Volcanic-Associated Massive Sulphide Deposits

for

Billiken Management Services

by

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Volcanic-associated Massive Sulphide (VMS) deposits constitute one of the world's significant sources of copper, zinc, lead, silver and gold as well was a range of by-products including tin, cadmium, antimony and bismuth. VMS deposits yielded 32.8% of the copper, 29.4% of the lead, 56.3% of the zinc, 3.6% of the gold, and 30.4% of the silver produced in Canada in 1988. Figure 1 and Table 1 illustrates the major global VMS districts accompanied by total and average tonnages; deposits are classified using five host rock compositions: mafic, bimodal-mafic, mafic-siliciclastic, bimodal-felsic, and bimodal-siliciclastic (Barrie and Hannington, 1999).

Volcanic massive sulphide (VMS) deposits occur in submarine volcanic rocks of all ages and in a variety of tectonic setttings, from currently forming deposits in modern spreading arc and back-arc regions to deposits in the pre-34Ma volcanic strata of the Pilbara Block in Western Australia (Franklin et al., 1993). An association with at least minimal sedimentary rock quantities exists. Deposits comprise two parts: a) massive sulphide ore formed either on or immediately below the seafloor and b) a stringer zone that contains less important vein and disseminated ore which immediately underlies the massive sulphide ore. The stringer ore is generally within an intensely metasomatized alteration pipe. Most deposits comprise ~90% iron sulphide (mainly pyrite) (Franklin et al., 1993).

VMS deposits vary from copper zinc and lead bearing, strata bound to stratiform lenses of solid to near solid sulphide in submarine volcanic rocks of typically intermediate to felsic composition (http://www.gov.mb.ca et al.). Many extensive VMS reviews are available, these include Franklin et al. (1981); (1993); Klau and Large, (1980); Lydon, (1984); and Franklin, (1986). Likewise, various classification systems have been proposed to include those based on depositional setting, host-rock compositions and ore compositions (Franklin et al., 1999).

Deposits are categorized into two groups:

1. *Cu-Zn;* barite is absent from the majority of these types of deposits. Deposits are concordant to semi-concordant, massive iron-sulphide-rich bodies are commonly underlain by vein systems comprising stringer ore, within volcanic sequences that consist of mafic volcanic rocks with locally significant felsic and/or sedimentary rocks (Franklin et al., 1999). Some examples include Precambrian deposits like the Noranda massive sulphide district (Mobrum, Vauze, Amulet, Millenbach and Norbec deposits), Mattagami Lake, Timmins, Abitibi belt, Mattabi Mine, Sturgeon Lake area, Confederation Lake area, Geco, Willroy, Nama Creek and Willecho deposits of the Manitouwadge area, Ontario and Coronation mine near Flin Flon, Manitoba (Franklin et al., 1981). Others include Cyprus and Oman ophiolite sequences and the Besshi deposits of Shikoku Island, Japan (Franklin et al., 1999). The average sizes and grades of 142 Canadian deposits are 5.3Mt (1.241Mt) hosting 1.95% (1.60%) Cu; 4.23% (3.07%) Zn; 0.09% (0.01%) Pb; 0.8 g/t (0.6 g/t) Au; and 19.0 g/t (8.0 g/t) Ag. (Franklin et al., 1981).

2. *Zn-Pb-Cu;* oxide facies iron formation is associated with this group. Barite is abundant in some deposits concentrated where Cu/(Zn+Pb) ratios are lowest. Examples include the Bathurst district, New Brunswick and the Kuroko deposits of Japan. Other deposits include Buttle Lake, B.C., Buchans, Newfoundland; Hokuroku Basin of Japan; the Iberian pyrite belt, Spain; Neves Corvo, Portugal; and the Tasman geosyncline, Australia. Deposits are tabular, concordant, massive pyritic bodies, typically underlain by less prominent stringer ore, in felsic volcanic sequences. The footwall may consist of a significant amount of sedimentary rocks.

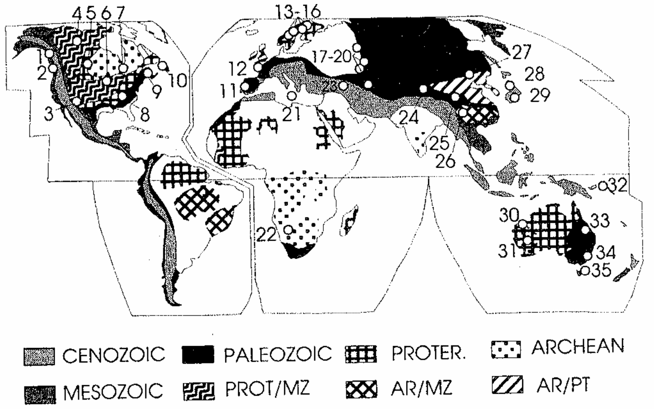

FIG. 1. Location of major VMS districts of the world, with total tonnages in million tonnes (MT). M: Mafic; B-M: Bimodal Mafic; M-S: Mafic Siliciclastic; B-F: Bimodal-Felsic; B-S: Bimodal-Siliciclastic.

1 Windy Craggy, NW British Columbia: 297 MT, Mesozoic M-S;
2 N. Cordillera, Canada (including Eskay Creek): 100 MT, L. Paleozoic, M, B-M, B-F;
3 Jerome, Arizona, USA: 30 MT, E. Proterozoic, B-M;
4 Slave Province, Canada: 50 MT, L. Archean, B-M, B-F;
5 Flin Flon-Snow Lake, Man. and Sask., Canada: 160 MT, E. Proterozoic, B-M, M;
6 Ladysmith-Rhinelander, Wisconsin, USA: 80 MT, E. Proterozoic, B-M;
7 Abitibi-Superior, Canada (incl. Kidd Creek): 500 MT, L. Archean, B-M, B-F.
8 Ducktown, Tennessee, USA: 180 MT, L. Proterozoic, M-S;
9 Bathurst, New Brunswick, Canada: 250 MT, E. Paleozoic, B-S;
10 Buchans-Victoria Lake, Newfoundland: 20 MT, E. Paleozoic, B-F;
11 Iberian Pyrite Belt, Portugal and Spain: 1000+ MT, E. Paleozoic, B-S;
12 Rouez, Bretagne, France: 100 MT, M. Proterozoic, M-S;
13 Trondheim, Norway: 40 MT, E. Paleozoic, B-M, M-S, B-F;
14 Skellefte (including. Boliden), Sweden: 75 MT E. Proterozoic, B-M, B-F;
15 Rana-Grong-Sulitjelma, Sweden, Sweden: 80 MT, E. Paleozoic, B-M, M-S;
16 Outokumpu-Pyhasalmi, Finland: 60 Mt, E. Proterozoic, B-M, M-S;
17 Central Urals, Russia: 100+ MT, E. Paleozoic, B-F, B-M;
18 Buribai-southern Urals, Russia and Kazikstan: 100+MT, E. Paleozoic, B-F, B-M;
19 Turkey (including Murgul): 170 MT, Paleozoic and Mesozoic, B-M, B-F, M;
20 Zyryanowsk, Kazakstan: 500 MT, Paleozoic, B-F, B-M;
21 Troodos, Cyprus: 35 MT, Mesozoic, M;
22 Presika, Otjahasi, Matchless, S. Africa-Namibia: 140 MT, M. Proterozoic, M-S;
23 Gai-Uchali, Kazakstan: 100+ MT, Paleozoic, B-F, B-M;
24 Yidan, China: ?, Mesozoic, B-F;
25 Qilian, China: ?, E. Paleozoic, B-M, B-F;
26 Kang Dian, China: 500 MT, L. Proterozoic, B-M;
27 Hongtouchan, China: ?, L. Archean, B-M;
28 Hokuroku, Japan: 100 MT, Miocene, B-F;
29 Besshi, Japan: 230 MT, L. Paleozoic and Mesozoic, M-S;
30 Big Stubby, Mons Cupri, Whim Creek, W. Australia: 15 MT, M.+L. Archean, B-F;
31 Scuddles-Golden Grove, W. Australia: 45 MT, L. Archean, B-M;
32 Philippines: 60 MT, Cenozoic, B-F, M, B-S;
33 Mt. Morgan, Queensland, Australia: 50 MT, E. Paleozoic, B-M;
34 Benambra-Woodlawn, Victoria-NSW, Australia: 35 MT, E. Paleozoic, B-F;
35 Mt. Read, Tasmania, Australia: 150 MT, E. Paleozoic, B-F.

