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**Sulphur Isotopic Evidence for the**  
**Genesis of the Au-Ag-Sb-W**  
**Mineralization of the Fairbanks Mining**  
**District, Alaska**  
**By**  
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ISOTOPE GEOLOGY UNIT

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Sulphur Isotopic evidence for the genesis  
of the Au-Ag-Sb-W mineralisation of the  
Fairbanks Mining District, Alaska.

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The analytical and other data presented in this report are made available on the understanding that extracts or reference will not be published in any form without prior approval of the author and the Officer in Charge, Isotope Geology Unit.

## INTRODUCTION

The Fairbanks Mining District is located within the northwestern portion of the Yukon-Tanana Uplands Schist Terrane in central Alaska (see Figure 1.) Figure 2 is a generalized geological map of the terrane which is bounded on the south by the Denali Fault and on the north by the Tintina Fault (Foster et al., 1973). The terrane is composed of Precambrian or Paleozoic metamorphosed sedimentary and volcanic rocks that contain lower greenschist to amphibolite facies, eclogite facies and granulite facies mineral assemblages. The metamorphic rocks were formerly designated Birch Creek Schist (Mertie, 1937). The metamorphic rocks are unconformably overlain by Paleozoic, Mesozoic and Tertiary sedimentary and volcanic rocks. The metamorphic and sedimentary sequences are intruded by Paleozoic, Mesozoic and Tertiary rocks ranging in composition from peridotite to granite.

Gold was discovered in the Fairbanks district in 1902 and since then the area has produced 7,500,000 troy ounces of placer gold and 250,000 troy ounces of lode gold. In addition, the district has produced several thousand tons of antimony and several thousand short ton units of tungsten.

Prindle and Katz (1913) were the first to provide a general description of the bedrock and surficial geology of the Fairbanks district. Many of the rock units which they defined have been retained by subsequent investigators; however, the most significant contribution was their detailed descriptions of the gold placer deposits. Prindle and Katz (1913) related the placer

Figure 1. Location Map of the Fairbanks mining district, Alaska.

