 2) the disappearance of hematite and muscovite, 3) the rapid decrease of the content of gold. Gold is observed to coexist with the alteration minerals of this assemblage, especially pyrite. The gold-rich Buff Band (BB) occurring in the mine represents the most typical product of this type of alteration. Minor amounts of relict muscovite and chlorite are also present in this mineral assemblage. Relict hematite may be occasionally observed as inclusions (< 30μm) enclosed in larger pyrite porphyroblasts and host rock porphyroclasts. Gold usually occurs in the fracture of pyrite or as inclusions in pyrite. It is obvious that this alteration type played an important role in gold mineralization.

4.2.1.3 Post-alteration assemblage

The post-alteration assemblage consists of barren fibrous extension veinlets. These veinlets are narrow, only several mm to 1 cm, and hosted by the shear zone. The veinlets crosscut all alteration lithologies including the gold-bearing BB bands, indicating that these veinlets are post-alteration products. Two conjugate sets of veinlets (Plate IXb) are observed: one parallels to the foliation of the schist, and the other almost orthogonal to it. These veinlets principally consist of sulfates, carbonates and rarely hematite (Couture and Pilote 1991). Gypsum is the principal sulfate and occurs in anhedral aggregates and shows a fibrous structure (Plate Xa).

Plate X



a: Gypsum veinlets under the microscope, Francoeur deposit; b: Chlorite-carbonate-fuchsite alteration mineral assemblage, Lac Fortune deposit.

4.2.2 Timing of alteration and gold mineralization

Tight constraints can be placed on the timing of alteration, even though absolute ages are unknown. The regional metamorphic rocks and ductile shear zones provide a framework in which mineralization and alteration can be placed.

The observations of the present study confirmed the order in alteration mineral assemblages from muscovite-chlorite to carbonate-hematite to albite-pyrite. During the early deformation, the rocks were redefined by aligned actinolite and feldspar. Some muscovite-chlorite aggregates preserve the actinolite alignment and grain shapes, but the individual chlorite grains within the aggregates are randomly oriented, suggesting that chlorite postdated the peak of regional metamorphism (Bartram et McCall 1971). The actinolite fabric is believed to be related to the metamorphic assemblage. Therefore, the muscovite-chlorite alteration assemblage overprinted on the metamorphic assemblage.

Secondly, a lot of relict chlorite and muscovite are observed within the carbonate-muscovite-chlorite-hematite zone, suggesting that the chlorite-muscovite zone was formed before the carbonate- hematite zone. Thirdly, the abundance of hematite abruptly decreases in the albite-pyrite alteration zone and hematite occasionally occurs in small inclusions enclosed in larger pyrite grains indicating that the latter overprints the former. We are thus brought to the conclusion that the chlorite-muscovite is replaced by the carbonate-hematite assemblage which is further replaced by the albite-pyrite assemblage.

Finally, since the veinlets filled with gypsum-hematite cut all rocks in the study area, it seems that the gypsum-hematite assemblage represents the post hydrothermal alteration event.

According to previous work (Couture and Pilote 1991), the process of alteration can be summarized by equations as follows:

Muscovite-chlorite assemblage:

$$2(Mg\text{-}Fe)\ \text{Amphiblole} + 4\ CO_2 + 2H_2O + 1/3\ O_2 = \text{Mg-Chlorite} + 4\ \text{Calcite} + 5/3\ \text{Magnetite} \quad (1)$$

$$6\ \text{Actinolite} + 12\ CO_2 + 14\ H_2O = 5\ \text{Chlorite} + 12\ \text{Calcite} + 28\ \text{Quartz} \quad (2)$$

$$3\ \text{Chlorite} + 15\ \text{Calcite} + 2\ K^+ + 15\ CO_2 = \text{Muscovite} + 15\ \text{Carbonate} + 3\ \text{Quartz} + 9\ H_2O + 2\ H^+ \quad (3)$$

Carbonate-Hematite assemblage

$$\text{Chlorite} + 6\ \text{Calcite} + 6\ CO_2 = 6\ \text{Carbonate} + 4\ \text{Quartz} + 4\ H_2O \quad (4)$$

$$2\ \text{Magnetite} + 1/2\ O_2 = 3\ \text{Hematite} \quad (5)$$

Albite-Pyrite assemblage

$$2\ \text{Hematite} + 8\ H_2S + O_2 = 4\ \text{Pyrite} + 8\ H_2O \quad (6)$$

$$\text{Muscovite} + 6\ \text{Quartz} + 3\ Na^+ = 3\ \text{Albite} + K^+ + 2\ H^+ \quad (7)$$

It is quite evident from these equations and geochemical analysis for alteration zones (Couture and Pilote 1991) that the alteration sequence corresponds to addition of K, CO_2, Na, and S. In other words, the sequence of actinolite-chlorite to muscovite-chlorite to carbonate-hematite to albite-pyrite zones suggested by textural relationships is compatible with the geochemistry of the alteration zones.

The geometry of the alteration zones is also totally compatible with the sequence above and provides additional constraints on the ablite-pyrite assemblage. The geometric control on the alteration zones by ductile shear zones thus implies that the albite-pyrite assemblage formed during or after the ductile shear zones.

The fine grain size, equivocal texture, and low concentration of gold preclude its direct use in timing gold mineralization; however, arguments based on other components of mineralization, especially pyrite, provide a viable means of timing gold. Other studies of gold mineralization timing is that pyrite and gold are spatially and genetically related. At Francoeur, virtually all economic auriferous areas have at least 1-4 percent pyrite, and the edge of the albite-pyrite zone is typically a sharp break in gold values (based on unpublished mine assay records). The confinement of economic gold in a shear zone implies that gold mineralization was syn- or post-shear zone formation. The close association of gold and pyrite suggests that gold mineralization occurred in the same restricted time with albite-pyrite alteration zone. It is known that there is anomalous gold values in the carbonate-hematite alteration zone, the carbonate-hematite alteration thus was thought to represent an early stage of gold mineralization. It appears highly likely that gold mineralization was also part of one progressive alteration event. On the other hand, there is no evidence suggesting that gold mineralization was temporally separated from the alteration.

Based on the geometry of the alteration zones, the textures in altered rocks, the characteristics of geochemistry of the alteration zones, and the distribution of mineralization, it may be concluded that the sequence of alteration is from muscovite-chlorite to carbonate-hematite to albite-pyrite, and that the formation of the carbonate-hematite zone and albite-pyrite zone appears to have been essentially synchronous with gold mineralization.

To sum up, five types of altered rocks occur in the deposit according to the alteration mineral assemblages. In chronological order, they are: 1) the metamorphic assemblage, that is those minerals predating of the alterations; 2) the muscovite-chlorite alteration mineral assemblage; 3) the carbonate-hematite; 4) the albite-pyrite altered mineral assemblage; and 5) the gypsum-hematite post-alteration mineral assemblage, which is a post-mineralization process related to sulfate-bearing alteration. The alteration assemblages display a distinct zonation, indicating the evolution of fluid-rock interactions with time and space. Gold mineralization is closely related to hydrothermal alteration, especially to the formation of the carbonate-hematite zone and albite-pyrite zone.

4.3 The Lac Fortune deposit

The Lac Fortune orebody is a quartz veins type gold deposit. Its hydrothermal alteration is relatively simple with respect to the Francoeur deposits. To study the hydrothermal alteration of quartz veins themselves and wall-rocks, 11 samples were collected in the Lac Fortune mine (Fig. 3.3) and 8 thin sections were done for observation under microscope.

Our observations on the quartz veins show that quartz was mainly derived from the direct precipitation of SiO_2 from the hydrothermal solution in open fractures. Some of quartz may have also replaced the wall-rock. Quartz grains are deformed and recrystallized. There is some late carbonatization in quartz-carbonate veins.

The wall-rocks are principally metavolcanic rocks, similar to those of the Francoeur deposit. The principal alteration mineral assemblage occurring near the quartz vein-volcanic rock contact zone is chlorite-carbonate-muscovite-±fuchsite (Plate 4.10). The chlorite and muscovite are arranged parallel the direction of the vein walls, and form some bands parallel to the vein walls and well-defined flow structures. The carbonate is granular, scattered in the intergranular planes of chlorite and muscovite. This alteration mineral assemblage often symmetrically occurs on both side of the quartz veins.

Based on our observations, gold mineralization in this mine took place mostly in the quartz veins and there is no mineralization in the altered wall-rock. There is no evidence that the gold mineralization in Lac Fortune has been directly related to hydrothermal alteration, although it has been well known that this gold deposit is closely associated with hydrothermal solutions (Fyfe and Henley 1973; Kerrich 1985). A more detailed study is needed for obtaining better knowledge of the relationships between gold mineralization and hydrothermal wall-rock alteration in the Lac Fortune gold deposit. For these, fluid inclusions study will be done.

CHAPTER V

GEOCHEMISTRY OF FLUID INCLUSIONS

Hydrothermal fluids are important for the formation of many gold deposits. Clear knowledge of them is very helpful in the study of gold deposits (Roedder 1979,1984). It has been known that fluid inclusions represent the actual samples of the fluids existing at some time in the geologic history of the ore deposit (Roedder 1984; Barnes 1979; Shepherd et al 1985). With the help of fluid inclusions techniques, the physicochemical conditions, including the chemical composition, temperature, pressure of the ore-forming fluid may be recognized, and the evolution history of the gold-bearing fluid can be outlined (Krupka et al. 1977; English 1981; Franklin et al. 1981; Davies et al. 1982; Smith et al. 1984; Walshe et al. 1984; Ho et al. 1986; Fyon and O'Donnell 1986; Wood et al. 1986; Colvine et al. 1988; Lu et al. 1990; Guha et al. 1991).

Fluid inclusions from the Francoeur and Lac Fortune deposits have not been studied. The study of the fluid inclusions related to the ore deposits will provide important clues in understanding the mineralization mechanism of the Francoeur and Lac Fortune gold deposits. This chapter focuses on the geochemical characteristics of the fluid inclusions from the studied gold deposits.

5.1 Occurrence of fluid inclusions

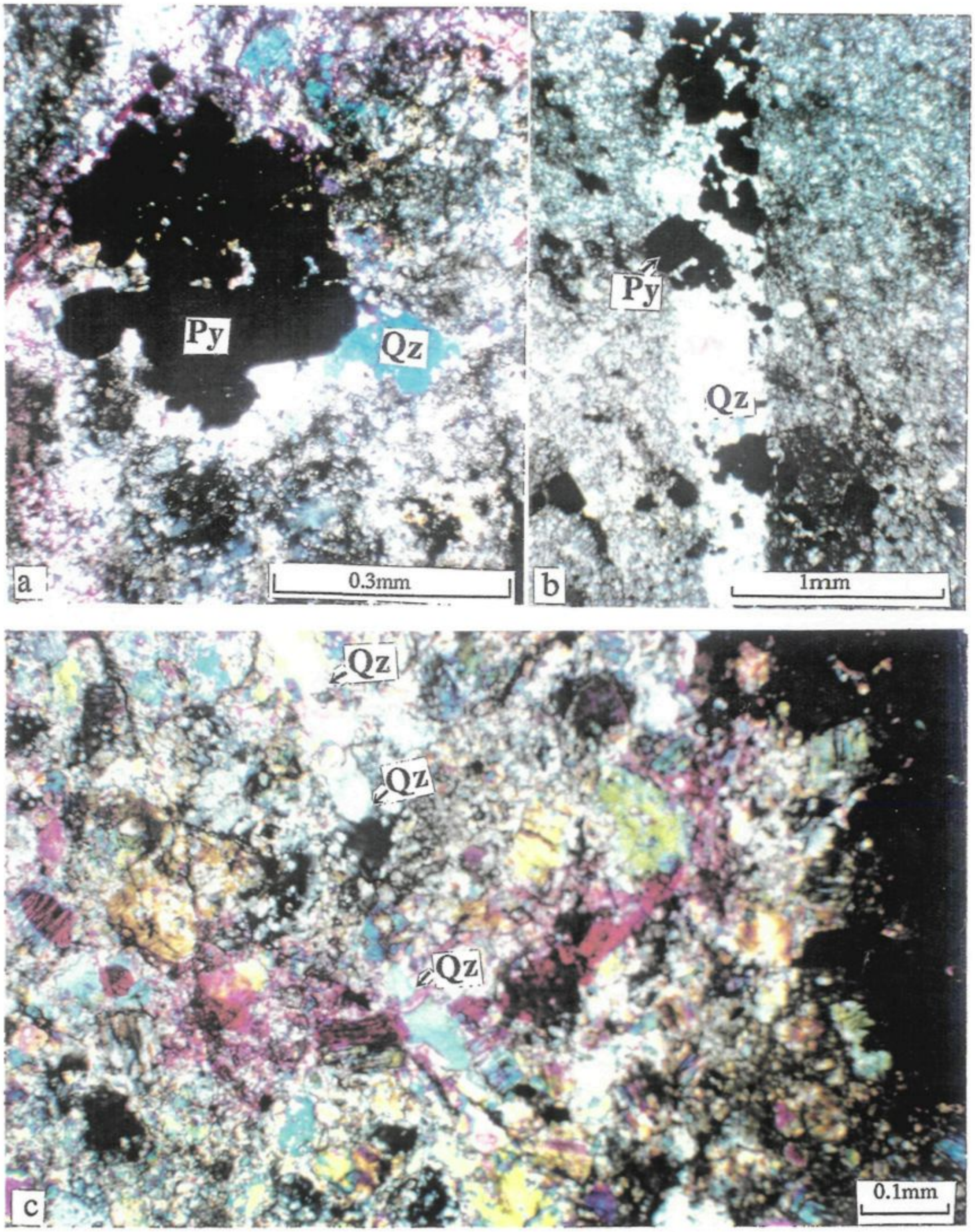
5.1.1 Selection of fluid inclusions

Fluid inclusions were examined in 28 doubly polished plates from 27 samples in the Francoeur deposit and 12 doubly polished plates from 9 samples of quartz veins in the Lac Fortune deposit. Selection of samples used for fluid inclusions analysis was based on the relationship of the host mineral and its fluid inclusions to gold mineralization. Only those fluid inclusions that are hosted by hydrothermal quartz were studied. Such hydrothermal quartz grains are commonly clean, and in paragenesis with pyrite. These quartz are believed to have been formed at the same time of the precipitation of gold.