Figure 1: Location of Major VMS Districts Globally
(after Barrie and Hannington, 1999)

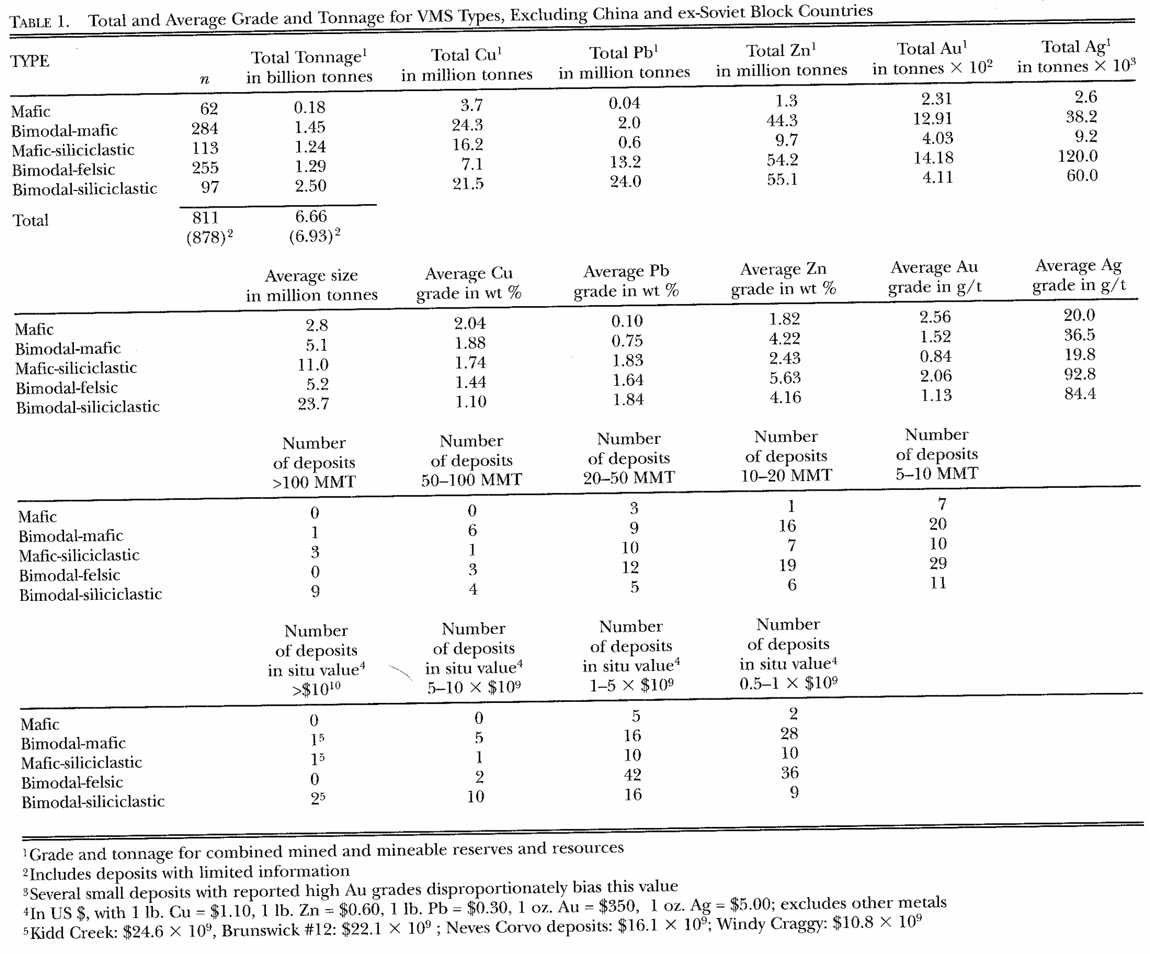

TABLE 1. Total and Average Grade and Tonnage for VMS Types, Excluding China and ex-Soviet Block Countries

TYPE	n	Total Tonnage[1] in billion tonnes	Total Cu[1] in million tonnes	Total Pb[1] in million tonnes	Total Zn[1] in million tonnes	Total Au[1] in tonnes $\times 10^2$	Total Ag[1] in tonnes $\times 10^3$
Mafic	62	0.18	3.7	0.04	1.3	2.31	2.6
Bimodal-mafic	284	1.45	24.3	2.0	44.3	12.91	38.2
Mafic-siliciclastic	113	1.24	16.2	0.6	9.7	4.03	9.2
Bimodal-felsic	255	1.29	7.1	13.2	54.2	14.18	120.0
Bimodal-siliciclastic	97	2.50	21.5	24.0	55.1	4.11	60.0
Total	811 (878)[2]	6.66 (6.93)[2]					

	Average size in million tonnes	Average Cu grade in wt %	Average Pb grade in wt %	Average Zn grade in wt %	Average Au grade in g/t	Average Ag grade in g/t
Mafic	2.8	2.04	0.10	1.82	2.56	20.0
Bimodal-mafic	5.1	1.88	0.75	4.22	1.52	36.5
Mafic-siliciclastic	11.0	1.74	1.83	2.43	0.84	19.8
Bimodal-felsic	5.2	1.44	1.64	5.63	2.06	92.8
Bimodal-siliciclastic	23.7	1.10	1.84	4.16	1.13	84.4

	Number of deposits >100 MMT	Number of deposits 50–100 MMT	Number of deposits 20–50 MMT	Number of deposits 10–20 MMT	Number of deposits 5–10 MMT
Mafic	0	0	3	1	7
Bimodal-mafic	1	6	9	16	20
Mafic-siliciclastic	3	1	10	7	10
Bimodal-felsic	0	3	12	19	29
Bimodal-siliciclastic	9	4	5	6	11

