IMPLICATIONS FOR VMS PROPECTIVITY IN THE FLIN FLON BLOCK FROM SULPHIDE STUDIES AND MAPPING OF PALEO-HYDROTHERMAL CORRIDORS

[1]Ames, D.E., [2]Kjarsgaard, I.M. and [1] Taylor, B.
[1]Geological Survey of Canada,
[2]14 Scotia Place Ottawa

Geological Survey of Canada

INTRODUCTION

Mineralogical, chemical and isotopic studies of the sulphide orebodies and hangingwall strata to the five Flin Flon block VMS deposits are used to constrain ore deposition and develop a model for detecting buried mineralization. Here we report an extensive suite of major and trace elements for the precious metal-bearing deposits, define key mineral and chemical vectors, their host minerals and illustrate the remobilization of elements within hydrothermal corridors in the hanging-wall mafic volcanic strata.

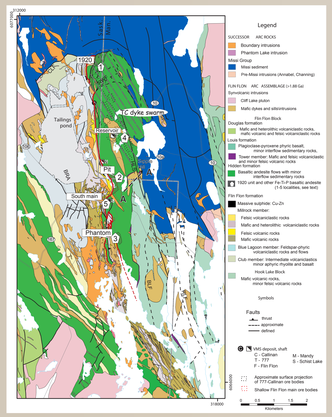

Figure 1: General geology and sample location map of the Flin Flon mining camp (modified from Simard et al., 2010). The distribution of mafic tuffaceous sedimentary rocks in the Flin Flon and Louis Formations and the five Fe-Ti-P basalt occurrences in the Hidden Formation are shown. Sulphide deposits are situated proximal to felsic volcanic centres near the top of the Flin Flon Formation and buried by the Hidden Formation basaltic lavas (contact thick red line). Generalized, vertically projected outlines of the principal VMS bodies (Callinan, 777 and Main Flin Flon) are indicated by dashed lines, A-A' South Main to Sipple corridor.

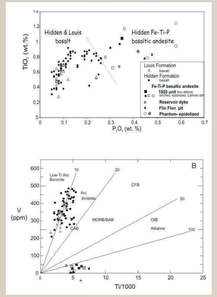

Figure 2: Chemical plots for the mafic volcanic rocks above the Flin Flon, 777 and Callinan VMS deposits. A. TiO2 vs. P2O5 plot for the hangingwall mafic volcanic rocks in Flin Flon showing the more highly fractionated Fe-Ti-P basaltic andesite in the Hidden Formation relative to the dominant basaltic compositions of the Hidden and Louis Formations. B. Classification plot V vs. Ti/1000 (Shervais, 1982) for mafic volcanic rocks in the hanging wall to the Flin Flon VMS deposits. Trend lines of constant Ti/V ratios=10, 20, 50 and 100 are shown and approximate tectonic settings. The majority of the Hidden and Louis Formation lavas are arc tholeiittes whereas the basaltic andesites have distinctive high Ti/V ratios >100.

Geochemical classification readily identified Fe-Ti-P basaltic andesite in the lower metamorphic grade rocks south of the Railway fault (Fig 2). Fe-Ti-P basaltic andesites are discontinuous over a 6 km strike length shown by the 1920 Flin Flon Pit and Phantom occurrences and dykes in the Reservoir and South Main localities (Fig. 1). South of the RWF stilpnomelane is the key Fe-rich mineral in these basaltic andesites whereas, to the north, the presence of asicular tschermakitic hornebleinde (Fig 10) readily distinguishes the 1920 unit in the field.

ORE MINERALOGY AND MINERAL CHEMISTRY

The Flin Flon massive sulphide ore has not been studied in over 60 years in a comprehensive mineralogical study (Table 2). Applied mineralogy studies were undertaken at the Callinan deposit in the 1980's (Healy and Petruk, 1990).

Detailed sulphide mineralogy of over 50 ore samples representative of the Flin Flon-777-Callinan deposits and 25 samples from the Schist and Mandy deposits was completed. The metamorphosed mineral assemblage of the Flin Flon VMS system contains over 30 minerals, with the major components comprising sphalerite, chalcopyrite, magnetite and pyrite and the trace minerals being dominantly antimony-bearing (Table 3). The Schist and Mandy deposit ore samples are severely deformed mylonites with S-C fabrics (Fig. 4).