The ore from the Francoeur mine is mainly composed of alteration minerals, such as albite, quartz, carbonate, pyrite with variable amounts of muscovite, hematite, magnetite and chlorite. Native gold grains are observed to coexist with fine-grained pyrite. If we can find some hydrothermal quartz which is associated with this pyrite, then the solutions contained in the primary fluid inclusions of these hydrothermal quartz grains represent the ore-forming fluid. Such quartz can be recognized based on the three following criteria: (1) It closely coexists with pyrite which is associated with mineralization (Plate XIa); (2) It is found in small quartz veins within which pyrite associated with mineralization occurs (Plate XIb); (3) It is found occurring along fractures crosscutting the orebody (Plate XIc).

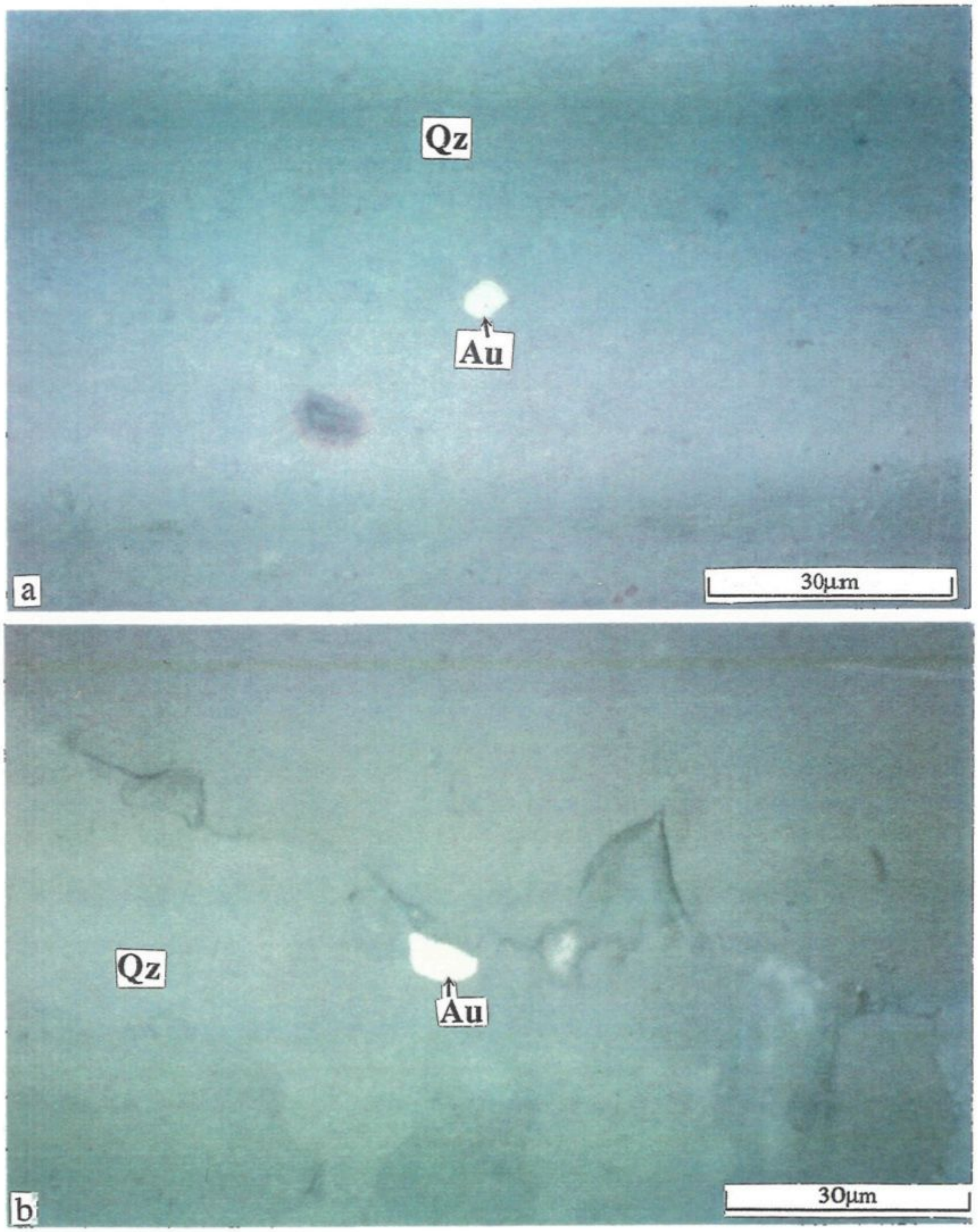
In the Lac Fortune gold mine, gold is scattered in quartz veins. Gold occurs principally as visible native metal grains in quartz. Under the microscope, gold is observed to occur within quartz grains (Plate XIIa) or along the interstices between quartz grains (Plate XIIb). In the first case, the occurrence of gold in quartz grains indicates that

Plate XI



a: Hydrothermal quartz closely coexisting with, Francoeur deposit; b: Pyrite occurring in a small hydrothermal quartz vein, Francoeur deposit; c: Hydrothermal quartz occurring in a fracture cutting the orebody, Francoeur deposit.

Plate XII



a: Gold occurring in a quartz grain in the Lac Fortune deposit; b: Gold occuring along the interstices between two quartz grains in the Lac Fortune deposit.

gold and quartz were formed at the same time, and that the solutions of the primary inclusions hosted in these quartz grains represent the mineralizing fluid. Isolated fluid inclusions in quartz grains are believed to be primary in origin. In the second case, where gold occurs along the interstices of quartz grains, inclusions occurring in healed fractures which abruptly stop at the boundary of the host grains may also represent the mineralizing fluid, but are secondary inclusions in origin.

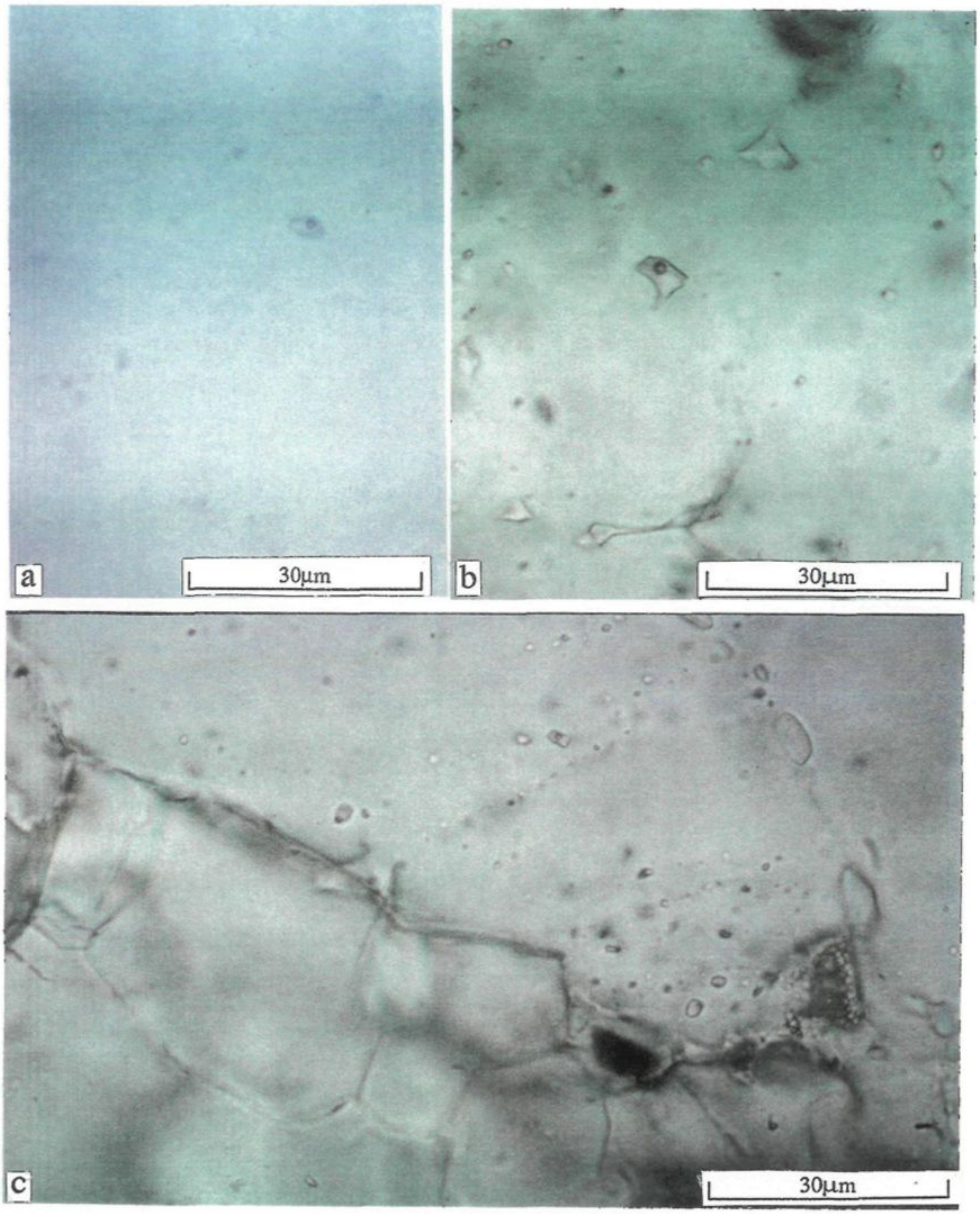
5.1.2. Occurrence of fluid inclusions

The fluid inclusions of the Francoeur and Lac Fortune deposits are usually small, especially those from the Francoeur gold deposit. Generally, the diameter of fluid inclusions ranges from < 1 to 20 µm, averaging about 5 µm. The fluid inclusions occur mainly in two distinct modes: as isolated inclusions within quartz grains (considered to be primary in origin) or as trails along healed fractures (considered to be secondary in origin).

The isolated inclusions (Plates XIII a,b) are often scattered in individual quartz grains. Distance between inclusions is more than 5 times the diameter of the inclusions. Generally speaking, the isolated inclusions are believed to be primary in origin and represent the hydrothermal fluid from which the host mineral formed (Roedder, 1979). If gold and isolated inclusions coexist in the same quartz grain, it is certain that these inclusions represent the ore-forming fluid. Isolated inclusions were observed and studied in both deposits.

Healed fractures are indicated by oriented arrays of many fluid inclusions (Plate XIIIc). Fluid inclusions occurring along healed fractures were evidently trapped during or

Plate XIII



a: Isolated inclusions from the Francoeur deposit; b: Isolated inclusions from the Lac Fortune deposit; c: Fluid inclusions occurring along healed fractures, Lac Fortune.

after the fracturing of the host mineral, and are thus secondary in origin (Roedder, 1984). However, several evidences indicate that some of these secondary fluid inclusions were formed during the gold mineralization. Under the microscope, healed fractures are often transgranular, cross-cutting subgrains, and could have been the result of multiple episodes of fracturing, fluid infiltration, and fracture healing. But some healed fractures of the host quartz grains end abruptly at the grain boundary with a pyrite and/or gold grain. The fluid inclusions in these healed fractures thus are believed to be associated with gold mineralization. These fluid inclusions are also considered for further examination.

5.2 Classification and relationships among different types of inclusions

5.2.1 Compositional types of inclusions

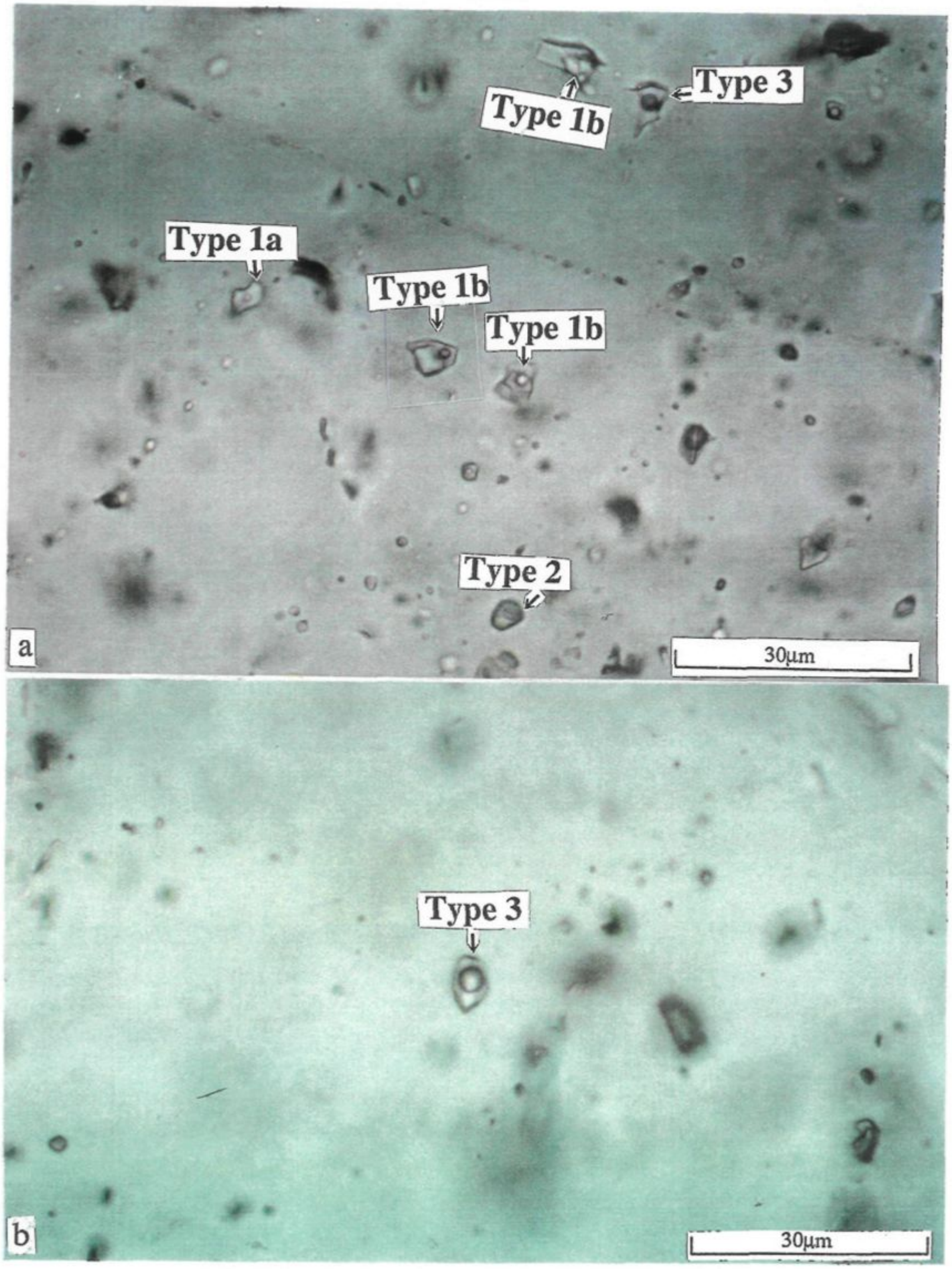
With some experience, the various types of inclusions could generally be distinguished on the basis of their appearance at room temperature, combined with their cooling behavior (down to about -20°C) and slight heating (up to about 30°C).