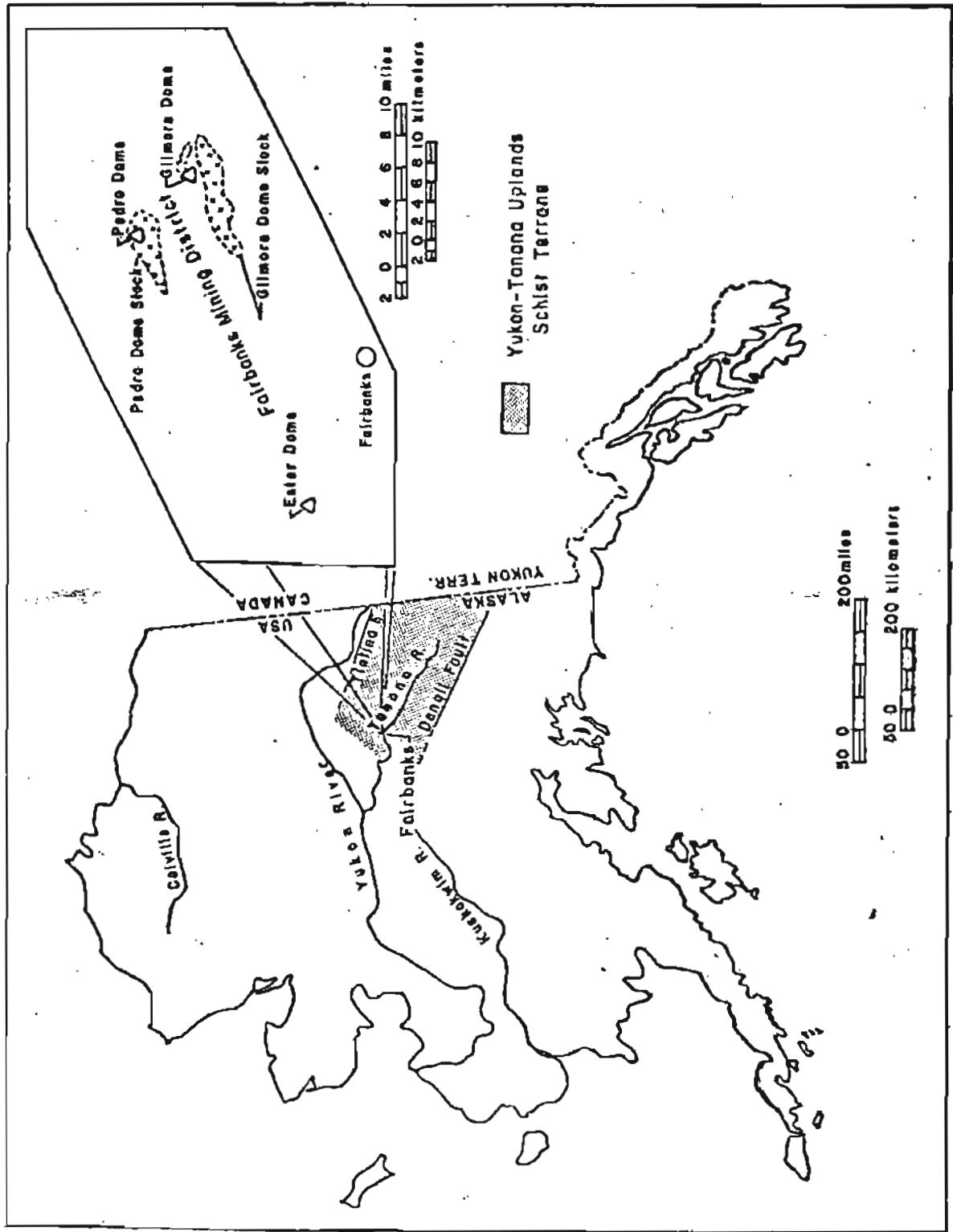
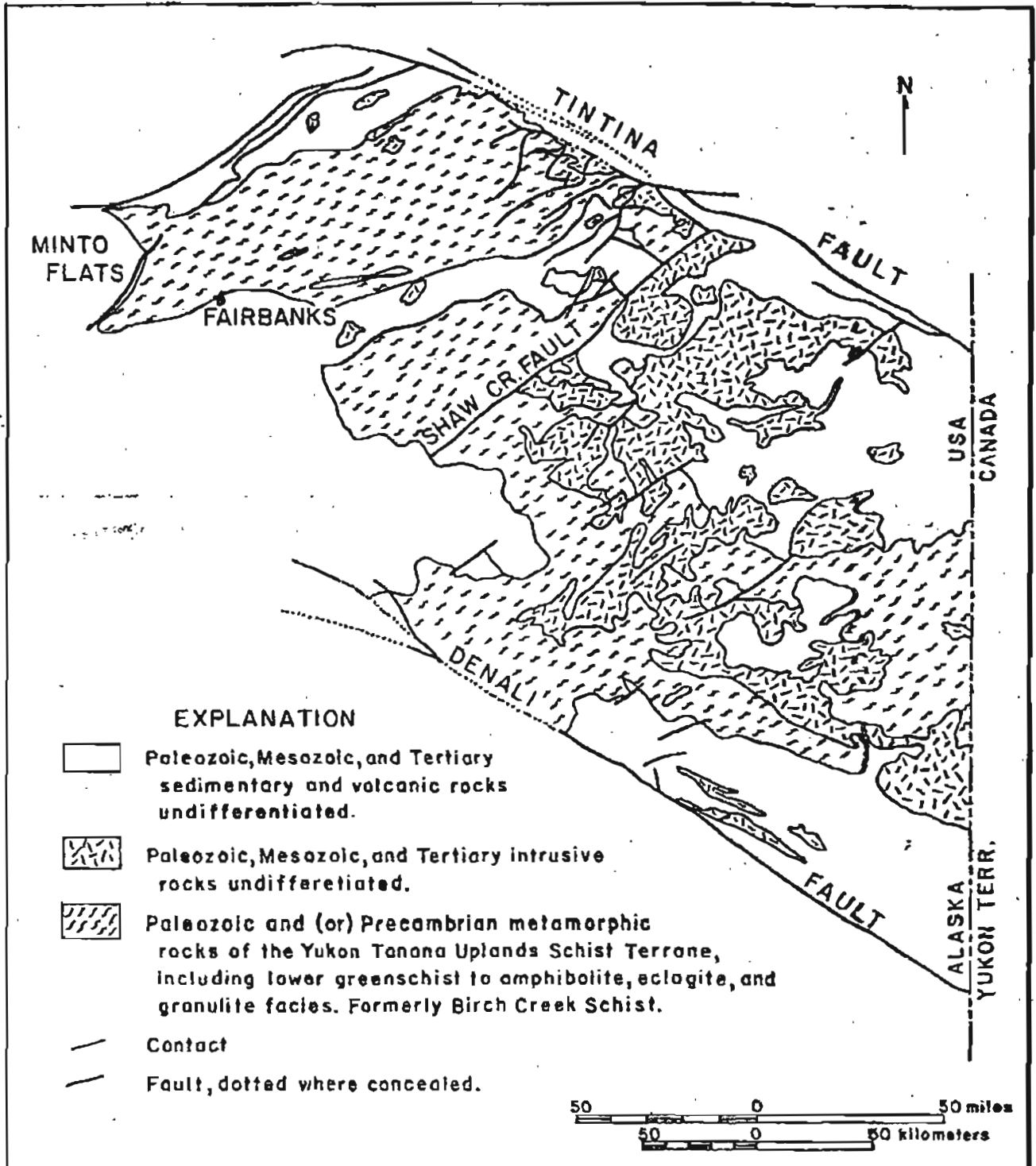