Table 2: Previous comprehensive ore mineralogy studies, Flin Flon VMS deposits

Deposit	Ore minerals	Reference
Flin Flon	11	Brownell and Kinkel, 1935
	14	HBED staff and Brodkewitz, 1948
Callinan	11	Healy and Petruk, 1988, 1990
Schist	7	HBED staff, 1957
Mandy	5	Alcock, 1922

Table 3: Sulfide mineralogy of the Flin Flon VMS system (Flin Flon- Triple 7-Callinan and Schist-Mandy deposits)

Major Minerals
Magnetite
Pyrrhotite
Chalcopyrite
Sphalerite
Pyrite

Minor Minerals
Cubanite $CuFe_2S_3$
Arsenopyrite Fe(Co)AsS
Ag-chalcopyrite $Ag-CuFe_2S_3$
Tetrahedrite $(Cu,Fe)_{12}Sb_4S_{13}$
Galena Pb:S

Flin Flon-777-Callinan
28 Ore minerals, *only in FFC*

Schist-Mandy
18 Ore minerals, *only in SM*

Trace Minerals

Altaite	*PbTe*
Rucklidgeite	*$(Bi,Pb)_3Te_4$*
Boulangerite	*$Pb_5Sb_4S_{11}$*
Clausthalite	*PbSe*
Hessite	*Ag_2Te*
Sylvanite	*$(Au,Ag)_2Te_4$*
Gold	*Au (Ag)*
Altaigentum	*$(Ag,Au)_2Sb$*
Freibergite	*$(Ag,Cu,Fe)_{12}Sb_4S_{13}$*
Antimony	*Sb*
Electrum	(Ag,Au,Sb,Hg)
Acanthite	Ag_2S
Dyscrasite	Ag_3Sb
Gudmundite	FeSbS
Ullmannite	NiSbS
Cobaltite	CoAsS
Maltagamite	Co_2Te
Willyamite	CoSbS
Vaesite	NiS_2
Breithauptite	NiSb

Important trace element associations for vectoring

Au-bearing minerals

Native gold (Au,Ag)
Electrum (Ag,Au,Sb,Hg)
Sylvanite $(Au,Ag)_2$ Te_4
Allargentum $(Ag,Au)_2$ Sb

Ag-bearing minerals

Ag-chalcopyrite Ag-$CuFeS_2$
Freibergite $(Ag,Cu,Fe)_{12}Sb_4S_{13}$
Acanthite Ag_2S
Dyscrasite Ag_3Sb
Hessite Ag_2Te

Co-As-bearing minerals

Arsenopyrite Fe(Co)AsS
Cobaltite CoAsS
Mattagamite Co_2Te

Sb- bearing minerals

Tetrahedrite $(Cu,Fe)_{12}Sb_4S_{13}$
Native antimony Sb
Valentinite Sb_2O_3
Gudmundite FeSbS
Ullmannite NiSbS
Breithauptite NiSb
Boulangerite $Pb_5Sb_4S_{11}$

Pb-bearing tellerides and selenides

Altaite PbTe
Rucklidgeite $(Bi,Pb)_3Te_4$
Clausthalite PbSe

Antimony (analyzed by ICP-MS) is a key exploration vector for these Flin Flon VMS deposits

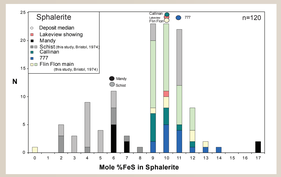

Figure 5: Sphalerite compositions of five Flin Flon block VMS deposits and the Lakeview showing. Mineral chemistry data from 120 analyses from this study including 68 analyses from the Flin Flon main deposit and 33 analyses from the Schist deposit from Bristol (1974).