Three principal types of fluid inclusions have been identified in both the Lac Fortune and Francoeur gold deposits: type 1, aqueous inclusions; type 2, CO_2-rich inclusions; and type 3, H_2O-CO_2 inclusions.

5.2.1.1 Aqueous inclusions

They usually contain two phases (liquid H_2O + vapor H_2O) at room temperature. Two subtypes are recognized. Type 1a (Plate XIV) contains a small vapor bubble

Plate XIV



Varrious types of inclusions from the Francoeur and Lac Fortune deposits.

(approximately 5 vol%). Type 1b is a daughter mineral-bearing aqueous inclusion, with a liquid phase, a vapor phase (5 vol%) and daughter minerals such as halite or other unidentified minerals. Most aqueous inclusions are type 1a. Type 1b is observed in just a few samples from the Lac Fortune deposit (Plate XIV).

5.2.1.2 CO_2-rich inclusions

These inclusions consist of a single or two CO_2-rich phases (liquid + vapor) at room temperature. Two subtypes are recognized: type 2a fluid inclusions contain only a single CO_2 phase which on cooling separates into liquid and vapor. Type 2b (Plate XIV) consists of liquid CO_2 plus a small CO_2 bubble, generally < 5 vol.%. Type 2 fluid inclusions have irregular shapes or negative crystal shapes. Small amounts of H_2O are occasionally observed in some CO_2-rich inclusions as a thin film rimming the inclusion walls or at the tips of inclusion walls that intersect at acute angles.

5.2.1.3 H_2O-CO_2 inclusions

Type 3 fluid inclusions usually consist of three phases at room temperature: H_2O liquid, CO_2 liquid , and CO_2 vapor (Plate VIX), CO_2 liquid is generally quite thin and forms a film around CO_2 vapor. Some inclusions may have only two phases (H_2O liquid + CO_2 vapor), especially those containing little CO_2. The inclusions may be rounded or irregular in shape. The CO_2 occupies about 5 to 50% of the total volume, most commonly about 20 vol%. Along an individual fracture or in the same quartz grain, the H_2O-CO_2 inclusions may have relatively constant or highly variable phase proportions.

Type 1 fluid inclusions occur abundantly in all the samples examined from both deposits, whereas type 2 fluid inclusions are generally not abundant and occur in significant numbers only in about half of the examined samples. Type 3 fluid inclusions are more abundant in samples from Lac Fortune than from Francoeur. In the Lac Fortune gold deposit, type 1a fluid inclusions and type 3 fluid inclusions are the main types, but some type 1b fluid inclusions with minor halite daughter mineral were also observed (Plate XIV). In the Francoeur deposit, however, type 1a fluid inclusions are the main type, no type 1b fluid inclusions were found. Type 1 and type 3 fluid inclusions may have irregular, rounded, or negative crystal shapes, whereas type 2 CO_2-rich fluid inclusions generally have rounded or negative crystal shapes. All fluid inclusions are very small and the degree of filling (F) varies in range from about 50%-95%.

5.2.2 Relationship between different types of fluid inclusions

All three types of fluid inclusions occur in the same quartz grains (Plate XIV) or in the same healed fracture in the Lac Fortune gold deposit. Type 1 and type 3 fluid inclusions are in equal proportion. In most cases, two of them occur together. In the Francoeur gold deposits, type 1a fluid inclusions are much more common than type 3 fluid inclusions, no type 1b daughter mineral-bearing fluid inclusion has been found. Type 1a fluid inclusions occur in 90% of the samples examined from the Francoeur deposit. The three types of fluid inclusions do not occur in the same quartz grain or in the same healed fracture.

5.3 Fluid inclusion microthermometry

A fluid inclusion study of selected samples from the Francoeur and Lac Fortune deposits was undertaken in order to obtain temperature, salinity and pressure data of the ore-forming fluids. Heating and freezing experiments were conducted using a Fluid Inc.-adapted U. S. G. S. gas-flow heating-freezing system which operates by circulating air or N_2 liquid, or N_2 gas around the sample. The measured temperatures include the following: the melting temperature of solid CO_2 (Tm CO_2); the eutectic melting temperature (Te); the last melting temperature of ice (Tm); the homogenization temperature of CO_2 (Th_{co2}); the last melting temperature of calthrate (Tcm); and the final homogenization temperature (Th). Microthermometric data of the Lac Fortune and Francoeur deposits are listed in Table 5.1 and Table 5.2, respectively.

It should be pointed out that Te and Tm may not always be determined in one fluid inclusion for all examined samples, mainly due to the small size of the fluid inclusions. The pressure, salinity, and density of the fluids can be estimated by comparison of the measurements with experimentally derived phase equilibrium diagrams (Roedder 1984; Collins 1979; Lu et al. 1990) or by the FLINCOR computer program (Brown, 1989).

Table 5.1 Microthermal measurements of the fluid inclusions in the Lac Fortune gold deposit,Quebec

Inclusion Number	Sample Number	Size (μm)	Type	Host Mineral	V% at 25°C	Tm(CO2) °C	Te °C	Tm °C	Th(CO2) °C	Th °C	Tcm °C	Salinity wt%	Bulk dens. g/cm3	Pressure Pa
1	LF-93-01	2	1a	Quartz	10					240				
2	LF-93-01	4	1a	Quartz	5					218				
3	LF-93-01	5	3	Quartz	15	-58.1	-21.8		31.3	233.7	7.4	5.0	0.99	3700
4	LF-93-01	2	1a	Quartz	10		-19.2			280.1		8.4	0.84	
5	LF-93-03	4	3	Quartz	15	-58.2	-24.8		30.2	322				
6	LF-93-03	12	1a	Quartz	5		-23.7			276		6.9	0.83	
7	LF-93-03	12	1a	Quartz	5		-21.6	-3.3		323		5.4	0.72	
8	LF-93-03	5	1a	Quartz	5		-22.8	-2.8		153.1		4.6	0.95	
9	LF-93-03	7	2a	Quartz	2	-58			30.3					
10	LF-93-03	4	1a	Quartz	5		-23.8	-3		156.2		4.9	0.95	
11	LF-93-03	10	3	Quartz	10	-58	-23.3		30.1	324.3				
12	LF-93-03	6	3	Quartz	15	-57.8	-20.6		31.1	297.1				
13	LF-93-03	5	3	Quartz	20	-58.1	-24		31.3	306.8	5.2	8.6	1.00	4700
14	LF-93-03	5	1a	Quartz	10		-23.7	-5.8		286.8		8.9	0.84	
15	LF-93-03	4	3	Quartz	25	-58	-22.6		29.7	315.1				
16	LF-93-03	5	1a	Quartz	15		-23	-5.9		260		9.1	0.87	
17	LF-93-03	3	2b	Quartz	5	-58.1			22.4				0.75	
18	LF-93-03	3.5	1a	Quartz	10		-35			306				
19	LF-93-03	5	2b	Quartz	10		-21.4	-2.3		247.8		3.8	0.85	
20	LF-93-03	3	2b	Quartz	30	-57.9			30.6				0.56	
21	LF-93-03	5	3	Quartz	35	-57.9	-22.2		28.4	340	4.9	9.1	0.96	4100
22	LF-93-03	6	1a	Quartz	10		-23.2			313.6				
23	LF-93-03	4	1a	Quartz	10		-21.9			353	5.9	7.5		4800
24	LF-93-03	7	3	Quartz	15	-58.2	-24.2	-3.8	31.7	280.3	3.8	6.1	0.81	
25	LF-93-03	5	1a	Quartz	20		-32.1	-5.2				8.1	0.59	
26	LF-93-03	8	3	Quartz	20	-57.9	-23.3		30.5	375	5.6	8.0	1.00	4900
27	LF-93-03	3	3	Quartz	10	-58	-20.9		30.9	290				
28	LF-93-03	6	1a	Quartz	10		-23.2	-3.6		385		5.8	0.59	
29	LF-93-03	6	3	Quartz	15	-57.5	-19.5		30.8	360				

30	LF-93-03	4	1a	Quartz	5		-22.1	-5.1		320		8.0	0.77	
31	LF-93-03	5	1a	Quartz	20		-16.5	-2.6		290.3		4.3	0.77	
32	LF-93-03	4	2a	Quartz	5	-57.8			27.1				0.68	
33	LF-93-03	4	3	Quartz	35	-58	-23		25.7	330				
34	LF-93-03	3.5	3	Quartz	10		-30	-6		105.6		9.2	1.02	
35	LF-93-03	4	1a	Quartz	15		-20.8	-3.6		278.3		5.8	0.81	
36	LF-93-03	5	1a	Quartz	15		-21.8	-1.1		228		1.8	0.84	
37	LF-93-03	5	3	Quartz	10	-57.6	-21.6		29	274	7	5.7	1.01	4100
38	LF-93-03	5	3	Quartz	15	-57.8	-25.1		28	277.4	6.9	5.9	0.96	3800
39	LF-93-03	8	3	Quartz	10	-58.5	-19.9		30.6	267.6	6.7	6.2	1.01	4500
40	LF-93-03	5.5	1a	Quartz	5		-21.7	-6		241.8		9.2	0.90	
41	LF-93-03	4	3	Quartz	10	-59	-24.4		31.2	324.5	4.6	9.9	1.04	4700
42	LF-93-03	4	3	Quartz	10	-57.9	-20		31.5	339.6	5.3	8.5	1.03	4600
43	LF-93-03	4	3	Quartz	15	-58.6	-25.3		28.3	361.7	5.4	8.3	1.01	4500
44	LF-93-05	4	3	Quartz	50	-58.7	-23		28.7	293.5	7.3	5.2	0.92	3200
45	LF-93-05	3	3	Quartz	5	-57.9	-21.6		30.8	290	7.9	4.1	1.00	4800
46	LF-93-05	6	3	Quartz	30	-60.4	-22.5	-4.3	25.8	334				
47	LF-93-05	4	1a	Quartz	5			-3.4		250		5.8	0.85	
48	LF-93-05	5	3	Quartz	25	-59	-21							
49	LF-93-05	6	1a	Quartz	5		-37	-14.4		180		18.1	1.03	
50	LF-93-05	7	1a	Quartz	5		-22.3	-7.3		205		10.9	0.97	
51	LF-93-05	8	1a	Quartz	5		-23.2	-7.4		232		11.0	1.06	
52	LF-93-05	6	3	Quartz	15	-57.6			25	280.4	6.1	7.2	1.00	4200
53	LF-93-05	5	3	Quartz	20	57.1			28.7	352	6.3	6.8	1.00	5100
54	LF-93-05	3	1a	Quartz	5		-33.7	-12.8		120				

1a = aqueous fluid inclusions, 2a and 2b = CO_2-rich fluid inclusions, 3 = H_2O-CO_2 fluid inclusions; Te = eutectic melting temperature
$TmCO_2$=melting temperature of solid CO_2, Tm = last melting temperature of ice, Th = homogenization temperature,
Tcm = melt temperature of clathrate; V% at 25° = ratio of vapor phase at room temperature, wt% NaCl equi. = weight percent salt equivalent;

Table 5.2 Microthermal measurements of the fluid inclusions in the Francoeur gold deposit,Quebec