Figure 2. Generalized geological map of the Yukon-Tanana Upland Schist Terrane  
Alaska

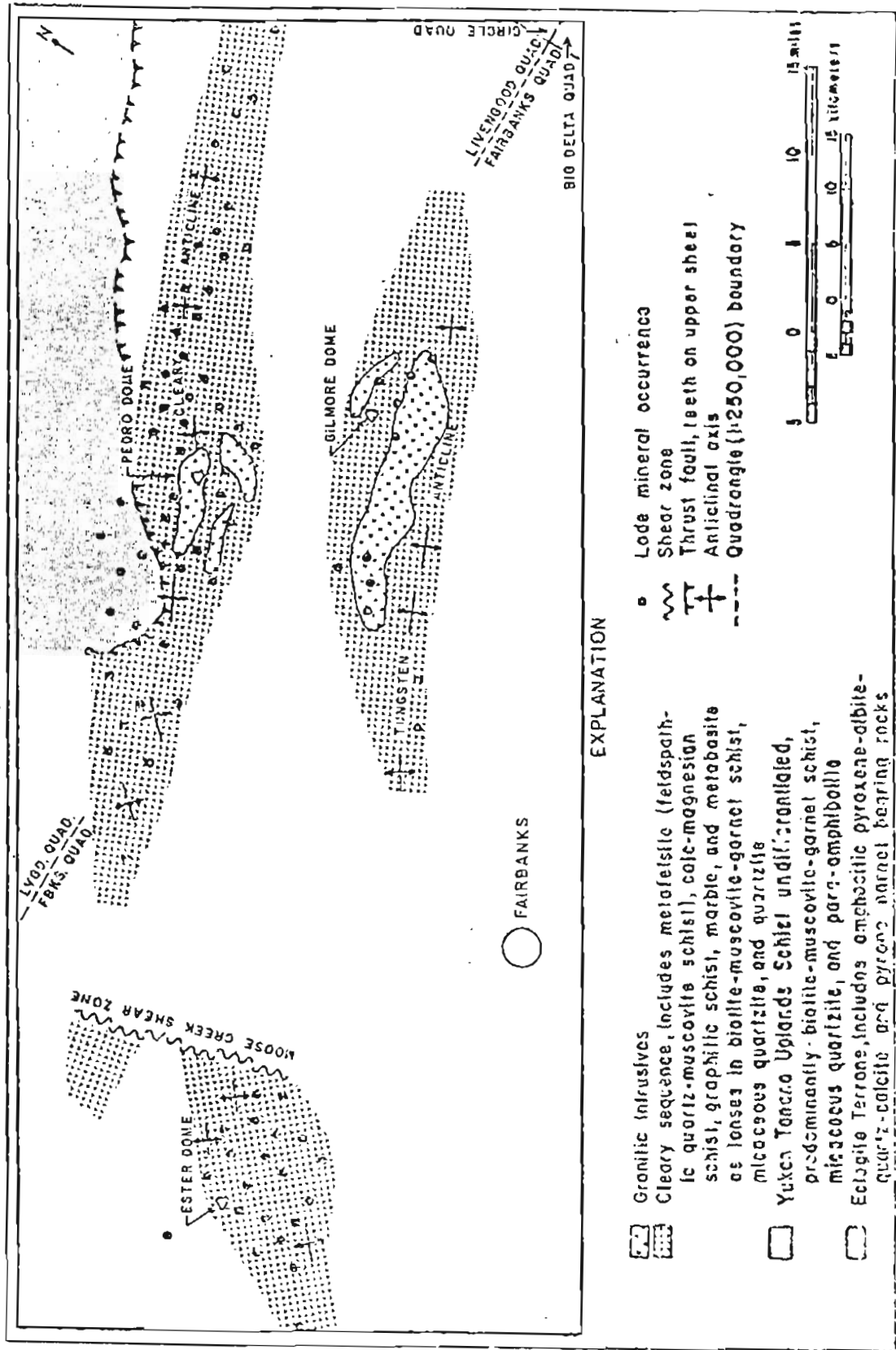


deposits to gold-quartz-sulphide veins, the formation of which in turn was attributed to the intrusion of granitic rocks in the district.