Table 4: Tetrahedrite-freibergite compositions in Flin Flon block VMS deposits

	Freibergite		Tetrahedrite		
	777 n=3	777 n=13	Callinan n=3	Mandy n=8	Schist n=14
Fe	5.30	6.58	6.27	5.60	5.93
Cu	22.56	32.13	25.20	25.63	28.30
Zn	0.31	0.94	0.92	1.43	1.97
As	0.10	0.27	0.20	1.32	0.40
Ag	26.37	7.13	15.82	16.56	11.33
Sb	19.29	28.00	27.14	26.06	27.64
Bi	0.06	0.12	0.02	0.20	0.09
S	20.83	23.63	23.23	23.43	23.96

Tetrahedrite has long been known as a minor component of the Flin Flon ore assemblage (Brownell and Kinkell, 1935), identified in the Callinan ores (Healy and Petruk, 1990) and now the 777, Schist and Mandy deposits (Tables 2-4). This antimony rich (21.2-32.9 wt%) mineral found in all five deposits is generally Ag-rich (1.7-18.7 wt. %) and probably accounts for most of the Sb and Ag in the ore. Tetrahedrite hosts Zn (1-3 wt%) in most deposits, Ni (2.28 wt %) at 777 and rare arsenic (<4.6 wt%) at the Mandy deposit.

The sphalerites from the five Flin Flon block deposits display a broad range of Fe contents whose average deposit compositions form two distinct clusters reflecting the deposits in the western FF block and eastern FF block. The Lakeview showing sphalerite compositions compare favourably with the western FF block orebodies and not Schist and Mandy (Fig. 5).

HIGHLIGHTS OF MINERAL-CHEMICAL AND OXYGEN ISOTOPE MAPPING OF PALEO-HYDROTHERMAL CORRIDORS

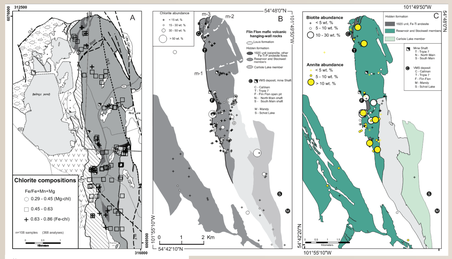

Figure 8: Chlorite and biotite distribution and mineral chemistry of volcanic sedimentary rocks and alteration in the hanging wall rocks of the Flin Flon area.

A) Distribution of Fe and Mg-rich chlorite in the Flin Flon main camp determined by microprobe analyses. Fe-rich chlorite is present in the mafic rocks above the three deposits associated with mafic tuffs proximal to Fe-Ti-P basalt including from north to south, the 1920 unit and the Reservoir, South Main and Phantom Lake "Icelandite" occurrences. Fe-rich chlorite occurs in the Millrock member at South Main and Phantom Lake.

B) Chlorite mineral abundances were determined by Reitveld analyses of x-ray diffraction patterns of volcanic and altered rocks in the hanging wall sequences. Abundant chlorite is, present in the mafic rocks south of the open pit (F), locally abundant in the Carlisle Lake member above the Schist and Mandy VMS deposits and negligible in the southwestern exposure of the Hidden Formation. Approximate positions of previously mapped metamorphic isograds are shown M1- hornblendein, M2- actinolite-out, M3- epidote + chlorite-out (Digel and Gordon, 1995).

C) Distribution of biotite in the Flin Flon camp. The sporadic and irregular occurrence of biotite throughout the area emphasizes the complexities of hydrothermal gradients and drawing metamorphic biotite-in isograds in VMS hosting terranes. The abundance of biotite in the hanging wall strata is generally < 5 wt % throughout the Flin Flon camp with anomalous abundances and Fe-rich mineral compositions restricted to the hanging wall above the 3 Flin Flon deposits. Anomalously high amounts of biotite (10-30 wt. %) occurs locally above the Flin Flon main mine and locally anomalous (10-15 wt. %) annite above the Callinan and Flin Flon deposits and south near Phantom Lake (Ames et al., 2011).

D) Histogram of (Fe/Fe+Mg) in biotite and chlorite showing similar trends between the two phyllosilicate minerals in the Flin Flon camp. Flin Flon chlorite compositions are compared to the dominant chlorite compositions in the Paleoproterozoic Kristenberg area of the Skellefte district and the Archean Noranda camp (Hannington et al., 2003).

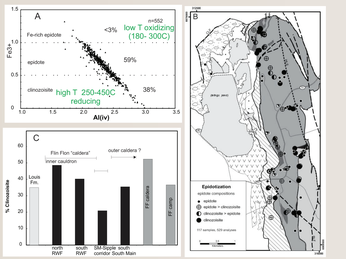

Figure 9: Epidote mineral compositions and distribution stratigraphically above the Flin Flon VMS deposits.