Inclusion Number	Sample Number	Size (µm)	Type	Host Mineral	V% at 25°C	Tm(CO2) °C	Te °C	Tm °C	Th(CO2) °C	Th °C	Tcm °C	Salinity wt%	Bulk dens. g/cm3	Pressure Pars
1	Fr-89-31	5	1a	Quartz	10		-21.9	-2.4		424.0		3.9	0.50	
2	Fr-89-31	7	1a	Quartz	10		-24.2	-1.8		485.0		3.1	0.48	
3	FR-89-38	4	3	Quartz	50	-58.1			29.5	370.0	8.2	3.5	0.90	4000
4	FR-89-38	2	1a	Quartz	10		-23.0	-5.0		280.1		7.8	0.60	
5	Fr-89-122	3	1a	Quartz	5			-3.0		185.0		4.9	0.93	
6	FR-92-11	3	3	Quartz	30	-56.7	-24.2			350.0	7.9	4.1	0.97	4100
7	FR-92-15	2	1a	Quartz	5		-22.4	-3.1		236.0		5.0	0.86	
8	FR-92-18	4	1a	Quartz	5		-22.9	-2.8		250.0		4.5	0.84	
9	FR-92-18	5	1a	Quartz	7			-3.6		204.1		5.8	0.91	
10	FR-92-18	3	1a	Quartz	5		-22.6	-3.2		198.0		5.2	0.97	
11	FR-92-18	3.5	1a	Quartz	5		-23.5	-2.7		234.0		4.4	0.86	
12	FR-92-18	3.5	1a	Quartz	5		-27.4	-2.8		159.5		4.5	0.94	
13	FR-92-18	3	1a	Quartz	6		-25.5	-3.0		231.9		4.9	0.87	
14	FR-92-18	3.5	3	Quartz	40	-58.1	-22.0		-1.4	414.1	8.8	4.3	0.99	4800
15	FR-92-18	4.5	3	Quartz	10	-58.4	-22.6		-3.6	315.1	4.7	9.4	1.04	4500
16	FR-92-08	4	1a	Quartz	10		-33.9	-2.1		145.0		3.4	0.95	
17	FR-92-08	3	2a	Quartz	5	-58.3			29.5				0.62	
18	FR-92-08	2.5	1a	Quartz	5	-59.1			30.1				0.62	
19	FR-92-08	4	1a	Quartz	15		-24.8	-2.6		466.0		4.2	0.50	
20	FR-92-08	5	1a	Quartz	5		-23.8	-5.7		173.2		8.7	0.96	
21	FR-92-08	3	1a	Quartz	5		-24.5	-4.1		578.0		6.5	0.56	
22	FR-92-08	3	1a	Quartz	10		-27.5	-5.9		446.2		9.0	0.62	
23	FR-92-08	3	1a	Quartz	5		-24.3	-3.7		493.3		5.9	0.55	
24	FR-92-08	5	1a	Quartz	10		-23.0	-1.7		486.3		2.8	0.62	
25	FR-92-08	6	3	Quartz	20	-59.6	-29.9		29.6	396.0	9.1	1.8	0.92	
26	FR-92-11	6	2a	Quartz	5	-57.8			-16.0				1.01	
27	FR-92-11	6	2a	Quartz	20	-58.1			-9.2				0.98	
28	FR-92-11	5	2b	Quartz	5	-58.0			10.9				0.86	
29	FR-92-11	4	3	Quartz	15	-58.2	-23.0		23.7	375.0	6.7	6.1	1.00	5000
30	FR-92-11	6	1a	Quartz	10		-28.3	-2.4		537.0		8.8	0.96	
31	FR-92-11	4	1a	Quartz	10		-22.4	-2.3		340.0		4.0	0.66	

1a = aqueous fluid inclusions, 2a and 2b = CO2-rich fluid inclusions, 3 = H2O-CO2 fluid inclusions; Te= eutectic melting temperature
TmCO2=melting temperature of solid CO2, Tm = last melting temperature of ice, Th = homogenization temperature,
Tcm = melt temperature of clathrate; V% at 25° = ratio of vapor phase at room temperature, wt% = weight percent salt equivalent;

5.3.1 Lac Fortune gold deposit

5.3.1.1 Aqueous inclusions

The freezing behavior of aqueous inclusions is complex and the small size of most of these inclusions limits the number of reliable observations. Upon warming after freezing to -120°C, the temperature at which coexisting solid+ liquid + vapor is first recognized, which should be close to the eutectic temperature of the system, ranges between -16° and -37°C (n=25; Fig. 5.1), with a mode around -21°to -24.2°C. This indicates that the major dissolved salt in the aqueous inclusions is NaCl. While the significant number of inclusions melting below -21°C suggests the presence of a small amount of $CaCl_2$ (Crawford 1981; Roedder 1984). Thus Na and Cl are the principal dissolved species in the aqueous inclusions, and hence the composition of these inclusions can be approximated in the binary system NaCl-H_2O, plus small amounts of $CaCl_2$.

The final ice melting temperatures mainly range from -6 ° to -2°C (Fig. 5.2), corresponding to salinities from 4.5 to 8.5 equivalent percent NaCl (Lu et al, 1990; Fig. 5.3). Temperatures of dissolution of halite could only be measured in a few aqueous inclusions and range from 125° to 145°C, corresponding to salinities from 28.7 to 29.5 equivalent percent NaCl. It seems that there is a big difference of salinity of aqueous inclusions, ranging from 4.5 to 29.5 equivalent NaCl.

The homogenization temperatures of the aqueous inclusions range from 105° to 353°C (Fig. 5.4). Main homogenization temperatures are between 225° and 275°C. Most aqueous inclusions are homogenized to a liquid phase, some to a gas phase. In general, there is no

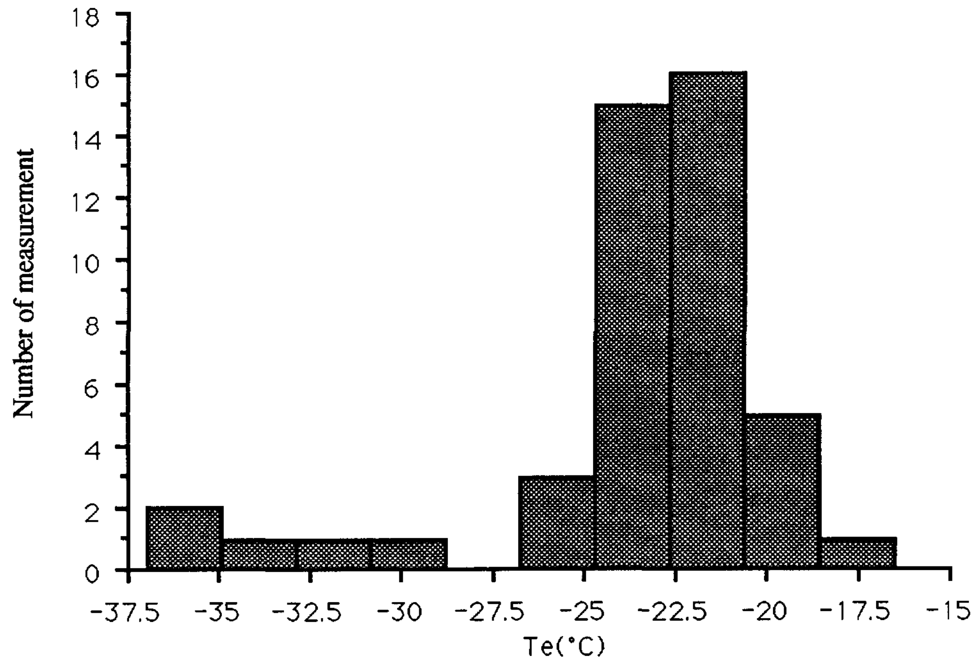


Fig. 5.1 Histogram of eutectic temperatures of aqueous fluid inclusions from the Lac Fortune gold deposit.

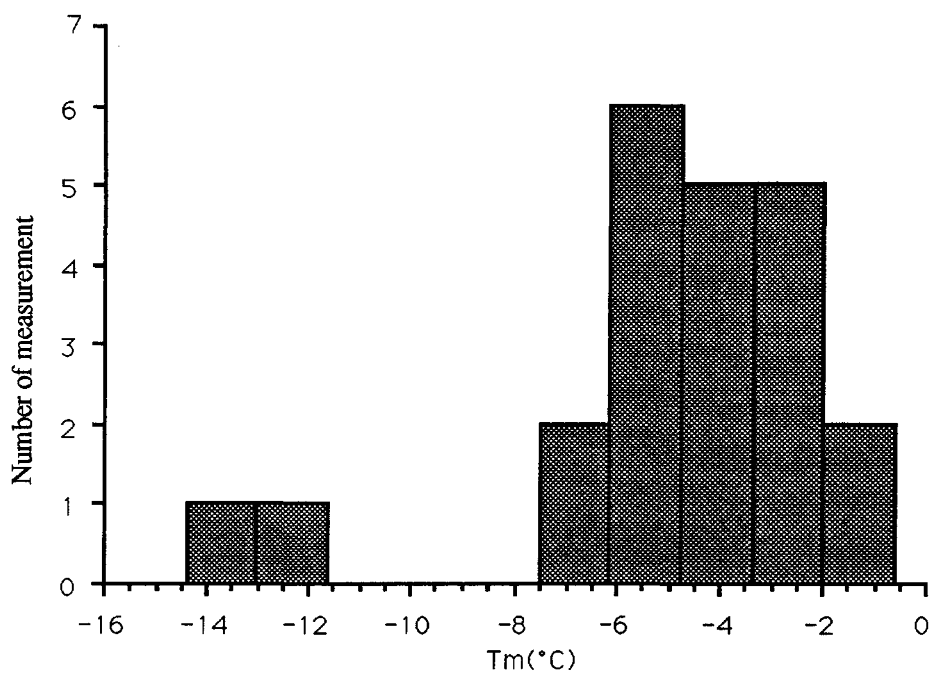


Fig. 5.2 Histogram of final melting temperatures of aqueous inclusions from the Lac Fortune gold deposit.

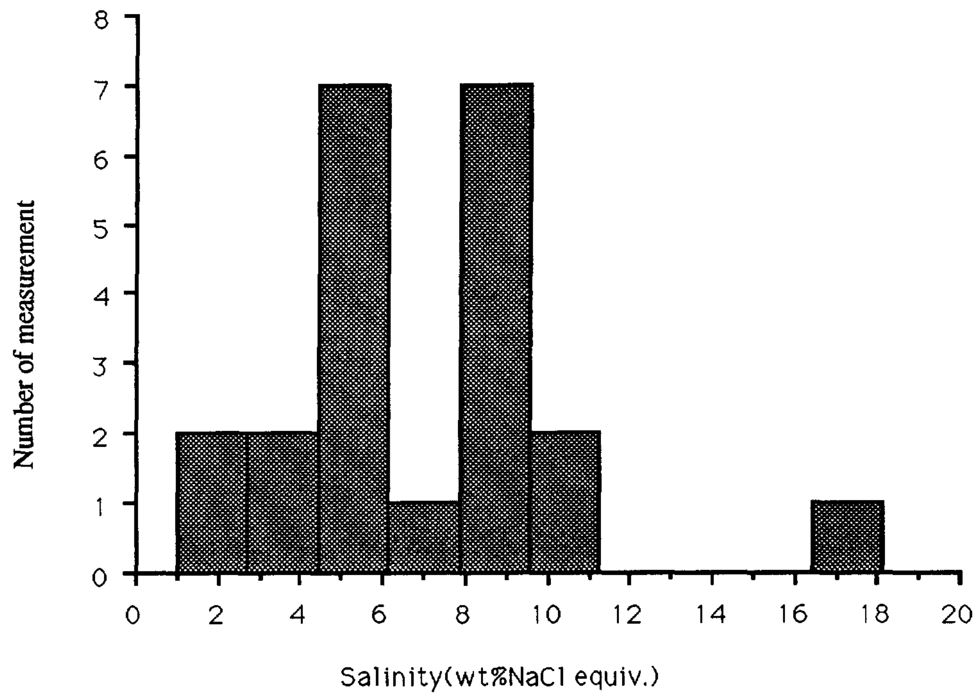


Fig. 5.3 Histogram of salinities of aqueous inclusions (1a) from the Lac Fortune gold deposit.

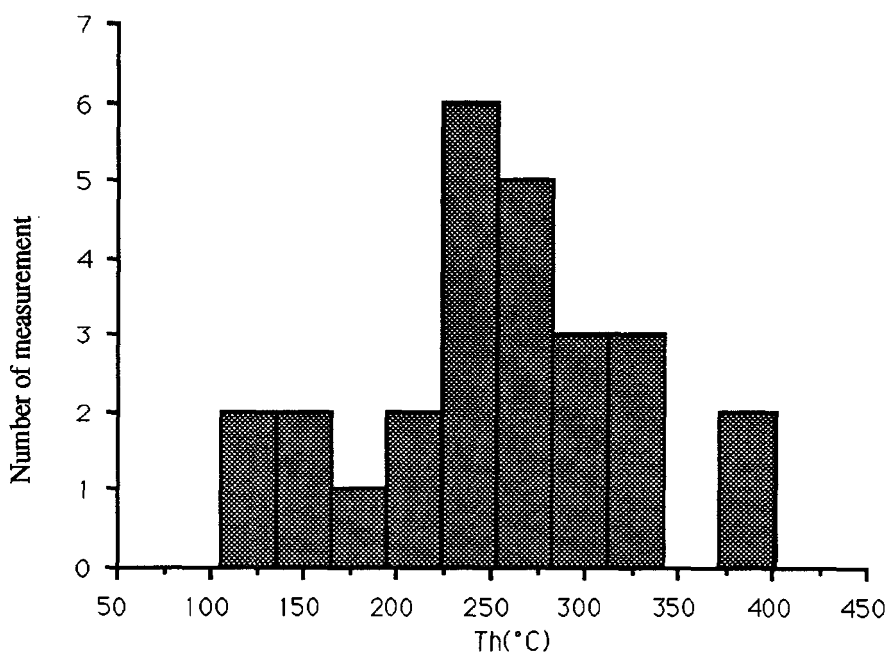


Fig. 5.4 Histogram of homogenization temperatures of aqueous inclusions from the Lac Fortune gold deposit.

significant difference of homogenization temperatures for the secondary and primary aqueous inclusions.

5.3.1.2. CO_2-rich inclusions

All of the melting temperatures of CO_2 in CO_2-rich inclusions are lower than -57.8°C, ranging from -57.8° to -58.1°C (n=3, Fig. 5.5), and CO_2-rich inclusions are homogenized to the liquid phase between 22.4° to 30.6°C (Fig. 5.6). The melting temperatures below that of pure CO_2 (-56.6°C) indicate the presence of additional components such as methane or other miscible phases. The CO_2 densities corresponding to homogenization temperatures range from 0.56 to 0.75 g/cc.

5.3.1.3 H_2O-CO_2 inclusions

Melting temperatures of CO_2 in H_2O-CO_2 inclusions range from -57.1° to -60.4°C (Fig. 5.7),and all of them are lower than -56.6°C, it indicates the probable presence of small concentrations of CH_4. Homogenization temperatures of CO_2 range from 25° to 31.7°C.