Smith (1913) has provided detailed descriptions of several lode deposits which gave support to the earlier observations of Prindle and Katz (1913). Chapin (1914, 1919), Mertie (1918) and Hill (1933) also described the lode deposits of the district and noted the close spatial relationship of the placer deposits to the lode occurrences. The gold-quartz veins were considered to be the sole lode source and the veins were thought to be related to the granitic intrusive rocks of Gilmore Dome and Pedro Dome. Chapman and Foster (1969) also related the gold-quartz vein deposits of the district to the granitoid intrusions of Cretaceous age and concluded that the quartz veins were the sole source of the placer gold.

Metz (1977) and Metz and Robinson (1980) suggest that the antimony-tungsten and associated lode gold mineralization of the Fairbanks district is related to previously unrecognized metavolcanic rocks in the Yukon-Tanana Uplands Schist. Recent 1:24,000 scale geological mapping (Metz, 1982; Bundtzen, 1982; and Robinson, 1982) has delineated the extent of these metavolcanic rocks (see Figure 3). The majority of the known lode mineral occurrences in the district are within these metavolcanic rocks which have been named the Cleary Sequence (Metz, 1982); however, the lode occurrences are not necessarily spatially associated with the exposed intrusive rocks.

Figure 3. Generalized geological map of the Fairbanks mining district of Alaska



Detailed investigations of the lode mineral deposits have resulted in the definition of the following five major types of lode mineralization within the district:

I. VOLCANOGENIC STRATABOUND MINERALIZATION- in which intergrowths of arsenopyrite, jamesonite, galena, sphalerite, pyrite, chalcopyrite, gold and scheelite occur in conformable laminae and lenses parallel to both foliation and compositional banding in the metavolcanic host rocks. The As-Sb-Zn-Pb-Au mineralization is associated with metafelsic rocks while Cu-W mineralization is associated with metabasic host rocks.

II. LEAD SULPHOSALT-BEARING QUARTZ SULPHIDE VEINS- with argentiferous galena, sphalerite, chalcopyrite, jamesonite, arsenopyrite and trace gold and stibnite occurring in shear zones in Cretaceous intrusives.

III. TUNGSTEN SKARN MINERALIZATION- in which scheelite bearing calc-silicate mineralization occurs adjacent to the Gilmore and Pedro Dome granitic stocks.

IV. GOLD- BEARING POLYMETALLIC QUARTZ SULPHIDE VEINS- which occur as fracture fillings in shear zones that cross-cut the metavolcanic host rocks of the schist sequence. The veins contain quartz, boulangerite, jamesonite, robinsonite, semseyite, galena, sphalerite, arsenopyrite, tetrahedrite, chalcopyrite, and gold.

V. STIBNITE GASH VEINS AND FRACTURE FILLINGS- associated with axial plane shears in the metavolcanic host rocks. The mineralization is monomineralic and includes massive and subhedral stibnite with minor traces of gold.

The above mineral classification system is based on mineralogic, petrologic, fluid inclusion, and field



investigations, however the classification system may be additionally constrained by sulphur isotope analyses.

#### SAMPLING AND ANALYTICAL TECHNIQUE

Of the 188 known lode mineral occurrences in the Fairbanks mining district, twenty-eight were selected for detailed mineralogic, petrologic, fluid inclusion and isotopic studies. Two of these occurrences are Type III tungsten skarn deposits with no suitable sulphides. The twenty-six sampled sulphide-bearing occurrences include: 43 sulphides from Type I mineralisation; and five stibnite samples from Type V deposits.

Sulphur isotope ratios were determined in the NERC Stable Isotope Facility at the British Geological Survey in London and at the Geochron Laboratories, Cambridge, Mass.

The following procedure was adopted at the London laboratory.

Sulphur dioxide from sulphides was extracted for analysis by oxidation with Cuprous oxide at 1070°C, using essentially the method described by Robinson and Kusakabe (1975). The isotopic analyses of the purified sulphur dioxide were made on a modified Micromass 602 mass spectrometer with heated inlet system. The results were corrected for isobaric interference assuming a constant oxygen isotopic content and instrumental crosstalk (Coleman, 1977; 1980) and expressed in conventional  $\delta$  notation with respect to the Canon Diablo meteoritic troilite standard.