	Number of deposits in situ value[4] >$\$10^{10}$	Number of deposits in situ value[4] 5–10 × $\$10^9$	Number of deposits in situ value[4] 1–5 × $\$10^9$	Number of deposits in situ value[4] 0.5–1 × $\$10^9$
Mafic	0	0	5	2
Bimodal-mafic	1[5]	5	16	28
Mafic-siliciclastic	1[5]	1	10	10
Bimodal-felsic	0	2	42	36
Bimodal-siliciclastic	2[5]	10	16	9

[1] Grade and tonnage for combined mined and mineable reserves and resources

[2] Includes deposits with limited information

[3] Several small deposits with reported high Au grades disproportionately bias this value

[4] In US \$, with 1 lb. Cu = \$1.10, 1 lb. Zn = \$0.60, 1 lb. Pb = \$0.30, 1 oz. Au = \$350, 1 oz. Ag = \$5.00; excludes other metals

[5] Kidd Creek: \$24.6 × 10^9, Brunswick #12: \$22.1 × 10^9 ; Neves Corvo deposits: \$16.1 × 10^9; Windy Craggy: \$10.8 × 10^9

(after Barrie and Hannington, 1999)

The average sizes and grades of 92 Canadian deposits are 5.6Mt (1.177Mt) hosting 1.23% (1.01%) Cu; 3.60% (2.80%) Zn; 1.46% (0.97%) Pb; 2.0 g/t (0.5 g/t) Au; and 79.0 g/t (57.0 g/t) Ag. (Franklin et al., 1999).

The following VMS classifications are noted with these groups:

1. Noranda-type: Cu-Zn
2. Mattabi-type: Zn-Cu-(Ag)
3. Kuroko-type: Zn-Pb-Cu
4. Cyprus-type: Cu+-Zn
5. Besshi-type: Cu+Pb

Ores comprise > 60% sulphide, predominantly pyrite and/or pyrrhotite plus variable amounts of sphalerite, chalcopyrite or galena. The massive ore may be underlain by Cu-rich vein and disseminated sulphides (stringer zone) and intensely altered rocks of the alteration pipe (Franklin et al., 1981). Importantly, deposits are characterized by an internal metal zoning that generally decreases upward and/or outward in a Cu/(Cu+Zn+Pb) ratio especially in deposits such as Noranda and Kuroko deposits that occur above their feeder pipes. In deposits like the Besshi, Bathust and New Brunswick, the orebodies are tabular and possess (or not) an underlying stringer zone. Orebodies may experience reworking and in areas partial or entire displacement from their discharge site (Franklin et al., 1993).

The *Cu-Zn group* includes those in the Canadian Shield and Scandianavian Caledonides comprised of bimodal volcanic sequences; mafic volcanic rocks constitute 90% of the total volcanic volume, however the felsic volcanic rocks are commonly prominent close to the deposits. Ophiolite-associated Cu-Zn deposits like the Cyprus, Turkey, Newfoundland and Saudi Arabia, nevertheless, are at the contact between two pillowed mafic volcanic sequences (Franklin et al., 1981).

Zn-Pb-Cu group deposits are located in felsic volcanic stratigraphic settings like that of the Green Tuff belt of Japan and in Tasmania or by felsic volcanic and sedimentary strata such as at Bathurst, New Brunswick and the Iberian pyrite belt.

The alteration pipes beneath the *Cu-Zn deposits* possess a chloritic core and a sericitic outer zone whereas pipes beneath *Zn-Pb-Cu deposits* generally possess a sericite + quartz core and a chloritic outer zone. Beneath or enclosing the alteration pipes occurring directly under individual deposits are large, semiconformable, regional scale alteration zones that underlie deposits in the Precambarian Shield as well as in ophiolite terranes (Franklin et al., 1981).

Although VMS deposits were formed at or near the discharge sites of submarine hydrothermal systems, their genesis have divergent views. The source of ore constituents may be from: underlying rocks; contemporaneous magmas; or coeval seawater. The remaining constituents eminates from leaching of the majority of the metal and some of the sulfur, from the underlying rocks and the balance of the sulfur from the coeval seawater (Franklin et al., 1981). The ore solutions were mobilized by either a convective hydrothermal cell or by a mechanism similar to that of seismic pumping. The former model postulates the ore solution was predominantly coeval seawater whereas the latter model the ore solution was predominantly connate water that in turn originated generally as trapped seawater. Minor introduction of magmatic or meteroic water is possible in both models. Fractures and faults focussed ore fluid discharge sites associated with local extensional tectonic activity. Sulphide precipitation is caused by cooling and oxidation due to mixing of the ore-forming solution with ambient seawater, or by boiling of the ore solution as it approaches the sea floor (Franklin et al., 1981).

Pyrite is the predominant sulphide mineral in VMS deposits, pyrrhotite is dominant in others. Marcasite is a minor constituent either as intergrown with fine grained pyrite or as a pyrrhotite replacement product; it may act as a potential source of acidic drainage due to its high reactivity relative to pyrite. Additional important phases in VMS deposits include sphalerite and chalcopyrite accompanied by galena associated with felsic rock. Other ore minerals exist in minor quantities but constitute significant potential of heavy metal sources. The most common accessory sulfide and sulfosalt minerals include tennantite-tetrahedrite series, arsenopyrite and various lead-antimony-bismuth sulfosalt minerals especially in deposits associated with felsic rock. Deposits associated with mafic rock may contain cobalt sulphide or thiospinel. Magnetite exists in various deposits and barite may be extremely abundant in Kuroko-type VMS deposits where it forms an important ore facies. In some Kuroko deposits gypsum and anhydrite are abundant. Quartz and chlorite are the most common silicate gangue minerals that are accompanied by sericite in deposits associated with felsic rocks. Less abundant are other gangue phases except in VMS deposits that have been metamorphosed to greenschist or higher metamorphic grades. At these grades phases like anthophyllite and cordierite form from chloritic protoliths (Singer, Cox, 1986; after http://pubs.usgs.gov/et al.).

In VMS deposits the metal zoning is well developed. In the footwall and stringer ore zones the quantity of copper is elevated and the zinc content increases upward and outward from the core of hydrothermal upwelling zones. Lead, arsenic and antimony amounts are enriched upward and outward from the zinc-rich zones in felsic-associated deposits. In the majority of Kuroko-type deposits barite and silica are also enriched toward the stratigraphic tops and distal edges (Singer, Cox, 1986; after http://pubs.usgs.gov/et al.).

COPPER-ZINC GROUP (Franklin et al., 1993)

Geological Features:

Deposits of this group occur in two geological settings: 1) regions of mafic volcanic rocks such as Archean and Proterozoic greenstone belts and Recent and Phanerozoic spreading ridges and seamounts and 2) regions of subequal quantities of mafic volcanic rocks and sedimentary strata like that in Phanerozoic arc and back-arc sequences.

Geological Setting:

1) Volcanic dominated terranes:

Significant composition variation and associated alteration occurs and is related to the water depth under which the deposits form, either 1) >500m and 2) shallow-marine to subaerial environments (<500m depths).