The eutectic temperatures of the H_2O-CO_2 inclusions are generally lower than -20.6°C, ranging from -22° to -24°C. This suggests that major dissolved salt in the H_2O-CO_2 inclusions is NaCl, but there may be some $CaCl_2$.

Formation of clathrate upon heating a frozen inclusion was observed in most H_2O-CO_2 inclusions studied. Clathrate melting temperatures, determined only in the presence of liquid and vapor CO_2, range from 5° to 7.9°C (Fig. 5.8). According to calculation by the

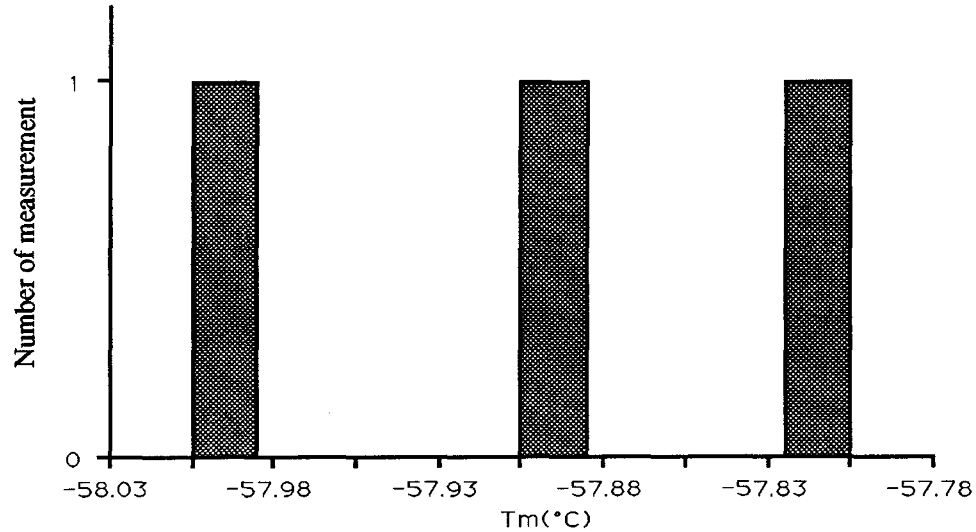


Fig. 5.5 Histogram of first melting temperatures of CO_2-rich inclusions from the Lac Fortune gold deposit.

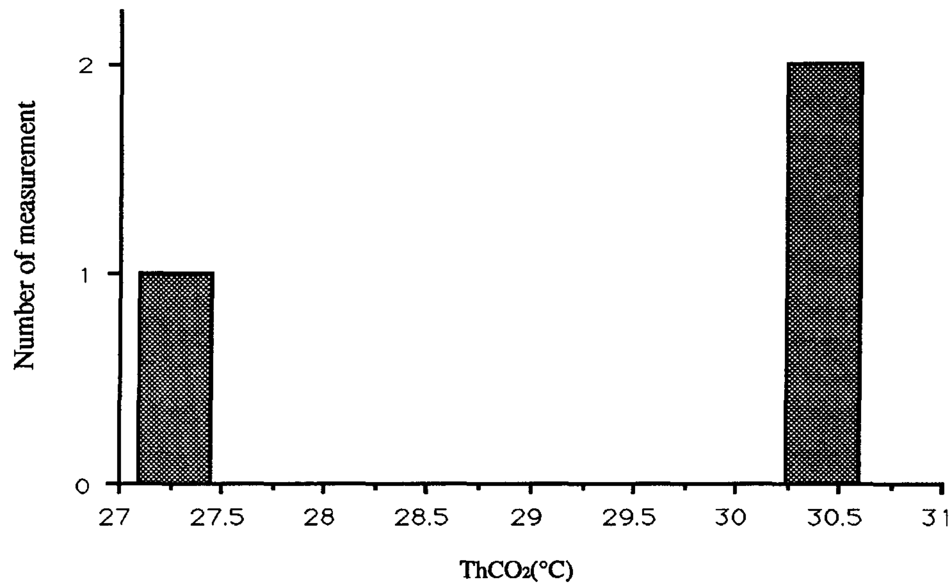


Fig. 5.6 Histogram of homogenization temperatures of the CO_2-rich inclusions from the Lac Fortune gold deposit.

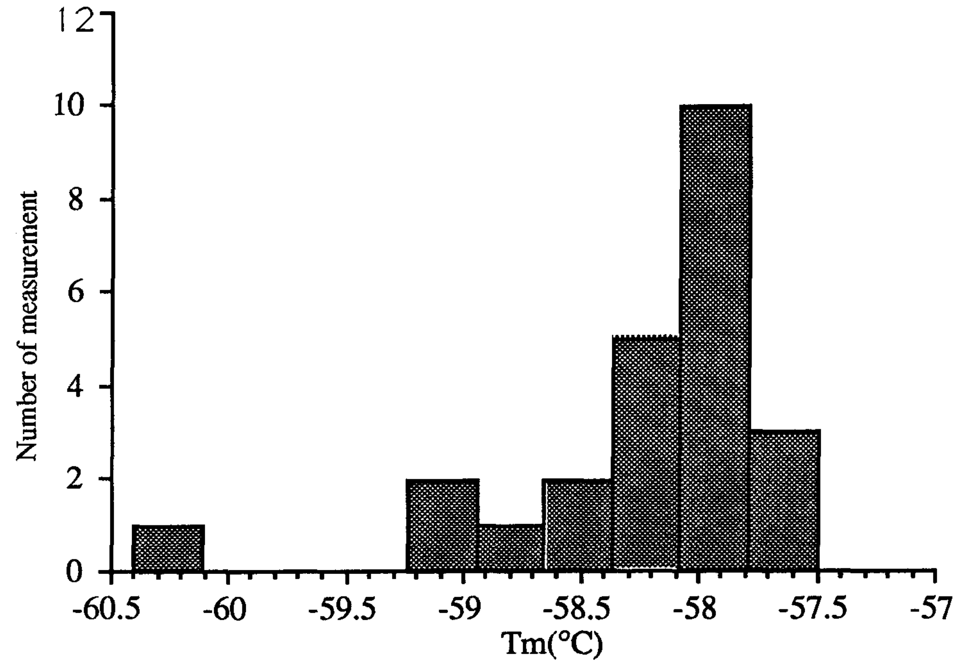


Fig. 5.7 Histogram of first melting temperatures of H_2O-CO_2 inclusions from the Lac Fortune gold deposit.

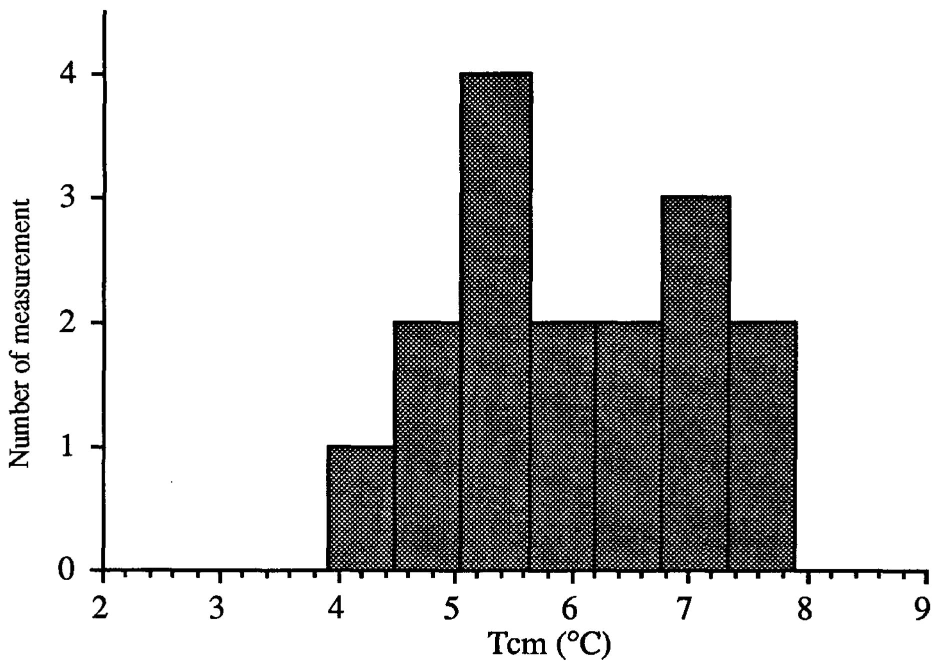


Fig. 5.8 Histogram of clathrate melting temperatures of H_2O-CO_2 inclusions from the Lac Fortune gold deposit.

FLINCOR computer program (Brown 1989), these clathrate melting temperatures correspond to salinities ranging from 5 to 9 weight percent NaCl (Fig. 5.9). It is obvious that the salinities of the H_2O-CO_2 inclusions are lower than those of the aqueous inclusions (ranging from 4.5 to 29.5 weight percent NaCl).

The homogenization temperatures of a small number of these inclusions range from 105.6 to 245°C, the main homogenization temperatures, however, range from 265° to 375°C (Fig. 5.10). The variation of content of CO_2 in the H_2O-CO_2 inclusions is large, ranging from 5 to 50 volume percent.

The thermometric data presented above indicate that three types of fluids have been trapped during mineralization: an aqueous fluid with moderate to high salinity in which the main dissolved species are Na and Cl with small amounts of Ca; a nonsaline CO_2-rich fluid, containing small amounts of another gas phase, probably CH_4; and a fluid with low salinity containing varying proportions of H_2O and CO_2, also containing dissolved Na, Ca, Cl and small amounts of probable CH_4.

5.3.2 Francoeur gold deposit

5.3.2.1 Aqueous inclusions

This type of fluid inclusions shows first melting temperature (Te) of aqueous phase below -21.9°C (Fig. 5.11), indicating the existence of another bivalent cations such as Ca^{++}

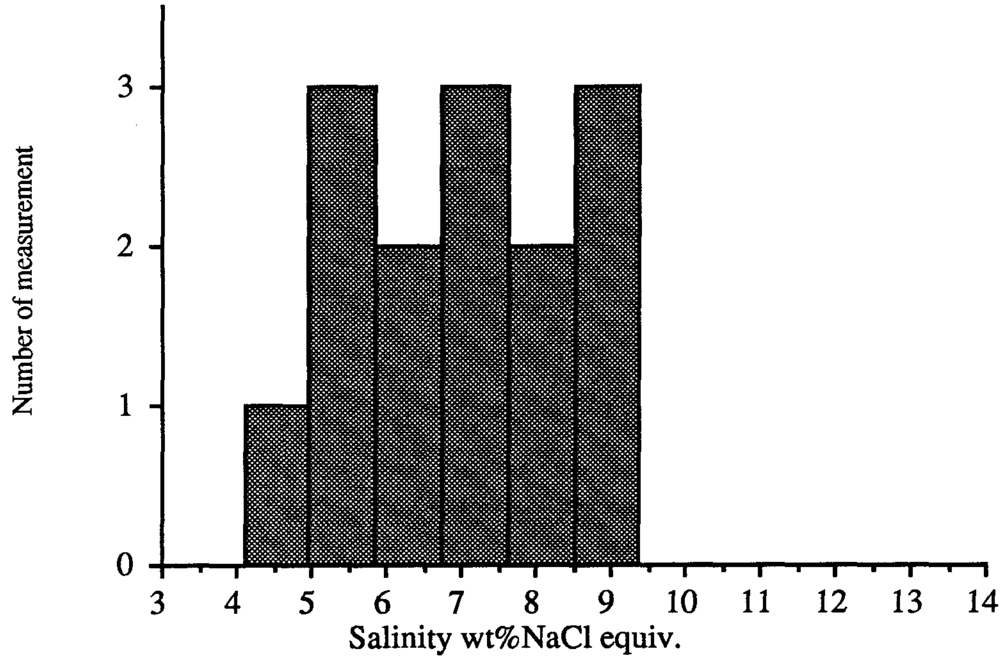


Fig. 5.9 Histogram of salinities of H_2O-CO_2 inclusions from the Lac Fortune gold deposit.

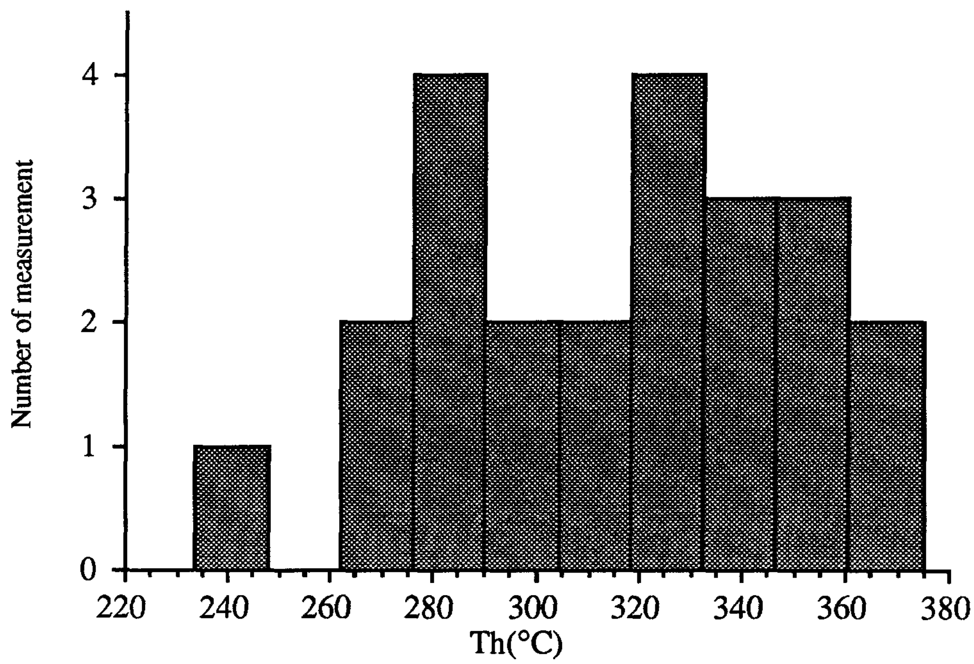


Fig. 5.10 Histogram of homogenization temperatures of H_2O-CO_2 inclusions from the Lac Fortune gold deposit.