Analytical uncertainty, mainly in the oxygen isotope correction, amounts to between 0.05 and 0.1 ‰.

$$\delta^{34}\text{S}_{\text{sample}} = \left[ \frac{^{34}\text{S}/^{32}\text{S}_{\text{sample}}}{^{34}\text{S}/^{32}\text{S}_{\text{standard}}} - 1 \right] \times 1000 \%$$

Fractionation between two phases is expressed as :

$$\Delta^{34}\text{S}_{\text{B-A}} = \delta^{34}\text{S}_{\text{B}} - \delta^{34}\text{S}_{\text{A}} \%$$

## RESULTS AND DISCUSSIONS

Sample descriptions and results are given in Table 1 and summarized in Figure 4. Generally the duplicate samples run at each laboratory were within 0.5 per mil and in some cases within 0.1 per mil. Stratabound sulphide from the Type I mineralization have a mean of 2.0 per mil excluding two samples of sulphides from a single disseminated occurrence in eclogite the have a mean of 8.8 per mil. Sulphides from both Type II mineralization (endoshears) and Type IV mineralization (exoshears) have a mean of 1.4 and 2.2 per mil respectively. Stibnite from late antimony veins (Type V mineralization) have a mean of -4.2 per mil. The mean per mil values for the stratabound and vein mineralization are approximately equivalent to the expected values for volcanic sulphide and modern hydrotherms respectively (Nielsen, 1979). The sample means of Types I, II and IV mineralization are not significantly different as are the variances of 1.19, 1.23 and 1.21 per mil respectively, however the small number of samples particularly from Type II mineralization preclude rigorous hypothesis testing.

The presence of disseminated galena and sphalerite in the eclogite rocks was not expected nor can descriptions of analogues

Table 1. Sulphur Isotopic Compositions of Sulphides from the Fairbanks District, Alaska.

Mineral Occurrence/ Sample No.	Description	Gm	S1	Py	CDT(‰)			Deposit Type
					Cp	As	Ja	
Chatham Creek Prospect								I
81 MI 01 B1	Banded Sulphides in marble and metachert		+1.7	+3.2				
*81 MI 01 B1	Banded Sulphides in marble and metachert	+2.6		+3.5				
*81 MI 01 B1	Banded Sulphides in marble and metachert		+2.0	+2.4				
Cleary Hill Mine								I, IV, V
81 MI 02 A	Quartz Sulphide vein			+2.7	+1.6			
*82 CH 02 A	Qtz Sulphide vein in calc-schist w/sulphides	-8.4						
82 CH 02 B	Banded Sulphides in calc-schist and metachert	-9.0						
82 CH 01	Stibnite vein w/trace sphalerite		-0.5				-5.1	
Clipper Mine								IV
81 MI 03	Qtz vein in mica-quartzite			+3.1	+3.2			
*81 MI 03	Qtz vein in mica-quartzite			+2.6				
Christina Adit								I, IV, V
82 CA 01	Massive Stibnite in metafelsite						-3.0	
82 CA 01	Quartz vein in metafelsite		+2.1					
*82 CA 04	Quartz vein in metafelsite			+2.9				

Mineral Occurrence/ Sample No.	Description	Cm	Sl	Py	CDT(%) Cp	As	Ja	St	Reposit Type
Engineer Creek Prospect 20509	Pyrite in adamellite dyke in shear zone			+0.3					IV
Farmer Prospect 81 MI 05	Massive Stibnite vein cutting metafelsite							+3.1	V
III-Yu Mine 81 MI 06	Qtz Sulphosalt vein in calc-schist w/sulphate		+2.7						I, IV
81 MI 06	Qtz Sulphosalt vein in calc-schist w/sulphate		+3.2						
82 MI 01	Qtz Sulphosalt vein in calc-schist w/sulphate			+3.2	+0.3		+1.0		
75 PI 03	Qtz sulphosalt vein in calc-schist w/sulphate	+2.0							
*875 PI 03	Qtz Sulphosalt vein in calc-schist w/sulphate	+2.8							
Johnson Prospect 81 MI 09 A	Massive Stibnite in shear zone							-5.6	V
*81 MI 09 A	Massive Stibnite in shear zone							-0.3	
McCarty Mine 81 MI 10 A1	Pyrite in metafelsite			+1.1					I, IV, V
81 MI 10 A2	Pyrite in metafelsite			+4.2					
82 MI 01	Massive Stibnite with minor quartz					+1.5		-0.4	
Mohawk Mine 81 MI 11	Quartz veinlets cutting chlorite schist					+8.2			IV
*82 M 30	Quartz veinlet cutting chlorite schist					+10.0			