A) Bimodal plot of Fe +3 versus Al (vi) in epidote in the hanging-wall strata above the Flin Flon-T-C VMS deposits. Generally, the Fe-Al substitution in epidote is a function of temperature and redox conditions with Fe-poor, Al-rich clinozoisite compositions indicative of higher temperature and reduced conditions and Fe-rich, Al-poor epidote indicative of low temperature, oxidizing conditions (Gillis and Thompson, 1994).

B) Distribution of epidote-clinozoisite based on microprobe analyses and reitveld modelling of XRD. Epidote of clinozoisite composition distinguish zones of anomalous magmatic activity in the FTC dyke swarm, synvolcanic fault in the Phantom area as well as highlighting peperitic tuffaceous rocks at the base of the Hidden and Louis Formations.

C) Amount of clinozoisite in the Flin Flon block. Fe-poor clinozoisite is most abundant in the high heat flow corridor north of the Railway Fault. The relative amount of clinozoisite is similar in the cauldron south of RWFF, out of the cauldron and at the base of the Louis Formation (35-40%) however epidote dominates above the proposed cauldron wall in the South Main- Sipple Hill corridor (~20%).

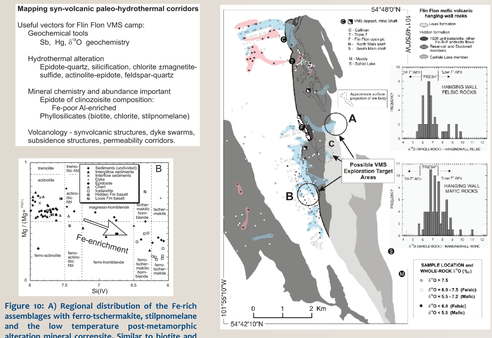

Figure 11: Simplified geologic map of principal hanging wall lithologies, with locations and generalized whole-rock oxygen isotope compositions of samples from both the hanging wall and footwall with respect to the mine horizon (heavy line). Inset histogram plots illustrate the distributions of whole-rock d18O values for felsic and mafic rocks from the hanging wall (low- and high-temperature and "fresh" rock labels are discussed in the text). The approximate location of slightly generalized, vertically projected outlines of the principal VMS bodies (Callinan, 777 and Main Flin Flon) are indicated by dashed lines, in addition to the location of an area suggested for possible future exploration .

Large hydrothermal system at predominantly low-temperatures (Zn 250°C) punctuated by higher temperature short-lived pulses. In the hangingwall, the largest zone of high-temperature alteration is situated 1100 m above the 777 deposit.

SULPHIDE STUDIES OF THE FLIN FLON BLOCK VMS DEPOSITS

Table 1: Major and trace element compositions of sulphides from five Flin Flon block VMS deposits

	Fe T %	Cu %	Zn %	Pb %	Au ppb	Ag ppb	S T %	Si2O %	Al2O3 %	MgO %	CaO %	Na2O %	K2O %	CO2 T %	REE T ppm
Western FF block															
Flin Flon (13)	32.42	5.47	10.85	0.80	27287	62	39.45	4.82	0.51	0.71	1.09	0.03	0.02	1.77	8.76
777 (10)	26.90	4.71	15.22	0.57	4064	102	34.06	8.38	1.96	0.75	1.36	0.40	0.26	1.51	10.99
Callinan (10)	31.22	6.14	9.87	0.20	5377	113	36.49	7.24	1.38	0.89	2.47	0.25	0.21	2.25	8.19
Eastern FF block															
Schist Lake (11)	28.58	2.84	14.91	0.81	3501	118	37.99	7.91	0.58	0.36	0.55	0.01	0.01	0.95	2.40
Mandy (13)	26.84	16.21	12.70	0.32	3625	55	34.48	2.33	0.87	0.50	0.37	0.00	0.00	0.58	8.70

	As ppm	Ba ppm	Bi ppm	Cd ppm	Co ppm	Cr ppm	Ga ppm	Hg ppm	In ppm	Mo ppm	Ni ppm	Sb ppm	Se ppm	Sn ppm	Te ppm
Western FF block															
Flin Flon (13)	2486	14	4	300	243	44	12	8	6	13	16	110	124	11	44
777 (10)	481	24	2	372	195	37	21	4	2	11	18	158	90	16	20
Callinan (10)	4355	618	2	260	432	36	8	7	3	21	6	54	102	6	44
Eastern FF block															
Schist Lake (11)	5140	4	1	309	273	39	22	13	2	4	6	285	145	15	20
Mandy (13)	9304	0	16	291	746	32	12	8	3	4	6	144	233	7	3

Figure 4: Tectonized massive sulfide ore types from the Schist and Mandy VMS deposits, eastern Flin Flon block.