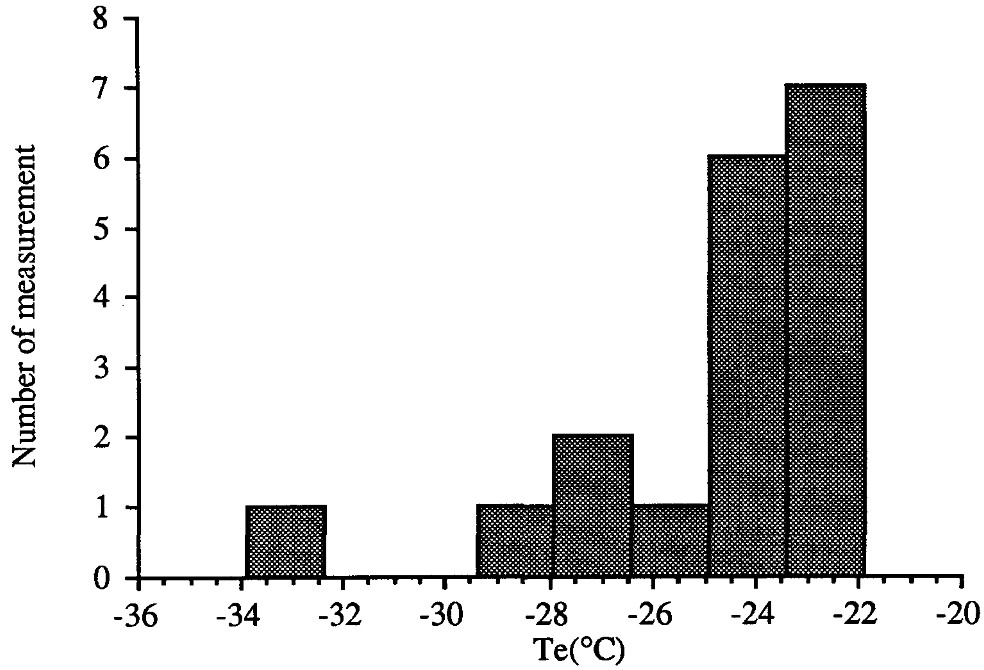


Fig. 5.11 Histogram of eutectic temperatures of aqueous inclusions from the Francoeur gold deposit.

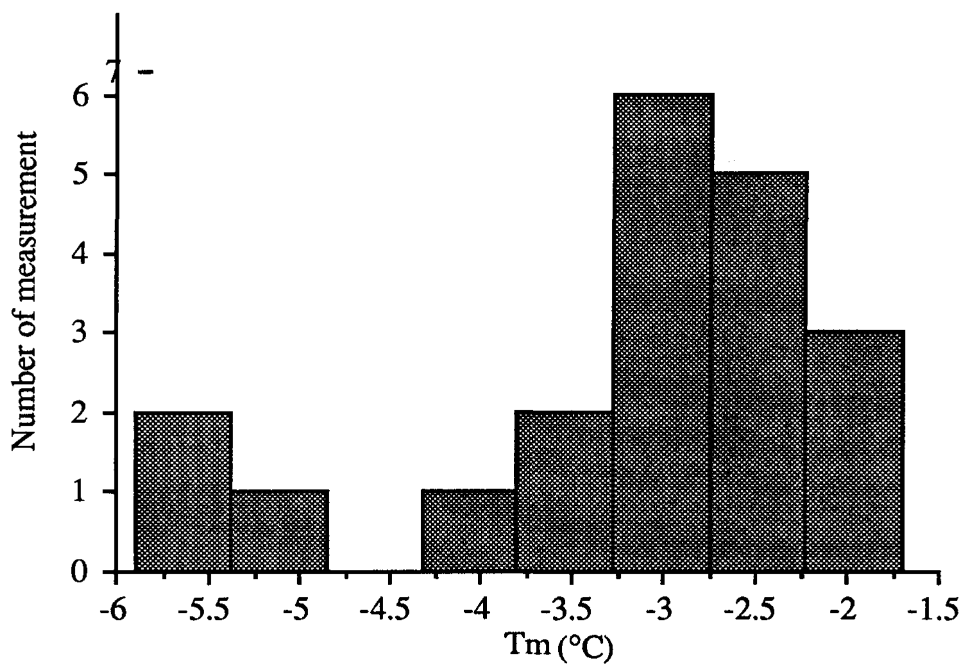


Fig. 5.12 Histogram of final melting temperatures of aqueous inclusions from the Francoeur gold deposit.

in addition to Na^+. Because the main range of Te is between -24° to -22°C, approaching the eutectic temperature (-21.2°C) of H_2O-NaCl system, then the major salt in these fluid inclusions is NaCl and the content of $CaCl_2$ is limited in the solution.

The melting temperatures of ice are between -5.7° to -1.8°C (mainly between -3.5° to -2°C, Fig. 5.12). The salinities can be estimated about 3 to 9 wt% NaCl equivalent. (Table 5.2, Fig. 5.13). It is noted that the salinity in this case is lower than the one from the Lac Fortune.

The homogenization temperatures range from 145° to 580°C. The histogram in Figure 5.14 shows two populations of aqueous inclusions: one is between 425° to 550° C, another is between 150° to 250°C. Bulk densities of the inclusions are estimated by using the equation of state of Brown and Lamb for the H_2O-NaCl system in the computer program FLINCOR (Brown 1986), ranging from 0.48 to 0.96 g/cm3.

5.3.2.2 CO_2-rich inclusions

The melting temperatures of solid CO_2 (Tm_{CO_2}) are about -59.6° to -57.8°C and indicate the existence of another gas species in addition to CO_2, probably CH_4. Homogenization temperatures of liquid and vapor CO_2 (Th_{CO_2}) are wide and range from -16° to 30.1°C (homogenized to liquid phase). The homogenization temperatures correspond to CO_2 densities ranging from 0.62 to 1.01 g/cm3.

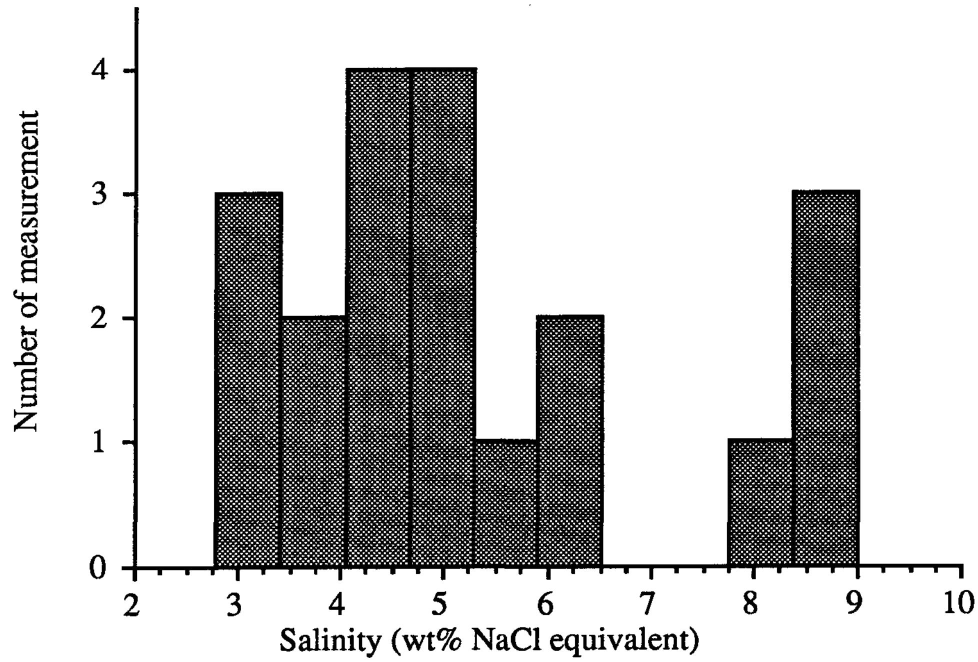


Fig. 5.13 Histogram of salinities of aqueous inclusions from the Francoeur gold deposit.

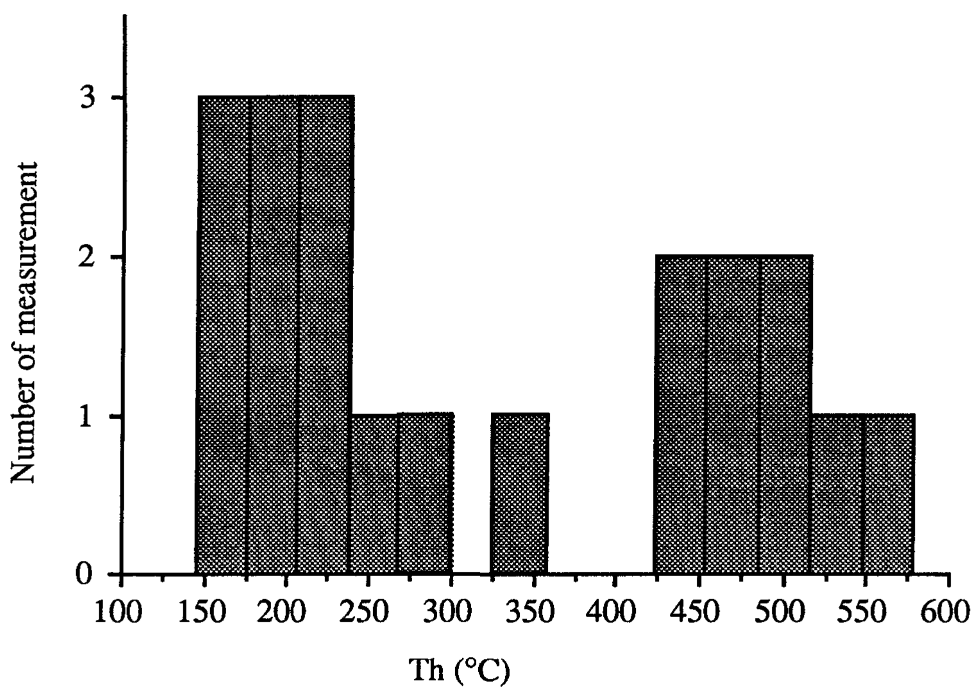


Fig. 5.14 Histogram of homogenization temperatures of aqueous inclusions from the Francoeur gold deposit.

5.3.2.3 H_2O-CO_2 inclusions

The microthermometric data of this type of fluid inclusions include melting temperature of solid CO_2 (Tm_{CO_2}), first melting temperature of the aqueous phase (Te), melting temperature of clathrate (Tcm), homogenization temperature of CO_2 (Th_{CO_2}), and final homogenization temperature (Th).

The Tm_{CO_2} range from -59.5°to -57.2°C and indicate the existence of another gas in addition to CO_2, probably CH_4 . The Te are similar to those of type 1 fluid inclusions and indicate the existence of another bivalent cation, probably Ca^{++} in addition to Na^+, but the content of Ca^{++} is limited because the Te mainly range from -24° and -22°C. The Th_{CO_2} range from -3.6° to 29.6°C (homogenized to liquid phase). The Tcm range from 4.7° to 9.1°C. The total homogenization temperature of type 3 fluid inclusions is mainly between 320° to 420°C. According to these microthermometric data, it is suitable that the composition, salinity, and density are estimated by approximating the system with H_2O-CO_2-NaCl, using the equation of state of Brown and Lamb, provided in the FLINCOR computer program (Brown 1989). The salinity is 2-6 wt% NaCl equivalent. The mole fraction of CO_2 is between 0.02 and 0.21. Bulk densities are between 0.92 and 0.99 g/cm^3.

The record of microthermometric data in the Francoeur gold deposit indicates that the composition of fluid is basically similar to that in the Lac Fortune gold deposit. Three types of fluids have been trapped during gold mineralization in both deposits: an aqueous fluid with Na^+, Cl^- and small amount of Ca^{++}; a nonsaline CO_2-rich fluid, containing small amount of other gas, probably CH_4; and a fluid of H_2O-CO_2, also containing dissolved Na, Cl and small amount of Ca and probably CH_4. Two different characteristics in salinity and homogenization temperature, however, exist between both deposits: 1) The salinities of type 1 fluid inclusions are 3-9 wt % NaCl equivalent for the Francoeur and 4.5-29.5 wt % NaCl equivalent for the Lac Fortune. The salinities of type 3 fluid inclusions are 2-6 and 5-9 wt % NaCl equivalent, respectively. It is obvious that the salinities of type 1 and type 3 fluid inclusions are approximate in the Francoeur while the salinity of type 1 fluid inclusions is evidently higher than that of type 3 fluid inclusions in the Lac Fortune; 2) The homogenization temperatures of type 1 and type 3 fluid inclusions in the Francoeur are different, the Th (< 580°C)of type 1 fluid inclusions is higher than that (< 500°C) of type 3 fluid inclusions while it is basically the same in the Lac Fortune (Figs. 5.15-5.16).There are two main Th ranges in the Francoeur: 150° -250°C and 425°-550°C, respectively while only one 225° -275°C in the Lac Fortune. Generally, the Th of fluid inclusions in the Francoeur are higher than those in the Lac Fortune.

5.4 Geological and geochemical interpretations

5.4.1 Fluid phase separation

As described above, the occurrence of three types of fluid inclusions in hydrothermal quartz of both deposits indicates that three types of fluids existed during the gold mineralization: (1) an aqueous fluid containing Na, Cl, and small amounts of Ca; (2) a non-saline CO_2-rich fluid, containing small amounts of H_2O and CH_4; (3) a H_2O-CO_2 fluid containing Na, Cl, and small amounts of Ca and CH_4.