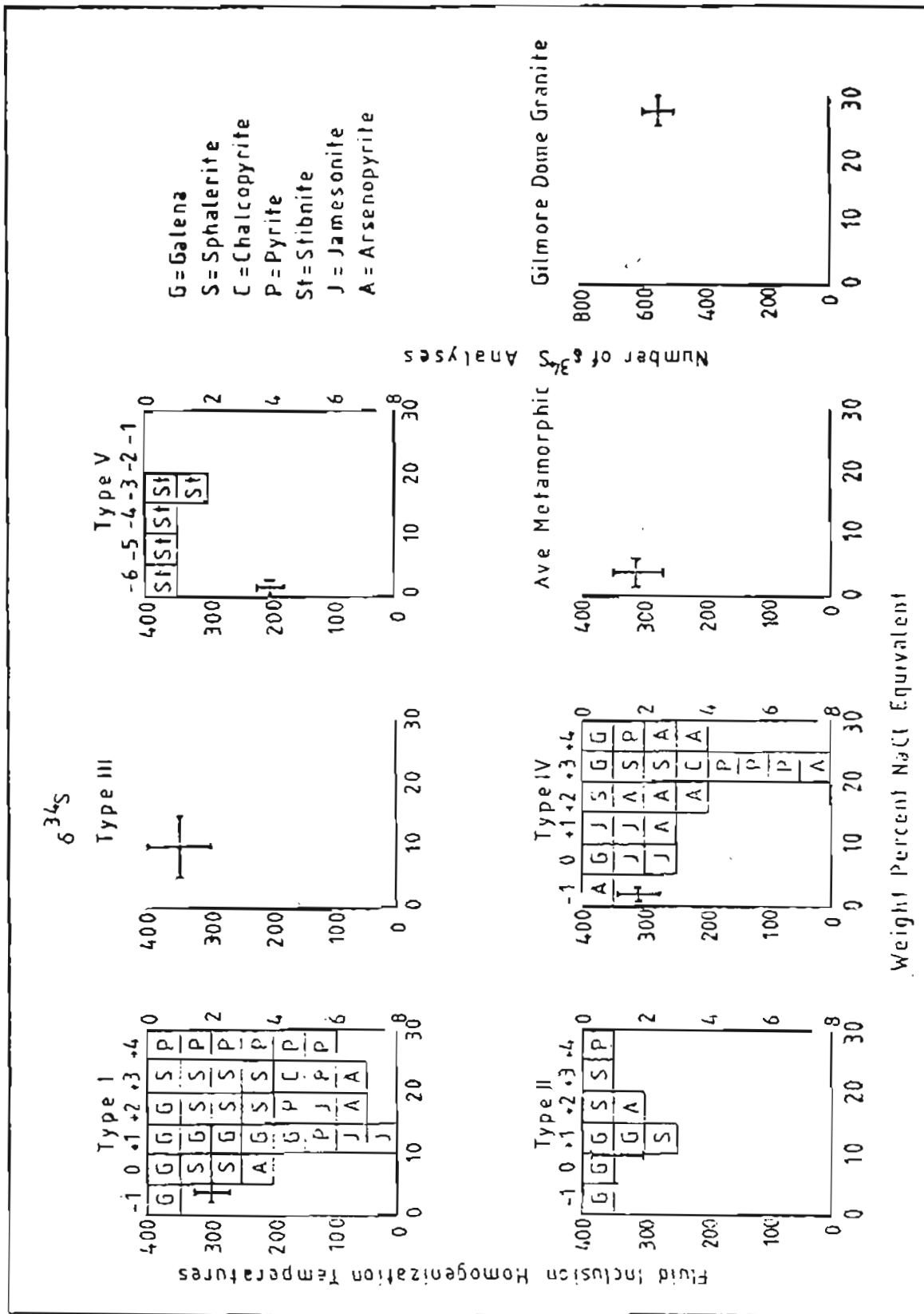
Mineral Occurrence/ Sample No.	Description	Cm	Sl	Py	CDT(%) Cp	Ab	Ja	St	Deposit Type
Newsboy Ext (Chechako) Prospect 81 NI 12 A	Banded Sulphides in marble and metachert	+0.3	+2.5	+2.8					I
*81 NI 12 A1	Banded Sulphides in marble and metachert	+1.7	+2.9						
*81 NI 12 A2	Banded Sulphides in marble and metachert	+0.5							
*81 NI 12 A3	Banded Sulphides in marble and metachert	+1.2							
Newsboy Mine 82 NB 01	Quartz Sulphosalt veins in metafelsite					+2.1	+0.5		IV
Nordale Adit 82 NA 01	Quartz Sulphosalt veins in calc-schist w/banded sulphides			+3.0			+0.5		1, IV
82 NA 02	Quartz Sulphosalt veins in calc-schist w/banded sulphides					-0.8			
*21150	Quartz Sulphosalt veins in				+3.0				
Ridge Prospect 81 MI 2R	Banded Sulphides in marble and metafelsite	+0.9	+3.1						I
Rogasch Prospect 81 MI 13 A	Quartz vein in mica quartzite	+4.1				+3.7			IV
Rowley Prospect	Shear zone near grano- diorite-schist contact	+0.7							II