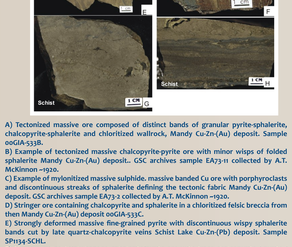

Figure 3: Typical metamorphosed ore types from the Flin Flon- 777-Callinan orebodies, western Flin Flon block.

A) Chalcopyrite-rich stringer ore containing chlorite-chalcopyrite-pyrite, minor biotite porphyroblasts, Kfeldspar and trace pyrrhotite - magnetite - cubanite - sphalerite and bierthierine. Sample 07AVFF54.

B) Massive chalcopyrite - pyrrhotite ore consisting of quartz - pyrrhotite - chalcopyrite, minor magnetite, pyrite and trace cubanite - sphaleriteserite - carbonate and Fe-rich minerals berthierine and stilpnomelane. Sample 07AVFF63.

C) Massive pyrite-sphalerite banded ore with minor chalcopyrite and pyrrhotite intergrown with sphalerite interstitially to pyrite. Ore contains trace arsenopyrite - magnetite - carbonate - stilpnomelane and chlorite. Sample 06AV-251.

D) Fine grained massive pyrite-sphaleritechalcopyrite ore from the 777 deposit, sample 06AV-254. Typical mineral assemblages include massive and granular pyrite, minor sphalerite - pyrrhotite - chalcopyrite and trace cubanite - galena-tetrahedrite-arsenopyrite-antimony and stilpnomelane - sericite or chlorite.

E) Fragmental ore, altered quartz phyric rhyolite fragments with semi-massive chalcopyrite/sphalerite in matrix, from 1600l- #5lens, Callinan Cu-Zn-(Pb, Au) deposit. Sample 00GJA-CALLI-531.2A1.

F) Semi-massive pyrite - chalcopyrite ore hosted in biotite - rich, rhyolite breccia. Fragmental ore sample 06AV-504.

G) Semi-massive pyrite - sphalerite - chalcopyrite ore from the Callinan deposit, sample 06AV- 239, drillhole 4Q- 43, 2413 ft.

H) Hand sample of massive sulphide from discovery outcrop (Figure 7A), Flin Flon Cu-Zn- (Pb, Au) deposit collected by A.T. McKinnon in 1920. Chalcopyrite - pyrite/Mg-chlorite fragmental ore with trace tellurides, and pink silliceous, fault gouge. Sample 00GJA-FL-10088_3 (Archive no. GSC-EA-18.3).

A) Tectonized massive ore composed of distinct bands of granular pyrite-sphalerite, chalcopyrite-sphalerite and chloritized wallrock, Mandy Cu-Zn-(Au) deposit. Sample 00GJA-533B.

B) Example of tectonized massive chalcopyrite-pyrite ore with minor wisps of folded sphalerite Mandy Cu-Zn-(Au) deposit.. GSC archives sample EA73-11 collected by A.T. McKinnon –1920.

C) Example of mylonitized massive sulphide- massive banded Cu ore with porphyroclasts and discontinuous streaks of sphalerite defining the tectonic fabric Mandy Cu-Zn-(Au) deposit. GSC archives sample EA73-23 collected by A.T. McKinnon –1920.

D) Stringer ore containing chalcopyrite and sphalerite in a chloritized felsic breccia from then Mandy Cu-Zn-(Au) deposit 00GJA-533C.

E) Strongly deformed massive fine-grained pyrite with discontinuous wispy sphalerite bands cut by late quartz-chalcopyrite veins Schist Lake Cu-Zn-(Pb) deposit. Sample SP1134-SCHL.

F) Massive milled thinly-banded sphalerite/pyrite ore with trace chalcopyrite / pyrite / galena Schist Lake Cu-Zn-(Pb) deposit. Sheared and transposed, Sample SP1138-SCHL.

G) Massive pyrite-sphalerite ore with quartzose augens and chalcopyrite in the pressure shadows, Schist Lake Cu-Zn-(Pb) deposit. Sample 06AV-534.