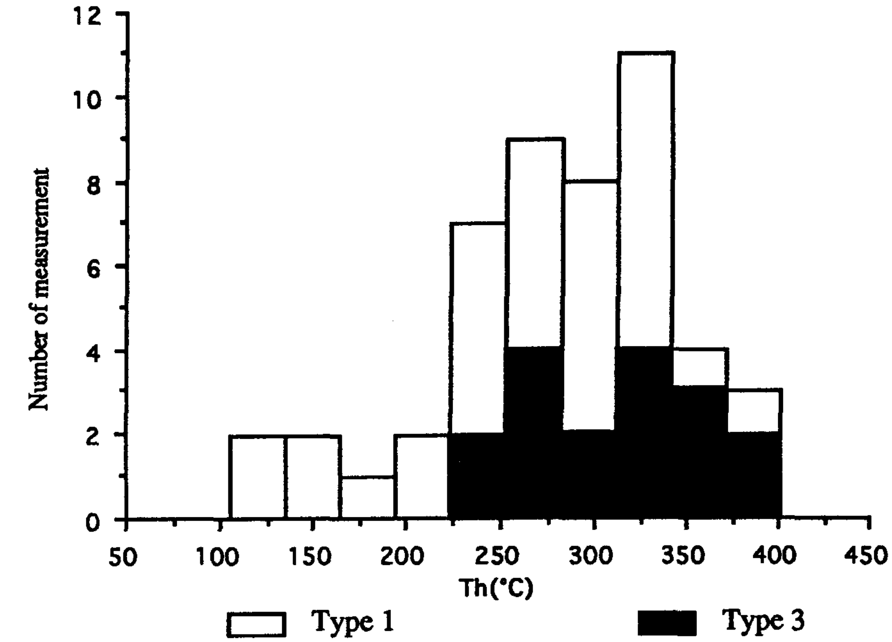


Fig. 5.15 Histogram of homogenization temperatures of type 1 and type 3 fluid inclusions from the Lac Fortune gold deposit.

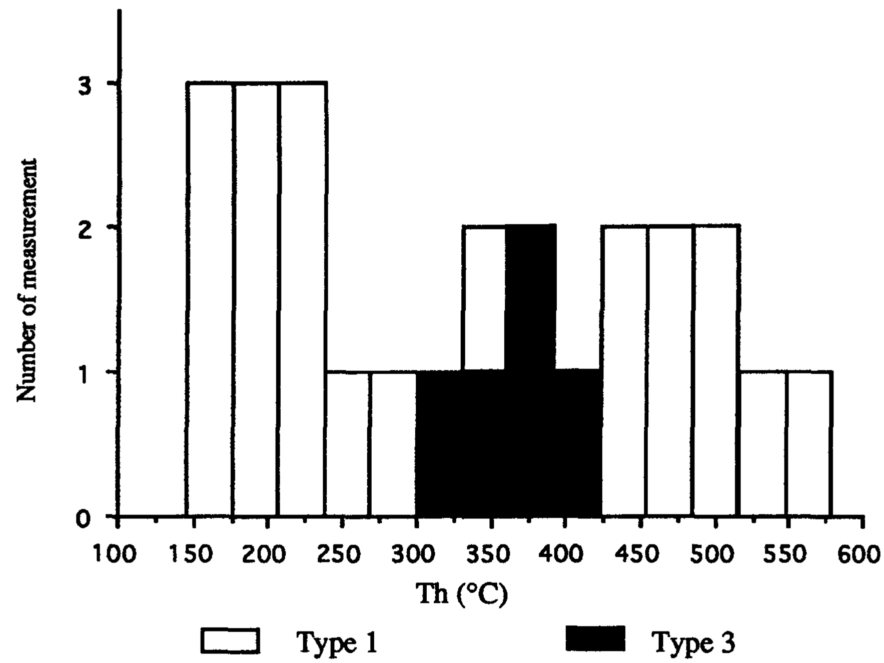


Fig. 5.16 Histogram of homogenization temperatures of type 1 and type 3 fluid inclusions from the Francoeur gold deposit.

In the Lac Fortune, three types of fluid inclusions occur in the same quartz grain or the same healed fracture, or in different healed fractures. Type 1 aqueous inclusions with relatively high salinity (4.5 -29.5 wt%) and type 3 H_2O-CO_2 inclusions with relatively low salinity (5-9 wt%) have similar homogenization. This may indicate that two immiscible fluids existed at the site of mineralization (Robert and Kelly 1987; Chi et al. 1993). A higher salinity aqueous fluid and a non-saline CO_2-rich fluid can be produced by phase separation of a relatively low-salinity H_2O-CO_2-NaCl fluid (Bowers and Helgeson 1983; Robert and Kelly 1987). So in this case, aqueous fluid and CO_2-rich fluid might have been derived from phase separation of initial monophase fluid. The initial fluid may belong to an H_2O-CO_2-NaCl system, represented by type 3 fluid inclusions. The immiscible liquid and vapor phases resulting from phase separation belong to a relatively high salinity H_2O-NaCl system and a CO_2-rich system, represented by type 1 and type 2 fluid inclusions, respectively.

One of the major concerns in analysis of Archean lode gold fluids has been the unmixing of H_2O-CO_2 and its implication for gold emplacement. Phenomenon of unmixing of H_2O-CO_2 is also found at the Sigma mine of Canada (Robert and Kelly 1987), the Linlong and Hetia gold field from China (Lu 1991; Zhou 1992, 1993) and some others (Smith et al. 1984; Krupka et al. 1977; English 1981; Walshe et al. 1984; Ho et al. 1986). Robert and Kelly (1987) discussed in detail the H_2O-CO_2 unmixing as opposed to mixed entrapment of two immiscible fluids and the effect of P-T conditions in the Sigma gold deposit. The pressure fluctuation at the time of entrapment is believed to be the principal factor responsible as unmixing and fluid immiscibility has played an important role in gold deposition.

The results of observation in fluid inclusions of the Lac Fortune gold deposit are similar to those of other Archean vein-type gold deposits (Robert and Kelly 1987). It is reasonable to conclude that phase separation (fluid unmixing) might also be an important mechanism of gold deposition in the Lac Fortune gold deposit.

5.4.2 Fluid-rock interaction

Although the microthermometric data of fluid inclusions in the Lac Fortune and Francoeur deposits indicate that the compositions of fluids are similar. The behaviors of the fluids seem to be different. In the Francoeur deposit, type 1 fluid inclusions constitute the main population. the three types of fluid inclusions do not occur in the same quartz grain or in a given healed fracture. The salinities of type 1 and type 3 fluid inclusions do not have pronounced differences, and the Th of type 1 fluid inclusions is generally higher than that of type 3 fluid inclusions.

All these above phenomena show that phase separation did not exist, or if it existed, was limited in fluids. The theory of phase separation thus can not be used to explain the behaviors of fluids evolution, although the compositions of mineralized fluids are similar in both deposits. It is obvious that the Francoeur gold deposit has another mechanism of gold deposition which is different from the one in the Lac Fortune. The mechanism of wall-rock interaction is considered first because the Francoeur deposit is closely associated with alteration in time and space (see chapter 4). It is reasonably concluded that the Francoeur gold formed under conditions of no or limited H_2O-CO_2 unmixing and gold mineralization took place along with the alteration as it was described in chapter 4. Summarily, the fluid-rock interaction played a role in gold deposition at the Francoeur gold deposit. In other words, fluid-rock interaction is an important mechanism of gold deposition in the Francoeur gold deposit. The fluid-rock interaction also played a role in gold deposition in other wallrock-hosted environments such as the McIntyre deposit (Smith et al. 1984), the Hollinger deposit (Wood et al. 1986), and the Tadd deposit (Guha et al. 1990).

5.4.3 Mineralization stage at Francoeur

There are two main homogenization temperatures in the Francoeur deposit: 150°-250°C and 425°-550°C, respectively. Two mineralization stages have been identified for the Francoeur deposit in the chapter 4: one is the early mineralization; the orther is the main mineralization. The early mineralization is associated with the carbonate-hematite alteration and the main mineralization is related to the albite-pyrite alteration. Generally, such an evolution of a mineralized fluid results from a drop of temperature and/or pressure (Helgeson 1970), thus producing two main ranges of homogenization temperature each one related to a different mineralization stage. The 425°-550°C may represent the early mineralization stage corresponding to the carbonate-hematite alteration mineral assemblage, and the 150°-250°C may represent the main mineralization stage corresponding to the albite-pyrite alteration mineral assemblage.

5.4.4 Temperature and pressure conditions at fluid entrapments

The homogenization temperature of fluid inclusions can be considered to be the minimum temperature of a primary hydrothermal fluid (Roedder 1984). The homogenization temperatures (110°-360°C) of the fluid inclusions from the Lac Fortune deposit are generally low in comparison to those (150°-578°C) from the Francoeur gold deposit. As have been discussed above, type 1 and type 3 fluid inclusions from the Lac Fortune deposit are interpreted to represent coexisting immiscible fluids. Thus Th and Pth (fluid pressure at homogenization temperature) represent real fluid temperature and pressure at the site of mineralization (Roberts 1989; Chi et al. 1993), but there is no obvious evidence that the fluid in any type of fluid inclusions from the Francoeur is in equilibrium with another immiscible fluid at the time of entrapment. Thus Th and Pth only represent the minimum fluid temperature and pressure at the site of mineralization. The fluid temperatures are 110°-360°C at the site of mineralization in the Lac Fortune deposit while the fluid minimum temperatures are 150°-578°C in the Francoeur deposit. These indicate that the temperature of mineralization is generally higher in the Francoeur deposit.

Because the ore-forming system is spatially related to a ductile shear deformation zone, the confining pressure of the hydrothermal fluid system is likely to vary as a result of dynamic deformation. The actual fluid pressure could vary from lithostatic to hydrostatic, depending on the leakage of the system (Roedder and Bodnar 1980). The estimation of confining pressure by the method of the equation of gas state of a vapor system and the method of isochore intersection of H_2O-CO_2 and H_2O-NaCl systems (Roedder, 1984; Brown and Lamb 1986) show that the entrapment pressure of the fluid inclusions at homogenization temperature varies from about 3200 to 5100 Pa (Table 5.1) in the Lac Fortune deposit and 4000 to 5000 Pa (Table 5.2) in the Francoeur deposit. Thus, the fluid pressure at site of mineralization in the Lac Fortune deposit is between 3200 and 5100 Pa and the fluid minimum pressure at site of mineralization in the Francoeur deposit is between 4000 and 5000 Pa. It seems that the variation of fluid pressure in both deposits is very wide.

It should be pointed out that both H_2O-CO_2 and H_2O-NaCl system are highly simplified systems, and that some of the microthermometric data can not be used to calculate isochores. On the other hand, the pressures estimated from isochores are strongly dependent on the equation of state adopted. Thus, the deviation of the calculated pressure from the real one seems inevitable. However, the estimated pressures provide a first approximation of the actual pressure.

5.5 Summary

There are three compositional types of fluid inclusions in the Lac Fortune and Francoeur deposits: H_2O-CO_2 fluid inclusions, aqueous fluid inclusions, and CO_2-rich fluid inclusions.

In the Lac Fortune deposit, the low-salinity H_2O-CO_2 inclusions represents the primary ore-forming hydrothermal fluid. It is a H_2O-NaCl-CO_2 system, with probable presence of other components such as Ca^{2+} and CH_4. During the ascent of the primary hydrothermal solution, CO_2 effervescence and unmixing took place and produced simultaneously relatively moderate to high saline H_2O-NaCl fluids. The unmixing of the primary hydrothermal fluid was caused by a drop of temperature and/or a sudden release of pressure. Phase separation is an important mechanism of gold deposition in the Lac Fortune gold deposit.

In the Francoeur deposit, the composition of the ore-forming fluid with low salinity is similar to that of the Lac Fortune, but the primary ore-forming fluid is not monophase H_2O-NaCl-CO_2 system. Phase separation in fluids do not exist or is limited and fluid-rock interaction is an important mechanism of gold deposition in the Francoeur gold deposit.

Homogenization temperatures in the Francoeur deposit have two main ranges: 150°-250°C and 425°-550°C, respectively. These two different ranges of homogenization temperatures may represent two different mineralization stages. 425°-550°C may represent the early mineralization stage and 150°-250°C may be represent the main mineralization stage.

Homogenization temperature ranges from 110°to 360°C in the Lac Fortune and 150° to 578°C in the Francoeur. The confining pressure of the fluid inclusions at homogenization temperature approximately ranges from 3200-5100 Pa and 4000 to 5000 Pa, respectively. 130°-360°C and 3200-5100 Pa respectively represent the real fluid temperature and pressure at site of mineralization in the Lac Fortune deposit, whereas 150°-578°C and 4000-5000 Pa respectively represent the minimum temperature and pressure at site of mineralization in the Francoeur. The variation of pressure of the fluids in both deposits is wide, but the temperature of mineralization and the lithostatic pressure are generally higher in the Francoeur deposit than those in the Lac Fortune deposit.

CHAPTER VI

COMPARISON BETWEEN FRANCOEUR AND LAC FORTUNE DEPOSITS AND DISCUSSION

6.1 Comparison between Francoeur and Lac Fortune gold deposits

The preceding chapters have described and discussed in detail the basic geology and fluid inclusions characteristics of both the Francoeur and the Lac Fortune gold deposits. The main geological and hydrothermal geochemical characteristics of these two deposits are summarized in Table 6.1.

In a general sense, they are similar to each other. They both occur in an Archean greenstone belt, with andesite and gabbro-diorite being the principal host lithology. They developed in ductile shear zones, and the hydrothermal fluids have actively participated in the transport and precipitation of gold. The fluid inclusions study also indicates that there are three types fluid inclusions in both deposits: aqueous inclusions, CO_2-rich inclusions and H_2O-CO_2 fluid inclusions, and that the ore-forming hydrothermal solutions responsible for the formation of these two deposits are closely similar in chemical composition, with H_2O, NaCl, CO_2 as the dominating components and small amounts of $CaCl_2$ and CH_4.