Mineral Occurrence/ Sample No.	Description	Gm	Sl	Py	CDT(%, ) Cp	As	Ja	St	Deposit Type
Ryan Lode Mine *81 MI 15A	Shear zone in chlorite- calc-schist					+0.5			IV
82 RLO-3A	Shear zone in chlorite					+3.7			
Scrufford Mine *81 MI 16	Massive Stibnite in metafelsite							+2.6	V
Silver Fox Mine 81 MI 17 A	Shear zone in grano- diorite	+0.5	+2.5	+3.5		+2.4			II
*81 MI 17 A1	Shear zone in grano- diorite	+0.2	+2.1						
*81 MI 17 A2	Shear zone in grano- diorite	-0.9	+1.3						
Stecse Arsenic Prospect 81 MI 18	Shear zone in mica- quartzite and metafelsite					+7.5			IV
Stecse Eclogite Prospect 81 MI 04	Disseminated Sulphide in eclogite	+8.0	+9.3						I
*81 MI 04 A	Disseminated Sulphide in eclogite	+9.3	+9.7						
*81 MI 04 B	Disseminated Sulphide in	+8.1							
Scrufford Mine 81 MI 1C	Massive Stibnite in metafelsite							+2.0	V

Mineral Occurrence/ Sample No.	Description	Gm	SI	Py	CDT(%) Cp	As	Ja	St	Deposit Type
Tolovana Mine S1 MI 19 A	Massive Sulphide lenses in metafelsite					+4.6			I, IV, V
Vetter Prospect S1 MI 21 A	Quartz vein in mica- quartzite and metafelsite	+0.2				+2.2			IV, V
S1 MI 21 B	Massive Stibnite in quartzite and metafelsite							-4.4	
Mackewitz Prospect S1 MI 22 B	Massive Sulphide lenses in metafelsite	-0.4	+0.4	+3.0		+1.4			I
*S1 MI 22 D1	Massive Sulphide lenses in metafelsite	+0.9							
*S1 MI 22 H2	Massive Sulphide lenses in metafelsite	-0.5							
Willow Creek S1 MI 23 B	Banded Sulphide in marble		+1.9	+4.0		+3.0	+1.3		I
*S1 MI 23 F	Banded Sulphide in marble		+2.6						
Woods Mine S1 MI 24	Massive Stibnite in mica quartzite							-0.1	V

NOTE: IGS (BGS) Laboratory

Figure 4. Sulfur isotopic and fluid inclusion data from the Fairbank mining district, Alaska





of that type of mineralization be found in the literature. Lead isotopic analyses of galena from the disseminated mineralization in the Eclogite Terrane and from stratabound and vein mineralization in the Cleary Sequence indicate two distinctive lead isotope populations for the two tectono-stratigraphic units (Metz and Swainbank, unpublished data). Although sulphur isotopic data for the Eclogite Terrane is very limited there is a difference of about 7 per mil. in the mean values of the Cleary Sequence and Eclogite Terrane sulphides. Although these two tectono-stratigraphic units both contain stratabound mineralization the modes of origin of the mineralization were probably significantly different. In addition, the two rock units and hosted syngenetic mineralization were subsequently subjected to radically different pressure-temperature conditions during one or more regional metamorphic events.