H) Tectonically banded sphalerite-pyrite ore in sharp contact with massive pyrite ore, Schist Lake Cu-Zn-(Pb) deposit. Sample 06AV-536.

GOLD IN THE 5 FLIN FLON BLOCK VMS DEPOSITS

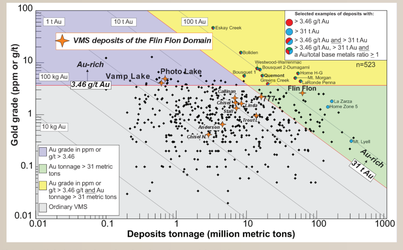

Figure 6: Global VMS deposits showing the Au-rich VMS deposits of the Flin Flon domain based on tonnage (Flin Flon-777,) or average gold grade (Vamp, Photo Lake), Lalor not shown although preliminary calculations suggest Au> 1 Moz (modified after Mercier-Langevin et al., 2011).

Mineral chemistry of gold-electrum in five VMS deposits

Gold was found in the Flin Flon deposiiton the 390mL pyrite-pyrrhotite ore, as well as different orebodies in the 777 deposit (Au90 , Ag10) with little to no mercury or antimony impurities. Electrum in the Schist and Mandy deposits are intermediate in Ag:Au ratios and also have few deleterious trace elements whereas Sb-Hg bearing electrum (Ag75, Au20) is common in the Callinan and 777 deposits.

Mineralogic repository of mercury in the Flin Flon ores: Separate Hg-minerals in the ores have not been found however gold and electrum contain 0.9 - 3.9% Hg. Mercury in sphalerite is very low in the five VMS deposits (<0.1 % Hg).

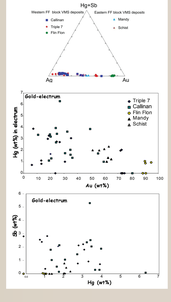

Figure 7: Textural features of gold- bearing assemblages in the three Western Flin Flon block VMS deposits.

A) Gold intergrown with sylvanite (sy) interstitial to coarse pyrite (py) with pyrrhotite (po) and altered pyrite (upper right). Flin Flon main deposit 390 level, sample FL D87C (3a), long edge 0.25 mm. Note the stronger yellow tint in the colour of gold compared to electrum in B and C reflecting the higher Ag content in electrum.

B) Electrum (el) and allargentum (al) in pyrrhotite intergrown with magnetite at the 777 deposit. Sample 06AV-254C (5), long edge ca. 0.15 mm.

C) Electrum (el) in galena (gn) which are interstitial to coarse pyrite porphyroblasts (py) in sphalerite (sp). Sample 06AV-188A), 777 deposit.

D) Two gold grains at either side of pyrite (py) in chalcopyrite intergrown with sphalerite (py), hessite (he) and rucklidgeite ru=(Bi,Pb)3Te4). Sample TSEV 534-3B, long edge 0.12 mm 777 deposit.

E) Electrum (el) intergrown unidentified Ag-Au-Sb mineral (arrow), willyamite (wi), pyrite (py), pyrrhotite (po) in chalcopyrite (cpy). Long edge of photo 0.20 mm, reflected light. Sample 00GJA-531.1A1, Callinan deposit.

F) Pyrrhotite (po) mixed with gold that occurs as turquoise tarnished inclusions, veining pyrite (py) in chalcopyrite (cpy). Long edge of photo is 0.26 mm; reflected light. Sample 00GJA-531.1A1, Callinan deposit.

G) Acanthite (ac) grey with iridescent colours with granular pyrite (py), sphalerite (sp) and gangue (black) in chalcopyrite (yellow). Acicular gangue mineral is stilpnomelane. Long edge of photo is 1.34 mm (reflected light). Sample 00GJA-531.1A1, Callinan deposit.

H) Electrum (golden) with willyamite (light blue) interstitial to pyrite (cream) intergrown with sphalerite (medium grey) and gangue (dark grey) in chalcopyrite. Long edge of photo is 0.26 mm (reflected light). Sample 00GJA-531.1A1, Callinan deposit.