Deposits in the first group are characterized by the Matagami Lake and Noranda districts, Quebec (Figure 2a), associated with massive to pillowed mafic flow sequences primarily. Felsic ash-flow tuff beds are common directly below the deposits although the amount of felsic rock in the footwall sequence may be minor like that of Flin Flon, Manitoba or comprise ≤ 30% like that of Noranda, Quebec. Felsic domes may enclose or immediately underlie the ore. The second group deposits are characterized by those close to Sturgeon Lake, Ontario that include mafic and felsic amygdaloidal and scoriaceous flows and pyroclastic rocks, volcanic breccia and epiclastic strata (Figure 2b). The footwall sequence is comprised of 30% felsic rocks. Both deposit types occur in the volcanic sequences that have subvolcanic intrusions close to their base; trondhjemitic intrusions predominate (ie. Noranda) (Franklin, 1993).

Those deposits that are actively forming occur within modern spreading ridges, seamounts and back-arc basins as two types: 1) sediment-free, basalt-dominated terranes: and 2) sediments. Deposits in volcanic regions are divided into two groups: 1) small deposits that form into ridge axes that are located in the active and early phases of volcanic formation like Jan de Fuca Ridge deposits and 2) larger deposits in larger volcanically evolved ridge crests that have prominent elongate volcanoes like the Mid-Atlantic ridge deposits.

Deposits associated with volcanic regions are located along bounding faults of narrow, central grabens formed on tops of main elongate and locally inactive volcanoes commonly 500m high; these deposits consist of inflated pillows.

Ophiolite sequence deposits may be forerunners of spreading-ridge or back-arc spreading associations. Examples include Cretaceous ophiolites of Cyprus and Oman, the Ordovician sequences of Newfoundland and Norway and the Jurassic Josephine sequence in Oregon that occur within basaltic to andesitic pillow sequences that overlie sheeted dykes and gabbroic portions of ophiolitic sequences.

Importantly, the volcanic sequences containing VMS deposits in tectonic settings as previously described are characterized by unusual petrogenetic trends. The host sequences generally have anomalously fractionated rocks resulting from either exceptionally efficient fractionation in a subvolcanic magma chamber, incursion of seawater into the same body or assimilation of altered crust (Morton et al., 1999).

2) Sedimentary-dominated terranes:

Terranes include arc-related basins that consist of sequences of volcanic (mafic mainly) and sedimentary (mainly pelitic) strata. Deposits formed near a tectonic boundary between the ocean floor and island arcs ocean floor and cratons or ocean floor and continental crust are also included. The volcanic to sedimentary ratio is variable and typically terranes are highly deformed. Examples of copper-zinc deposits in sediment hosted environments (Figure 2c) include Granduc and Windy Craggy deposits in northern British Columbia.

Deposits in the sediment covered areas of the actively spreading ridges are considerably greater than those in the modern volcanic ridges (ie. Middle Valley deposit in the Juan de Fuca Ridge).

Form and Composition

The typical cross-section of Noranda-type deposit is illustrated in Figure 3. It is generally a conformable conical mound of at least 60% pyrite, sphalerite, chalcopyrite and pyrrhotite. The typical (1Mt) undeformed deposit's length/thickness ratio is between 3:1 and 10:1. Upper contacts are sharp, the lower is transitional into the stringer zone that consists of disseminated and vein -type chalcopyrite, phyrrohotite and pyrite within strongly altered host rocks. The latter type stringer zones contain economically recoverable ore for tens of metres beneath the deposit ie. Millenbach Mine, Quebec. Mattabi type deposits are more stratiform with contact relationships similar to the Noranda-type deposits; ore amounts are small however.

Alternatively, sediment-covered region deposits are tabular exhibiting layering or bedding within the sulphide zones however some are mainly massive sulphide ie. Besshi deposit in Japan. Iron formation (oxide and silicate facies) is common on some of the ore horizons ie. Vasskis of Norway. Alteration zones are not as pronounced as those of the volcanic-dominated regions. Thin sedimentary strata which may have considerable lateral extent overlies the deposits in volcanic-dominated areas ie. Key Tuffite horizon of the Mattagami Lake anticline. In fact, graphitic shale overlies the Kidd Creek orebody and is host to the Westarm mine, Flin Flon, Manitoba.

VMS deposits comprise at least 50% and commonly >80% sulphides by volume, 50-90% pyrite, and ~10% sphalerite, chalcopyrite and galena. Metamorphosed deposits like Manitouwadge, Ontario may contain abundant pyrrhotite whereas others in sediment-dominated oceanic settings have abundant pyrrhotite as the dominant primary mineral. Deep water formed deposits like the Noranda-type contain only sphalerite and chalcopyrite as principal ore minerals but those formed in shallow water also contain galena. Importantly, barite occurs in the oldest deposits (pre 3.0 GA) and in some Phanerozoic deposits. The Ansil deposit, Quebec contains massive magnetite and the Kidd Creek Mine in Oregon has bornite zones with abundant selenium minerals. Gangue minerals consists of quartz, chlorite, sericite, carbonate, magnetite and alumino-silicate minerals and metamorphic equivalents. In all deposits gahnite is an accessory mineral that has reached amphibolite metamorphic grade. Stringer ore mineral assemblage consists of chalcopyrite, pyrite, pyrrhotite, sphalerite and magnetite.

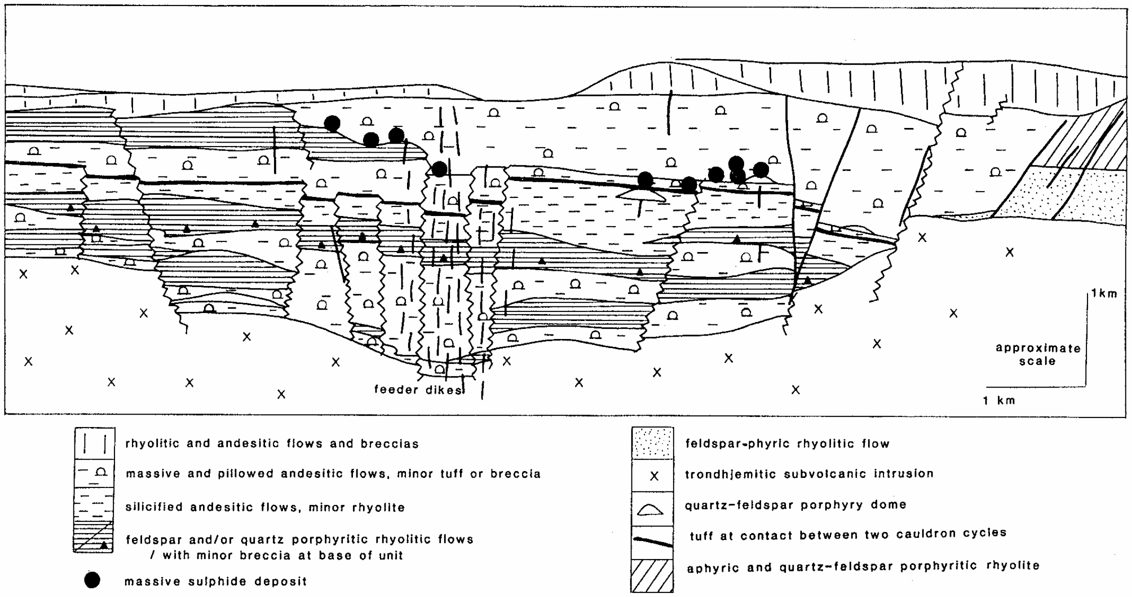

Figure 2a. *Cross-section of the main caldera, Noranda massive sulphide district. After Gibson and Watkinson (1990). This section is oriented approximately north-south and is based on information from mines and drill holes.*