Mineral deposit Types II and IV show the largest difference in sulphur isotope sample means however the sample means are not significantly different above the 90 percent confidence interval. Given the order of isotopic exchange rate galena > sphalerite > chalcopyrite > pyrite (Crown et al., 1975) it may be expected that the metamorphosed Type I mineral occurrences would show narrower ranges for galena than pyrite as compared to Types II and IV mineralization. This is not the case as shown in Figure 4. Therefore it can be concluded that metamorphism has had no significant effect on the sulphur isotope values and the degree of equilibrium or disequilibrium in the systems are a function of the original conditions of ore deposition.

The stibnite from Type V mineralization contains significantly lighter sulphur than the other mineral deposit types. The antimony bearing phase in Type V is always restricted to stibnite. The stibnite contains only trace amounts of arsenic and gold. Conversely in Types I, II and IV mineralization, the antimony bearing phases are complex sulphosalts and stibnite occurs only in trace amounts in a limited number of occurrences. Figure 4 includes fluid inclusion homogenization and salinity data (Metz, 1984) for Types I (except the eclogite occurrence) thru V mineral occurrences as well as selected metamorphic and intrusive igneous rocks from the mining district. Table 2 is a tabulation of calculated temperatures from sulphide mineral pairs from seven Type I mineral locations (including the eclogite occurrence) and one Type II mineral occurrence. Four of the Type I occurrences have sulphide pairs that indicate temperatures compatible with the ranges of temperatures indicated by the sulphide and metamorphic mineral assemblages and by the fluid inclusion homogenization. The remaining three Type I sulphur isotope pairs indicate temperatures incompatible with those obtained from fluid inclusion measurements. The two sulphide mineral pairs from the Silver Fox Mine (Type II occurrence) indicate temperatures 200°C above the fluid inclusion homogenization temperatures. From these data it can be concluded that isotopic equilibrium may have been attained in some of the Type I occurrences but was not approached in the Type II occurrence. No suitable sulphur isotope mineral pairs were available for Types IV and V mineralization thus no estimate can be made from sulphur species concerning equilibrium conditions in these systems.

Table 2. Calculated temperatures from sulphur isotopic compositions of sulphide mineral pairs and fluid inclusion homogenization temperature ranges from the Fairbanks Mining District, Alaska.

Mineral Occurrence	Sulphide Mineral Pair	Calculated Temp. (°C)	Deposit Type	Range of fluid Inclusion Homogenization Temp (°C)
Chatham Creek Prospect	Py-Ga	700	I	280-360
Christina Adit	Py-Sl	300	I	
Newboy Ext Prospect	Py-Ga	700	I	
	Sl-Ga	630	I	
Ridge Prospect	Sl-Ga	290	I	
Silver Fox Mine	Py-Ga	580	II	300-380
	Sl-Ga	600	II	
Steese Eclogite Prospect	Sl-Ga	330	I	?
Wackwitz Prospect	Py-Ga	400	I	280-360
	Py-Sl	100	I	
	Sl-Ga	100	I	
Willow Creek Prospect	Py-Ga	630	I	
	Sl-Ga	1200	I	

Types I, II, and IV mineral occurrences contain quartz with CO<sub>2</sub> rich fluid inclusions. Types II and IV mineral occurrences often contain variable density CO<sub>2</sub> inclusions that homogenize at the same temperature thus suggesting effervescence of CO<sub>2</sub> during vein formation. Type V mineralization contains relatively minor CO<sub>2</sub> (3 mole percent maximum) compared to Types I, II and IV mineralization (13+ mole percent). Type V mineral occurrences do not show any evidence of CO<sub>2</sub> effervescence. The effervescence of CO<sub>2</sub> will result in an increase in pH and an increase in pH should shift the sulphur species to more positive  $\delta^{34}\text{S}$  values. A decrease in temperature or an increase in oxygen partial pressure should cause a shift to lighter  $\delta^{34}\text{S}$  (Ohmoto, 1972). The disequilibrium conditions in some of the Type I mineral occurrences and in the Type II deposit probably reflects rapid changes in pH, temperature and partial pressure of volatile phases.

The sample means of Types I and V and IV and V mineralization differs by approximately 6 per mil. Ohmoto and Rye (1979) and Robinson and Farrard (1982) suggest that equilibrium stibnite values are about 4 per mil lower than H<sub>2</sub>S in an ore fluid at the temperature range of 150 to 200 degrees °C. Fluid inclusion homogenisation temperatures for Type V mineralization indicate ore deposition took place between 180 and 220 degrees °C, thus sulphur from either Types I, II or IV mineralization could account for the  $\delta^{34}\text{S}$  values in Type V mineral deposits. In addition, it is possible that Type I mineralization could have been the source of sulphur for Types II and IV mineral deposits.

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