Recommended Citation

Ames, D.E., Kjarsgaard, I.M., and Taylor, B., 2013. Implications for VMS propectivity in the Flin Flon block from sulphide studies and mapping of paleo-hydrothermal corridors: Geological Survey of Canada, Open File 7328, 1 poster. doi:10.4095/293336

Available from

This publication is available for free download through GEOSCAN (http://geoscan.ess.nrcan.gc.ca/). doi:10.4095/293336

South of the RWF, ~20% stilpnomelane is the key Fe-rich mineral whereas to the north, the presence of asicular tschermakitic hornebleinde readily distinguishes the 1920 unit.

A sulphide ore geochemical database of the Flin Flon belt deposits and mineralogical databases of the metamorphic assemblages of the Hidden and Louis Formations may be found in companion publications (Ames et al., 2011; Jonasson et al., 2009).

Detailed discussion of the study is in a paper entitled "Hanging wall vectoring for buried VMS deposits, Paleoproterozoic Flin Flon Mining Camp, Manitoba, Canada" to be published in a coming special issue of Economic Geology.

References

Alcock, F.J., 1922. Flin Flon map area; Canada Department of Mines, Geological Survey, 1922 Summary report, p. 1-36.

Ames, D.E., Kjarsgaard, I.M., and Stirling J., 2011. Flin Flon mineralogy database of metamorphic and alteration minerals associated with the Flin Flon-777- Callinan volcanogenic massive sulfide deposits, Trans-Hudson Orogen: Electron microprobe mineral chemistry and Reitveld X-ray Diffraction from the Flin Flon VMS camp, Manitoba, Canada; Geological Survey of Canada Open File 6548.

Bristol, C.C., 1974. Sphalerite geobarometry of some metamorphosed orebodies in the Flin Flon and Snow Lake districts, Manitoba; Canadian Mineralogist, v. 12, p. 308-315.

Brownell, G.M., and Kinkel, A.R., 1935. The Flin Flon mine, geology and paragenesis of the ore deposit; Transactions Can. Institute of Mining and Metallurgy, v. 38, p. 261-286.

Digel, S., and Gordon, T. M., 1995. Phase relations in metabasites and pressure-temperature conditions at the prehite-pumpellyite to greenschist facies transition, Flin Flon Manitoba, Canada: in Schiffman, P., and Day, H.W., eds., Low Grade Metamorphism of Mafic Rocks: Geological Society of America Special Paper 296, p. 67-80.

Gillis, K.M. and Thompson, G. 1993. Metabasalts from the Mid-Atlantic Ridge: New insights into hydrothermal systems in slow-spreading crust; Contributions to Mineralogy and Petrology, v. 113, p. 502-523.

Hannington, M.D., Santaguida, F., Kjarsgaard, I.M. and Cathles, L. M., 2003a. Regional-scale hydrothermal alteration in the Central Blake River Group, western Abitibi subprovince, Canada: Implications for VMS prospectivity: Mineralium Deposita, v. 38, p. 393-422

Hannington, M.D., Kjarsgaard, I.M., Galley, A. G. and Taylor, B., 2003b. Mineral-chemical studies of metamorphosed hydrothermal alteration in the Kristenebery volcanogenic massive sulfide district, Sweden; Mineralium Deposita, v. 38, p. 423-442.

Jonasson, I.R., Ames, D.E. and Galley, A.G., 2009. Sulfide ore geochemistry database for volcanogenic massive sulfide deposits of the Paleoproterozoic Flin Flon belt; Geological Survey of Canada Open File 5433, CD-ROM.

Mercier-Langevin, P., Dubé, B., Hannington, M. D., and Bécu V., 2011. The gold content of volcanogenic massive sulfide deposits: Mineralium Deposita, v. 46, p. 509-539.

Shervais, J.W., 1982. Ti-V plots and the petrogenesis of modern and ophiolitic lavas; Earth and Planetary Science Letters, v. 59, p. 101-118.

Simard, R.L., MacLachlan, K., Gibson, H.L., DeWolfe, Y.M., Devine, C., Kremer, P.D., Lafrance, B., Ames, D.E., Syme, E.C., Bailes, A.H., Bailey, K., Pehrsson, S., Price, D., Cole, E., Lewis, D. and Galley, A.G. 2010. Geology of the Flin Flon area, Manitoba and Saskatchewan (part of NTS 63K10, 11); Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Geoscientific Map MAP2009-1 and Saskatchewan Ministry of Energy and Resources, Geoscience Map 200- 1.

OPEN FILE DOSSIER PUBLIC 7328 2013