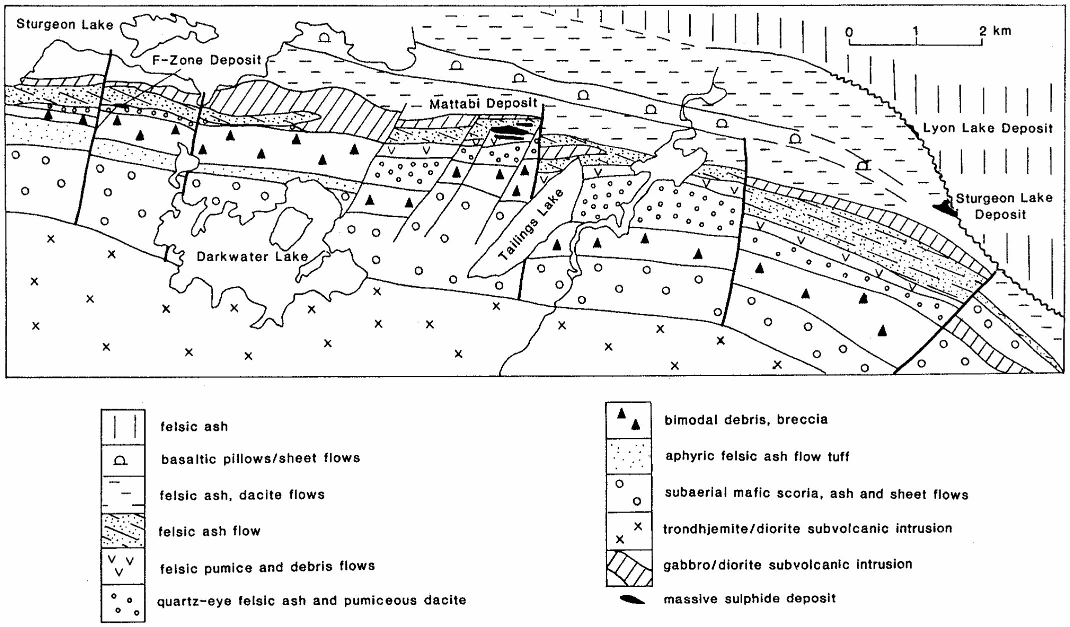

Figure 2b. *Map of the Sturgeon Lake massive sulphide camp, northwestern Ontario. After Morton* et al. *(1990). This map represents a cross-section through the Sturgeon Lake caldera and is at about the same scale as Figure 2a. Both diagrams closely reflect a right-section through their respective districts. Note that both districts have subvolcanic intrusions at their base and subequal amounts of felsic and mafic volcanic rock. However, the Noranda district is dominated by felsic flows, whereas Sturgeon Lake is dominated by subaerial mafic scoria deposits and subaqueous pyroclastic flows and breccia.*

(Franklin, 1993)

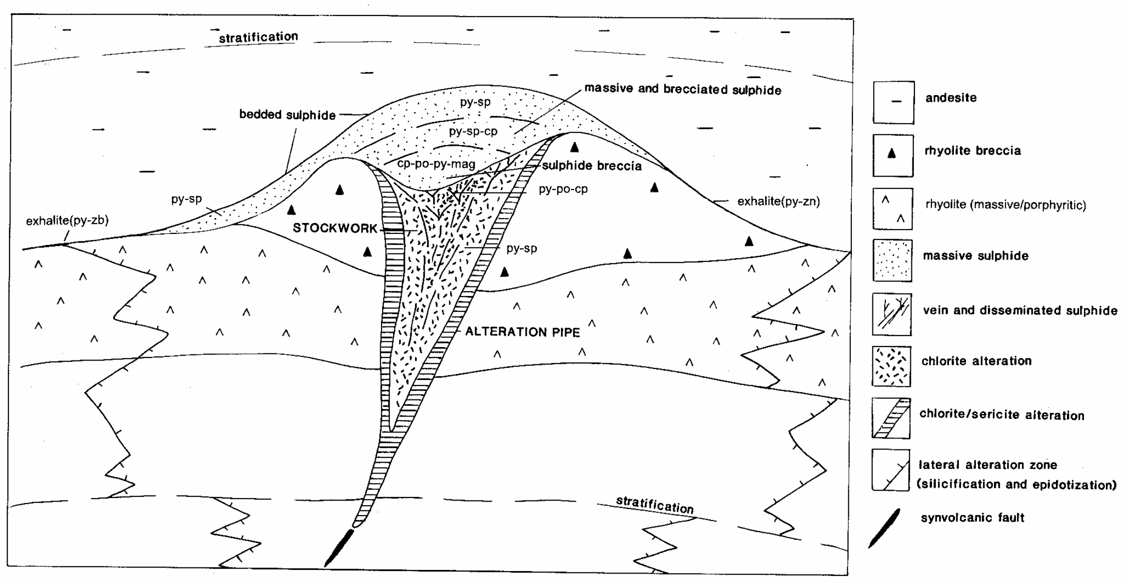

Figure 3. *Summary cross-section of a typical Noranda-type deposit.*

(after Franklin, 1993)

The volcanic-dominated region deposit pattern of high copper/ (copper + zinc) ratio in the stratigraphically lower zone and lower ratio in the upper zone is extremely common. Massive zones tops and flanks are iron rich (pyritic). Various stringer zones possess a narrow zinc-rich edge zone and a copper-rich core.

Some less deformed orebodies like the Millenbach deposit possess copper/zinc ratios that show the presence of a 'copper spine' that is transgressive to the bedding. This spine consists of massive chalcopyrite and pyrite; pyrrhotite is more abundant than in the laterally adjacent pyrite-sphalerite ore. Ophiolite-associated deposits are copper rich with the copper/zinc ratio being 3-4:1. The central areas of the orebodies are complex with zoned veins or pseudo sulphide beds that trace fractures within massive sulphides like the Archean Mine Gallen. The margins of massive bodies may consist of sulphide breccia perhaps formed from fallen chimney structures.

Alteration underneath Copper-Zinc Massive Sulphide Deposits

Two alteration types exist:

1. *Alteration pipes:* exist below the massive sulphide zones.
2. *Lower semi-conformable alteration zones:* exist hundreds of metres plus beneath the massive sulphide deposits (reservoir zone).

Deep water formed deposits alteration pipes possess a chloritic core surrounded by a sericitic rim (Figure 4). Deposits like the Matagami Lake deposit possess talc, magnetite and phlogopite (Costa et al., 1983) and there is one deposit (Linda deposit) near Snow Lake, Manitoba that contains margarite (Zaleski et al., 1991). Usually pipes taper down tens to hundreds of metres to a fault-controlled zone less than 1m in diameter. Typically illite, iron-rich chlorite, quartz and pyrite exist in the central portions of these pipes. Deposits formed under shallow water like that of the Mattabi type (Figure 5) possess silicified and sericitized pipes. Chlorite is subordinate and most abundant in pipe peripheries. The most abundant minerals are aluminosilicates and iron-bearing carbonate minerals may be significant. As in deposits formed under deeper water the alteration assemblages occur however less frequently as those just described for shallow water deposits.