Despite the similarities mentioned above, there are certain differences between the Francoeur and Lac Fortune gold deposits. First, their mineralization styles are very different. They belong to two different classes of gold deposits. The Francoeur is a gold deposit of

Table 6.1 Comparison of the principal geological and geochemical characteristics between the Francoeur and Lac Fortune gold deposits, Rouyn-Roranda area, Quebec

Characteristics	The Francoeur deposit	The Lac Fortune deposit
Host Lithologies	Metavolcanic rocks of Blake River Group + gabbro-diorite + dikes of albitite	Metavolcanic rocks of Blake River Group + gabbro-diorite + dikes of felsic porphry
Metamorphism	Greenschist facies	Greenschist facies
Host structure	Ductile shear zone	Ductile shear zone
Mineralization	Replacement type	Quartz-carbonate vein type
Alteration	Muscovite+chlorite+hematite carbonate+albite+pyrite	Carbonate-chlorite+muscovite
Composition of the ore-forming fluid	H_2O-dominated, CO_2-rich with NaCl and small amounts of $CaCL_2$ and CH_4	H_2O-dominated, CO_2-rich with NaCl and small amounts of $CaCL_2$ and CH_4
Temperature of homogenization	150°- 578°C	110°-360°C
Salinity of fluid	2-6 wt % NaCl equiv.	5-9 wt% NaCl equiv.
Range of pressure at homogenization	4000-5000 Pa	3200-5100 Pa
Major mechanism of mineralization	Interaction of fluid-wallrock	Phase separation of fluid

replacement type, with close coexistence of gold and pyrite disseminated in the altered shear zones, while the Lac Fortune belongs to the quartz veins type, and gold is scattered in quartz veins, with Pb-Bi tellurides and little pyrite.

Secondly, the extent of hydrothermal alteration are also different. In the Francoeur deposit, hydrothermal alteration is well developed, and alteration minerals have distinct zonation from orebody outward: albite-pyrite to carbonate-hematite to muscovite-chlorite. Gold mineralization is closely associated with these alterations, especially albite-pyrite alteration. In the Lac Fortune deposit, hydrothermal alteration is relatively simple, only a carbonate-chlorite-muscovit alteration mineral assemblage was identified. Gold mineralization is related to the filling of the ore materials from hydrothermal solutions. Hydrothermal alteration, if any, played a secondary role in gold mineralization.

Finally, the mechanism of mineralization is different. In the Francoeur deposit, interaction of fluid-rock play an important role in gold deposition while phase separation is an important mechanism of gold precipitation in the Lac Fortune.

6.2 Discussion

What are the factors which result in different types of mineralization in the Francoeur and Lac Fortune gold deposits?

The tectonic settings of Archean gold deposits have been the subject of several genetic models discussion. For example, many authors draw analogies between Achean greenstone belts and modern environments such as island arcs, marginal basins, and oceanic crust. Card and Ciesielski (1984) regard the settings of Achean greenstone belts in the Superior Province of the Canadian Shield as analogous to modern oceanic island arc-interarc basin, accretionary wedge systems. They suggest that subduction-driven accretion caused ductile deformation and granulite facies metamorphism at deep crustal levels and ductile to brittle deformation and lower grade metamorphism at higher crustal levels. Colvine et al. (1988) regard Archean gold deposits as the final product of collisional tectonics and cratonization. Gold mineralization was emplaced along crustal-scale deep-seated fractures which may represent reactivated structures that extend into the mantle. These same structures also formed channels for the fluids.

It is known that there are two ore types in Archean lode gold deposits (Roberts 1989): one consists of veins (open space filling), such as the Sigma deposit (Robert and Kelly 1987) and the Lac Fortune (present study); another is the replacement orebody, such as in the Red Lake district (Andrews et al., 1986), in the Golden Mile deposits, Kalgoorlie (Phillips 1986) and the Francoeur deposit (present study).

Roberts (1989) has studied a lot of Archean gold deposits and believed that the formation of veins is a part of the deformation process. Shearing does not appear to be a ground preparation process during which open structures are formed, and into which veins are later emplaced. Rather, shearing and veining are parts of a continuous process. For the replacement type, they are controlled by the degree of strain in the rock and high grade ore is confined to comparatively narrow mylonitic rocks enclosed in less strained rocks.

Even though internal structures, geometry and mineralization of many Achean mesothermal gold deposits may be explained in terms of the development of a simple shear strain system or by the other models, these models only considered the condition of structural environment. In fact, the physicochemical conditions of the ore-forming fluid are important factors which affect mineralization.

The different mineralization styles may be caused by the difference of physicochemical conditions of the ore-forming hydrothermal solution. It is shown in the preceding chapter that the geological context and the composition of the hydrothermal fluids in the Francoeur and Lac Fortune gold deposits are similar, but with apparently different mineralization temperature. The mineralization temperature is evidently higher in the Francoeur than in the Lac Fortune. This is consistent with known knowledge that high temperatures of hydrothermal solution favor replacement, whereas filling dominates in lower temperature domains. The higher the temperature at site of mineralization, the more active the ore-forming fluid and the easier the fluid-rock interaction. The fluid-rock interaction happens and accompanies gold precipitation when the ore-forming fluid with high temperature rises up along shear zones. On the other hand, fluid-rock interaction is not favorable to the ore-forming fluid with relative low temperature. Open-space filling veins will be formed and gold will precipitate with phase separation of the ore-forming fluid if the pressure drops suddenly during ascent of the fluid.

CHAPTER VII

CONCLUSIONS

The Francoeur and Lac Fortune gold deposits are situated in the Rouyn-Noranda area, a typical sector of the Abitibi Archean greenstone belt of the Superior Province, Canada. The host lithologies include the metavolcanic rocks of the Blake River Group, sedimentary rocks of the Timiskaming and Cobalt Groups, synvolcanic and late-tectonic intrusive rocks.

The Francoeur deposit developed along the east-west striking Francoeur-Wasa shear zone, in contact with southern margin of a gabbro-diorite stock. Albitite dikes occur in the mine area. Hydrothermal alteration is commonly limited to the shear zones. The major products of alteration include chlorite, muscovite, pyrite, carbonate and hematite. They display alteration zonation. The sequence of typical alteration zonation from the orebody outwards changes from the albite-pyrite assemblage, through the carbonate-hematite assemblage, to the muscovite-chlorite assemblage.

In the Francoeur deposit, gold mineralization is related to hydrothermal wall rock alteration, especially to the formation of the albite-pyrite assemblage. In fact, the ore is mostly contained in various altered mylonites, in which gold is disseminated with close association with pyrite. This deposit essentially belongs to the replacement type of gold deposit.

The Lac Fortune deposit occurs in a small shear zone parallel to the Francoeur-Wasa shear zone. It belongs to the quartz-vein type gold deposit, and is characterized by the development of quartz veins. Hydrothermal alteration did not developed so well as in the

Francoeur. The alteration mineral associations are relatively simple, and occurs mainly in the wall rocks or near the contact zone between the wall rocks and quartz-carbonate veins, with chlorite-carbonate-muscovite-fuchsite being the principal alteration mineral assemblage. The minerals of the quartz-carbonate veins were formed mainly by the filling or direct precipitation of ore materials from hydrothermal fluids. Gold-bearing minerals, including coarse free gold and Pb-Bi tellurides, are scattered in the quartz-carbonate veins.

Detailed fluid inclusions study shows that there are three groups of fluid inclusions in relation to the gold mineralization of the Lac Fortune and Francoeur deposits. They are aqueous inclusions, CO_2-rich inclusions and H_2O-CO_2 inclusions. The aqueous inclusions are in a H_2O-NaCl-dominated chemical system, with the presence of small amounts of $CaCl_2$ and CH_4. Besides the predominant CO_2, the CO_2-rich inclusions also contain minor amounts of other gases, such as CH_4. The composition of H_2O-CO_2 inclusions is similar to the one of aqueous inclusions, except for the existence of CO_2. The solution preserved in the H_2O-CO_2 inclusions represents the primary ore-forming hydrothermal fluid in the Lac Fortune gold deposit. i.e., the initial ore-forming hydrothermal fluid is in the H_2O-CO_2-NaCl system fluid.

While the CO_2-rich inclusions are basically non-saline, the salinity of aqueous inclusions is higher on average than that of the H_2O-CO_2 inclusion, although there is a large overlap in the range of salinity for them in the Lac Fortune deposit. But the salinities of the type 1 and type 3 fluid inclusions are almost equal in the Francoeur deposit.. The salinity ranges from 2 to 6 wt% NaCl equivalent for the fluid inclusions from the Lac Fortune, and from 5 to 9 wt% NaCl equivalent for those from the Francoeur. The ore-forming fluids of the Francoeur and Lac Fortune deposits are both rich in CO2 with low salinity, resembling other Archean mesothermal gold deposits in the Superior Province.

In the Francoeur deposit, the homogenization temperatures of fluid inclusions have two main ranges: 425°-550°C and 150°-250°C. The former may represent early mineralization stage corresponding to carbonate-hematite alteration mineral assemblage, the later may represent the main mineralization stage corresponding to albite-pyrite alteration mineral assemblage.

The mineralization temperature and pressure respectively ranges from 110°C to 378°C and 3200 to 5100 Pa in the Lac Fortune gold deposit, and the minimum mineralization temperature and pressure are respectively 150° to 578°C and 4000-5000 Pa in the Francoeur gold deposit. It is apparent that the temperature at the site of mineralization is higher in a general sense in the Francoeur than in the Lac Fortune.

In the Lac Fortune gold deposit, an unmixing (phase separation) mechanism of the primary hydrothermal solution might play an important role in gold precipitation, whereas in the Francoeur gold deposit, the fluid-rock interaction might play an important role in gold deposition.

The important factor resulting in the different types and mechanisms of mineralization may be the physicochemical conditions of the ore-forming fluid. In the Francoeur deposit, the temperature of the ore-forming fluid is relatively high. Thus, it is more suitable for the fluid-rock interaction with gold precipitation. In the Lac Fortune deposit, however, the temperature of the ore-forming fluid is relatively low. The ore-forming fluid is relatively lazy to alteration of the wall-rock. Open-space veins and phase separation of the ore-forming fluid with gold mineralization will be formed in case the pressure drops suddenly.

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Appendix I

SAMPLE DESCRIPTION

SAMPLES IN THE FRANCOEUR GOLD DEPOSIT

RR-89-027	typical ore from the south orebody, disseminated Py in metasomatized rock (Albite-pyrite alteration)
FR-89-031	typical ore from the south orebody, disseminated Py in metasomatized rock (Albite-pyrite alteration)
FR-89-038	typical ore from the south orebody, disseminated Py in metasomatized rock (Albite-pyrite alteration)
FR-89-060	typical ore from the north orebody, disseminated Py in metasomatized rock (Albite-pyrite alteration)
FR-89-65	There are two parts in this sample. 1) Smoky quartz vein that is undergoing replacement by 2) BB-disseminated Py in metasomatized rock
FR-89-072	Smoky quartz vein showing sulphide stringers (same quartz as FR89-065)
FR-89-081	Altered gabbro approximately level 5 in the hanging wall of BB horizon on section 15 325E
FR-89-090	There are two parts in this sample: 1) Smoky quartz vein undergoing replacement by 2) BB- disseminated Py in metasomatized rock. This sample is from draw point #3 on level 11 in the north orebody

FR-89-107	partially altered gabbro approximately level 10 in the hanging wall of a BB in the north ore zone
FR-89-110	Barren quartz vein cut by gypsum veinlet, North orebody.
FR-89-121	BB horizon from the south ore zone (Albite-pyrite alteration)
FR-89-122	Albitite dyke from the south ore zone
FR-89-123	Mylonitic schist typical of the hematite-muscovite alteration facies (pre-mineralization).
FR-92-11	ore from the south orebody
FR-92-12	poor ore (hematization)
FR-92-13	ore with hematization from south orebody
FR-92-14	ore from the depth of the south orebody
FR-92-15	albitite dyke
FR-92-16	orebody in depth
FR-92-18	contact between albitite dyke and orebody
FR-92-19	contact between albitite dyke and orebody
FR-92-20	orebody in depth
FR-92-21	orebody in depth
FR-93-01	Contact band of BB in level 12
FR-93-02	Wall-rock in level 12
FR-93-03	Shear zone in level 12
FR-93-04	BB zone of mineralization in level 12
FR-93-05	Dyke of albitite in level 12
FR-93-06	Fresh BB in level 12-sublevel 4
FR-93-07	BB in the hanging wall of fault in level 12-sublevel 4
FR-93-08	BB in the foot wall of fault in level 12-sublevel 4
FR-93-09	Dyke of albitite in shear zone in level 11
FR-93-10	Dyke of albitite in wall-rock in level 11

FR-93-11	The contact between BB and dyke in level 13
FR-93-12	Dyke of albitite in level 13
FR-93-13	BB in level 13

SAMPLES IN THE LAC FORTUNE GOLD DEPOSIT

Number	Sample description
LF90-05	Mylonitic schist typical of the shear zone, level 1
LF90-07	Gabbro, wallrock of quartz vein parallel to shear zone boundary, level 1
LF90-08	Quartz vein on level 1, Py-Cpy, Tellurides (?)
LF90-11	Gabbro outside the shear zone, level 1
LF90-13	Mafic volcanic carbonatized and sericitized, level 1
LF-93-01	Quartz vein + wall-rock
LF-93-02	Alteration zone
LF-93-03	Quartz vein with pyrite
LF-93-04	Alteration zone with green mica
LF-93-05	Quartz vein with gold
LF-93-06	Shear zone
LF-93-12	Porphyry

Appendix II

LIST OF ABBREVIATIONS USED IN THE PLATES

Hem.	Hematite
Chl.	Chlorite
Ca.	Carbonate
Fu.	Fuchsite
Qz.	Quartz
Py.	Pyrite
Au.	Gold
Al.	Albite
Mu.	Muscovite
Gy.	Gypsum
Type 1a	Aqueous inclusion
Type 1b	Daughter mineral-bearing aqueous inclusion
Type 2	CO_2-rich inclusion
Type 3	H_2O-CO_2 inclusion