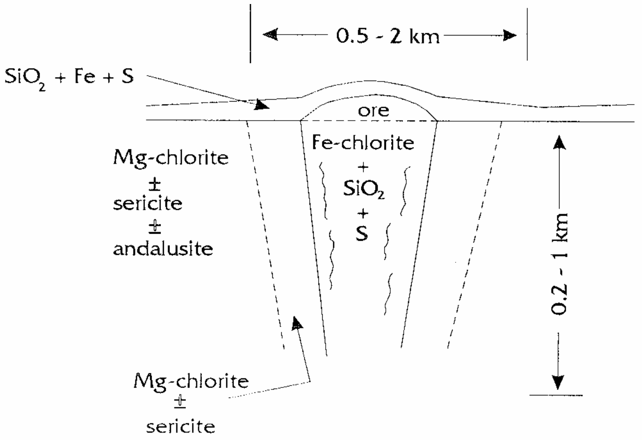

Figure 4. *Synthesis of alteration zones immediately beneath copper-zinc deposits, such as those at Noranda and in Cyprus and the Proterozoic deposits of the Canadian Shield. Note that the **Mg-chlorite ± sericite zone** is gradational into both the central **Fe-chlorite + SiO_2 + S zone** and the outermost **Mg-chlorite ± sericite ± andalusite zone.***

(after Franklin, 1993)

The lower semi-conformable alteration zones are laterally extensive (kilometers of strike length) quartz-epidote zones that are several hundred metres thick and extend downward from a few hundred metres stratigraphically under many deposits like those in Noranda, Quebec and Snow Lake, Manitoba. Some deposits possess zones of variably carbonatized and thermally indurated strata that occur immediately beneath in the deposits in sedimentary sequences like the Middle Valley deposits. Others in volcanic rocks like the Mattabi-type are accompanied by sodium depletion under the deposits. Several deposits in the Bergslagen district in Sweden possess disseminated to massive carbonate in their immediate footwall portions while one deposit (Zincgruven) is formed of sulphide veins in carbonate. Under deposits like the Sturgeon Lake deposit the carbonatized alteration zones may extend tens of kilometres along strike while occurring within the upper few hundred metres of the footwall.

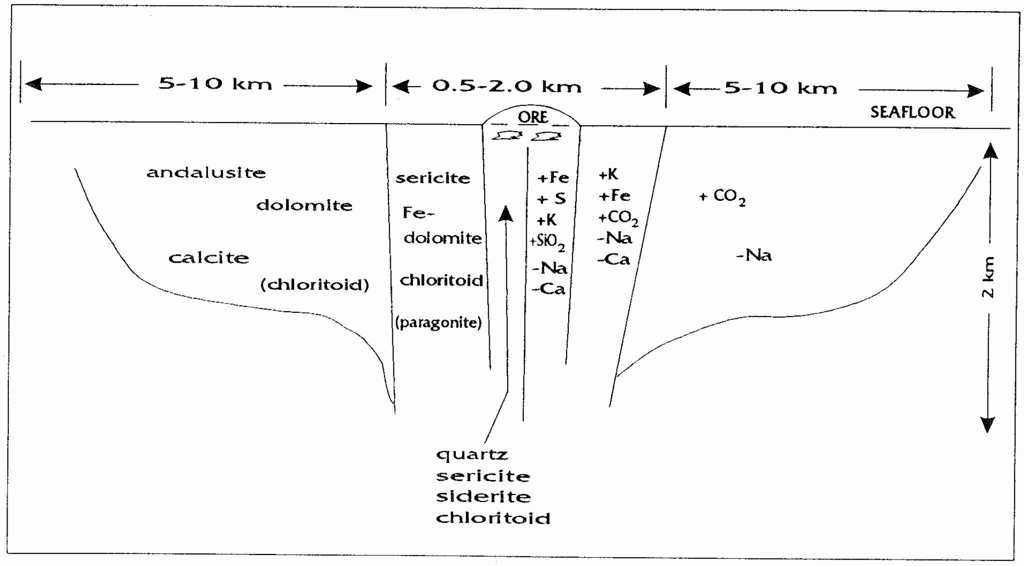

Figure 5. *Synthesis of alteration zones adjacent to zinc-lead-copper deposits, such as the Mattabi deposit, Ontario, and others that formed in sequences dominated by felsic tuff, breccia, and mafic scoria and sheet flows. Adjacent to the main alteration pipe, the alteration zones are not well defined. Sodium depletion is laterally extensive but confined to a few hundred metres vertically. Metasomatic carbonate alteration is pervasive in the footwall. Minerals in parentheses are present in minor amounts.*

(after Franklin, 1993)

ZINC-LEAD-COPPER GROUP (Franklin et al., 1993)

Geological Features:

This group are predominantly Phanerozoic in age and occur commonly in arc-related terranes with bimodal volcanism where felsic volcanic rocks (with or without sedimentary strata) are dominant in the footwall sequences like the Buttle Lake district in British Columbia. Deposits range from felsic volcanic-rock dominated footwall sequences like the Buchans area of Newfoundland to those with both felsic volcanic strata and thick sedimentary sequences in their footwall portions like the Bathurst district, New Brunswick. The latter are similar to the Cu-Zn group. However, the Zn-Pb-Cu group have notably minimal or no mafic volcanic rock in their footwall sequences.

Geological Setting:

1) Volcanic dominated terranes:

The best known major volcanic dominated terrane is the Hokuroku district of Japan. The Kuroko-bearing area of Japan is located in the geological province called the Green tuff belt which is a 13 m.y. old basin consisting of a bimodal suite of island arc-related volcanic rocks and mudstone (Economic Geology Mongraph 5, 1983). Canadian and Australian deposits of the Zn-Pb-Cu group exist in the more deformed terranes yet some of the characteristics of the orebodies are best exhibited in the Hokuroku district. The Rea Gold Mine in British Columbia is a Canadian example of a Kuroko-type exhalative massive sulphide, metamorphosed late Paleozoic, island-arc deposit in alkalic volcanic rocks (Mutschler and Mooney, 1993).

Footwall sequences are comprised of calc-alkalic felsic porphyritic ash-flow tuff, rhyolite domes and flows and some felsic epiclastic rocks. Basalt may occur at the base of sequences like at the Buchans deposit.

2) Volcano-sedimentary terranes

The largest deposits of the Zn-Pb-Cu group are in the Lower Carboniferous rocks of the Iberian pyrite belt in southern Portugal and southwestern Spain. Canadian examples are in the Bathurst district, New Brunswick; the Sudbury Basin, Ontario; and the Omenica crystalline belt, British Columbia. The ore exhibits extensive lateral continuity as well as extensive alteration and an association with sedimentary rocks similar to arc-related deposits of the Cu-Zn group. The Bathurst camp deposits possess a few hundred metres of felsic ash-flow tuff (footwall rock) underlain by thousands of metres of greywacke and pelite. Iron formation constitutes the hanging wall of 7 of the 30 deposits in this camp.

Form and Composition

Volcanic-dominated deposits are well-zoned, massive and underlain by variably developed stringer ore (Figure 6). Kuroko deposit zones from the stratigraphic bottom upward includes the following:
1) siliceous pyrite + chalcopyrite + quartz stockwork ore; 2) gypsum + anhydrite + pyrite + chalcopyrite + sphalerite + galena + quartz + clay stratabound ore; 3) stratiform pyrite + chalcopyrite + quartz ore; 4) pyrite + chalcopyrite + sphalerite + barite + quartz stratiform ore; 5) sphalerite + galena + chalcopyrite + pyrite + barite stratiform ore; 6) thin, well-bedded baritic ore locally consisting of minor calcite, dolomite and siderite; and 7) a thin bed of ferruginous chert. Transported breccia units are associated with these deposits like in the Buchans deposit, Newfoundland and constitute ~50% of the ore. In most other deposits the breccia is formed as a sulphide talus at the base of the endogenous mounds (vent sites).

Sediment-dominated terrane orebodies like Bathurst are tabular and laterally extensive. Iron-rich rocks are common in the deposit hanging wall sequence in both volcanic-rock and sediment-associated deposits. Some ferruginous strata formed poorly bedded massive oxide zones while others are ferruginous and usually cherty precipitates associated with hydrothermal activity.

Mineralogical Composition, Textures

Zn-Pb-Cu group deposits are mineralogically more complex than the Cu-Zn group. Besides pyrite, sphalerite, galena and chalcopyrite, barite is common especially in the volcanic-rock associated deposits like the Buchans deposit. At the Bathurst deposit, barite is rare. The majority of the Zn-Pb-Cu deposits are fine grained and intergrown, this creates recovery processing problems. Alternatively, Cu-Zn ores are coarser grained and more easily milled.

Alteration

Alteration including Canadian deposits are typified by that in the Hokuroku district of Japan (Figure 7). The lower semi-conformable alteration zones are unknown. Four alteration zones as noted in Figure 7 are identified and described by several authors (Ijima, 1974; Shirozu, 1974 and Date et al., 1983). The most intense is #4 which is located immediately below the deposits. It consists of silicified, sericitzed rock with minimal chlorite. The other zones are as noted in Figure 7.

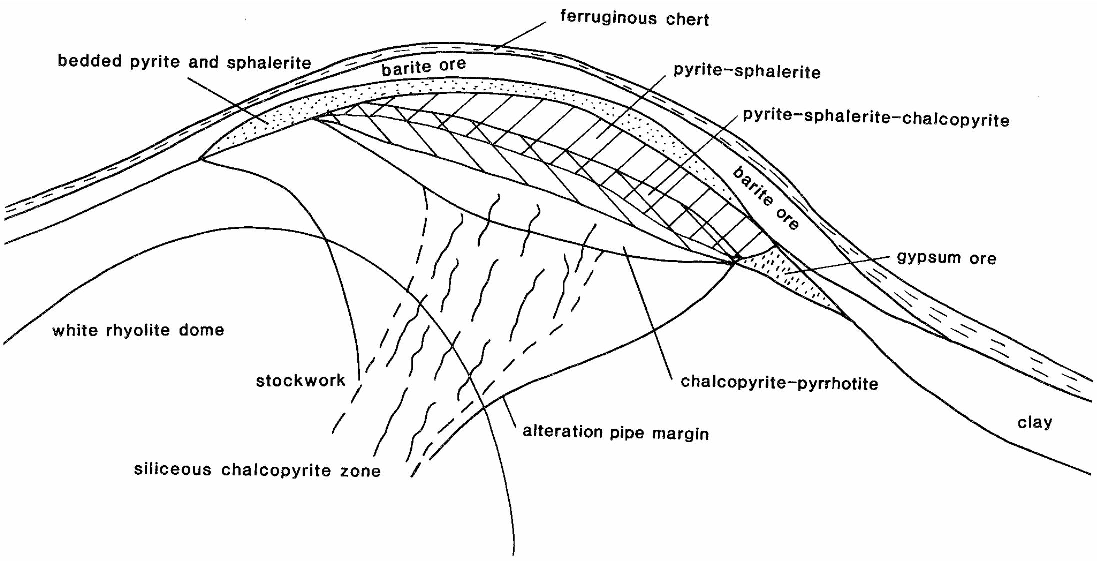

Figure 7. *Typical cross-section of zinc-lead-copper ore zone illustrating the principal ore zones. After Eldridge* et al. *(1983), Lambert and Sato (1974) and others.*

Figure 6: (after Franklin, 1993)

Chlorite is less abunant under Zn-Pb-Cu deposits than under Cu-Zn deposits. Alteration under sediment-associated deposits of the Zn-Pb-Cu group consists of locally distributed sericite-quartz. Importantly, many Zn-Pb-Cu deposits do not have obvious alteration zones.

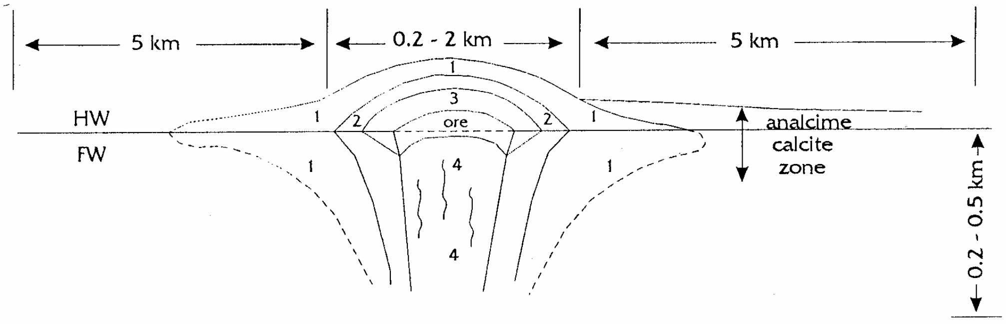

Figure 8. *Alteration immediately associated with Kuroko-type zinc-lead-copper deposits. After Shirozo (1974). Zone* ***1****: montmorillonite, zeolite and cristobalite; Zone* ***2****: sericite, mixed-layer sericite-montmorillonite, iron-magnesian chlorite, minor feldspar; Zone* ***3****: sericite, mixed-layer clays; and Zone* ***4****: quartz and sericite.*

Figure 7: (after Franklin, 1993)

GENETIC MODEL

The genetic model of massive sulphide deposits was established in the late 1950s by Oftedahl (1958), it summarizes this paper. The model states that these deposits formed from hydrothermal fluids as syngenetic accumulations of sulphide and sulphate minerals on or near the sea floor. The following evidence supports this model: typical stratiform nature, sharp upper contact, close massive sulphide deposit association with immediate overlying well-bedded chemical sedimentary rocks comprising abundant transported hydrothermal vent products; locally transported sulphide breccia beds; and extensive alteration and stringer zones confined to stratigraphic footwall of massive sulphides. Figure 8 illustrates the VMS model for both the Cu-Zn and Zn-Pb-Cu groups. The two fluid source possibilities are 1) circulating seawater and 2) magmatic water.

Further in-depth information into the generation of hydrothermal fluid development, depositional mechanisms, sulphide deposition, distal depositional products, etc. the reader is referred to Reviews in Economic Geology, Volume 8 (1999) and Franklin (1993, 1981).

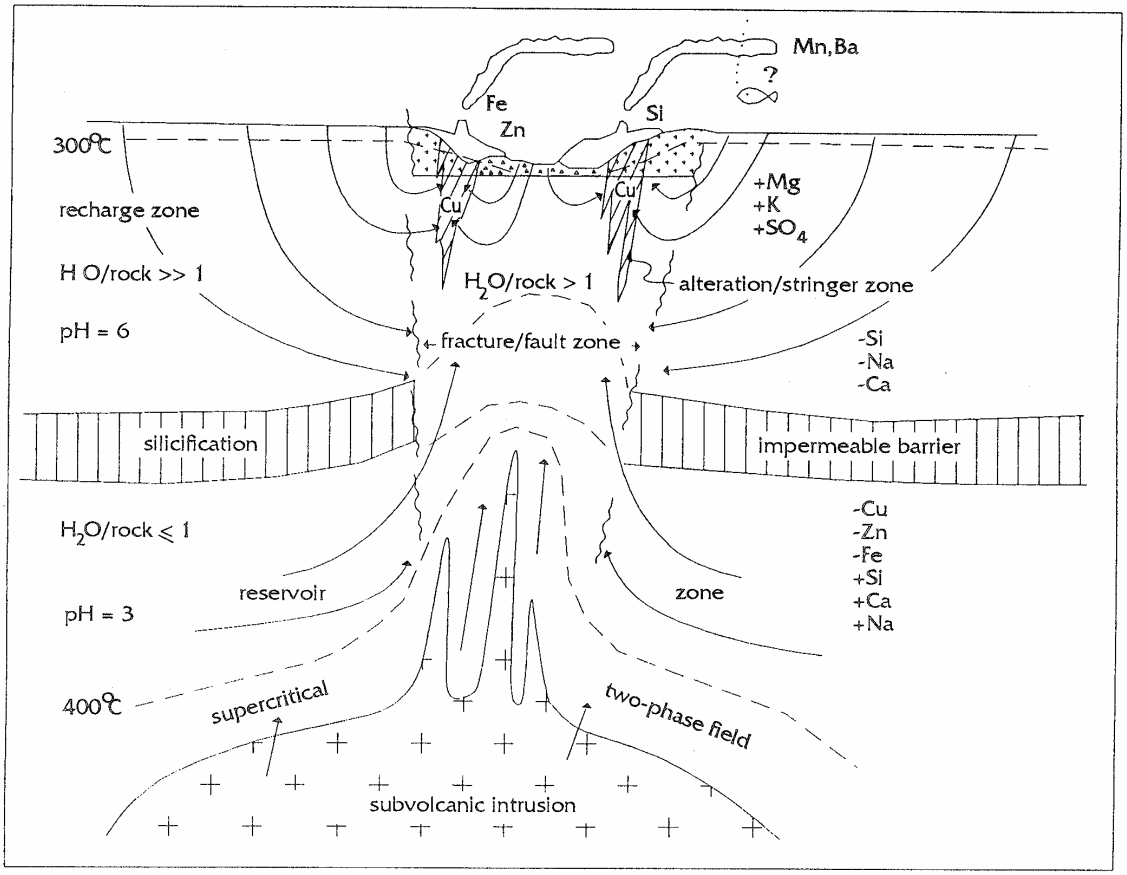

Figure 9. *Model of VMS-producing hydrothermal system, incorporating elements of all subtypes of VMS deposits. Crosses are a subvolcanic intrusion, which may be contributing some metals and gases to the hydrothermal fluid. The heavy cross-hatched areas under the massive sulphide deposits are alteration pipes. Copper precipitates within these and in the core of the massive sulphide mounds. This diagram is drawn perpendicular to the fracture system that controls hydrothermal discharge.*

Figure 8: (after Franklin, 1993)

Geological Assessment Criteria

- Greenstone belts
- Calc-alkaline and/or tholeiitic volcanic assemblages
- Submarine bimodal mafic to felsic or intermediate to felsic volcanic sequences; or komatiite to tholeiite volcanic sequences with isolated volcanic centres
- Intermediate to felsic volcanic sequence ± sedimentary host sequence.
- Typically a regional association with intermediate to felsic volcanic calderas; localized volcanic centres; especially marked by coarse pyroclastic breccia, domes and flows.

(http://www.gov.mb.ca/itm/mrd/geo/field/roa00pdfs/00gs-22.pdf)

Considerations

It is noted that gold-rich massive sulphides are associated with barite-rich assemblages.

Special consideration of Archean VMS deposits similar to preliminary findings of Spider Resources Inc. and joint venture partner KWG Resources Inc.'s jointly held McFauld's Lake property in northwestern Ontario was observed throughout this review of VMS deposits. In particular, it was observed that the Manitoba Geological Survey has explored the Archean Superior Province for VMS deposits. The following documents the Manitoba Geological Surveys findings for potential VMS settings, environment and Archean deposit types.

Potential Settings in the Northwestern Superior Province

1. Central Knee Lake
2. Little Stull-Rorke Lakes area
3. Knife Lake
4. Bigstone Lake
5. Oxford Lake

VMS Geological Environment

District Scale: in submarine volcanic assemblages of tholeiitic and/or calc-alkalic affinities. Various associations including bimodal mafic to felsic and intermediate to felsic volcanic successions, and komatiite to tholeiite assemblages with felsic volcanic centres. Intermediate to felsic volcanic rocks are the principal hosts. Subvolcanic intrusions of mafic to felsic composition are common and may be essential features. Common occurrence of volcaniclastic and epiclastic sedimentary units in the sequence and thin exhalite horizons.

Archean VMS deposits have been subdivided into two main types:

1. Noranda - type: volcanic sections include both mafic to intermediate and felsic rocks - although the mafic to intermediate rocks are more abundant rock types are dominated by mafic to intermediate pillow lavas, hyaloclastites, massive amygdaloidal flows and flow breccia felsic rocks occur as lava flows or domes and as hyaloclastites local bedded volcaniclastic and exhalites generally lack or contain only minor amounts of pyroclastic rocks and subaerial rocks.

2. Mattabi - type: volcanic section is dominated by felsic volcanic rocks abundant fragmental rocks dominate; felsic tuff, massive and bedded pyroclastic flows, hyaloclastite, debris flows and dome and flow breccia also mafic to intermediate tuff and flow breccia pillow lava and breccia may or may not be present lava domes and welded tuff are commonly present high amygdule content in flows submarine and subaerial volcanic rocks common (after http://www.gov.mb.ca/itm/mrd/geo/field/roa00pdfs/00gs-22.pdf)

The potential VMS environments of Central Knee Lake, Little Stull-Rorke Lakes area, Knife Lake, Bigstone Lake and Oxford Lake are located in the Knee Lake Belt of northeastern Manitoba close to the Ontario border. The Geological Survey of Canada (2000) has reported concerning the geological investigations of this belt in detail. This entire report is included to provide information and assist with preliminary findings found to date on the McFauld's Lake property.

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Exploration Geologist

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SUBMISSION INCLUDED: Geological investigations in the Knee Lake Belt

GEOLOGICAL INVESTIGATIONS IN THE KNEE LAKE BELT (PARTS OF NTS 53L)

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